On Processing Potato

Anton J. Haverkort

Propositions

1. The Four-Tier Analysis is an essential tool in interdisciplinary research.
   (this thesis)

2. Of all staple crops, potato has the strongest information exchange from consumer to breeder.
   (this thesis)

3. Higher temperatures, northerner land and increased CO_2 promise more food.

4. Perfecting porosity of electrodes is vital to improve hydrogen yield in electrolysis.

5. Exoplanets hunters sensing chlorophyll reflection, detect life as we know it.

6. Einstein Telescope’s gravitational waves reveal more than James Webb’s infrared.

7. The less hi-tech kitchen appliances used, the more creative cooks are.

Propositions belonging to the thesis, entitled

On Processing Potato

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On Processing Potato

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On Processing Potato

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Thesis

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ABSTRACT

Potato is, after wheat and rice, the third food crop. The potato crop is propagated clonally with seed tubers that degenerate within a few generations, it can be harvested before crop maturity, it contains about 20% dry matter, it has varieties, environments and crop management practices specific for the kind of products made from it. The crop is only stored for a limited period under refrigerated conditions and for most products water has to be extracted. Tubers need to be heated to gelatinize starch that makes it digestible for humans. Products are made in large centralized factories that in North America and North Europe use well more than half of the crop but worldwide most of the tubers are purchased fresh and prepared in kitchens. The picture is completely different for generatively multiplied easily storable wheat, collected in bulk, ground centrally and baked decentral in many bakeries, where water is added for processing into bread. This uniqueness of potato alone would be reason to write this thesis, but it is at least as significant to elucidate the close-knit community of consumers, cooks, outlets, processors, growers and breeders of potato which is a unique social phenomenon in food production.

Specifically for this research a Four-Tier Analysis was developed to structure, process, quantify and perceive data. First a domain is formulated and delimited. In the second tier, data in the domain are assembled through Methodological Triangulation (observation, interviews, talks, literature, www) and condensed to classes of things and supplied with attributes. In tier number three all attributes are awarded a value according to the degree they apply to a class. This yields a heatmap. Finally hierarchical clustering of classes and attributes is made visible through a dendrogram. There is Theoretical Triangulation where different persons award values from their perspective and there is Environmental Triangulation where values differ in another setting. Useful points of departure are kitchen operations, the history of products, the range of products found in supermarkets, dishes from all over the world and the sustainability reports of globally operating companies.

Five super-domains (underlined) are distinguished with each at least three *domains* (italics). The ontology of "On Processing Potato" shows cooperation through *tubers*, *products* and *preparations*. Manufacturing of *products* is through *processes* and underlying *operations*. *Performance* of fields (yield) and factories (recovery) of which the productivity is determined by *efficiencies* and *losses. Dishes* with potato products serve as nutrition with *sensory properties* and contain needed *nutrients*. The fifth super-domain society treats the *benefits* of processing, *sustainability* issues and the social *surroundings* of the industry in various stages of development of potato and the economy. Formulation and condensation of all these domains including theoretical and environmental triangulation yielded 29 heatmaps. Class × attribute combinations in these maps totaled 6382, the number of times a value between 1 and 5 was awarded to an attribute.

Theoretical triangulation was done, such as with values of attributes of sustainability measures awarded with successively processors, policymakers and obstructors in mind and for environmental triangulation availability and possibilities of cooking with products in a developed and a developing market were compared. All scores were given by a single person, the author; when another researcher formulates a domain differently, with altered sets of classes and attributes and different values, such Data Triangulation produces new heatmaps, dendrograms and, possibly, new conclusions.

A glossary is supplied on page 253

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Chapter 1

General Introduction

Global perspective

Energy from potato and other important staples

In terms of fresh matter produced, potato is the third food crop grown worldwide, after wheat and rice. Of the top 21 potato producing countries presented in Table 1.1, none shows a caloric intake as high as that of potato nor from corn and their products. Rice is a primary deliverer of energy in China, India, Bangladesh and Peru, in the other countries wheat (bread and pastas) is the major source. The highest energy intake from potato is in Belarus with 1378 kJ per day followed by Ukraine and Russia. Peru is fourth with 932 kJ per day. Due to the fixed ratio energy/protein per crop, the same order applies to protein consumption for this and all crops. Daily energy derived from the four staples is highest in Bangladesh with 8576 kJ/day/capita, which is substantially higher than in the Netherlands with 3121 kJ/day/capita and the USA with 3625 kJ/day/capita. The inhabitants of the USA on average have the highest daily energy intake from all foods, 15900 kJ/day/capita of which 23 % is from the four crops.

Table 1.1. Energy (kJ/capita/day) intake from four crops and total food intake in the top 21 potato producing countries (FAOSTAT), proportion (%) obesity (https://data.worldobesity.org/rankings/)

Rank	Country	Potato	Wheat	Rice	Corn	Total of 4 crops	Total food intake	Obesity
1	China	349	2289	3511	256	6405	12510	6.2
2	India	197	2218	2944	281	5641	9660	3.9
3	Ukraine	1012	4028	101	416	5557	13566	24.1
4	Russia	865	4238	214	21	5338	13890	24.0
5	USA	357	2566	315	386	3625	15900	36.2
6	Bangladesh	403	651	7497	25	8576	9500	3.6
7	Germany	529	2885	143	311	3868	14810	22.3
8	France	395	3478	244	370	4486	14770	21.6
9	Poland	785	3583	67	420	4855	14270	23.1
10	Netherlands	605	2247	151	80	3121	13608	20.4
11	Belarus	1378	2327	122	21	3847	13180	24.5
12	Canada	428	2734	395	554	4112	14770	29.4
13	Iran	428	5594	1142	113	7279	12760	25.8
14	Peru	932	1596	2285	878	5691	10214	19.7
15	United K	739	3251	294	118	4402	14430	27.8
16	Egypt	315	4897	1554	2444	9211	13220	32.2
17	Algeria	542	5993	122	533	7190	12930	27.4
18	Pakistan	113	3499	491	491	4595	9450	8.6
19	Turkey	382	4561	412	680	6014	14616	32.1
20	Kazakhstan	794	3259	315	38	4406	14112	21.0
21	Belgium	481	2911	177	103	3672	15440	20.5
R^2 : obesity – rice = -0.457, obesity – potato = + 0.064, obesity all crops = +0.598, obesity - all crops = -0,224								

In Bangladesh, 90 % of the daily energy intake is from these 4 staple foods. Total daily energy intake is highest in the USA with 3800 kJ/day, 67 % higher than in Bangladesh with 2270 kJ/day. This seems also to be reflected in the frequency of obesity: 36.2% in the USA against 3.6 % in Bangladesh. Cconcerning obesity, some coefficient of determination (R^2) are shown in Table 1.1. Eating more rice and its products is associated with reduced obesity in a population. The R^2 of this relationship is + 0.457

indicating that almost 50 % of obesity is explained by high consumption of other products than rice. There is a barely perceptible opposite trend for potato but with a non-significant coefficient of determination. If the four low obese rice consuming countries are discarded the trend, however, is reversed with a decrease of obesity from on average 30 % at 300 kJ to 20 % at 1400 kJ caloric intake from potatoes. The clearest trend is that of increased obesity with daily caloric intake from all foods which explains about 60 % of obesity. There is an indication of a trend of reduced obesity and food intake from the four staple foods only, it is obvious that on average obesity does not follows from consumption of these four staples but from other sources presumably sugar and animal products.

Potato related economic data

It is concluded that energy from potato in these 21 major potato producing countries with proportions varying from 2 to 10 % of all energy from the 4 main staples foods is relatively marginal and that the data do not support evidence of potato contribution to obesity at the national levels as is concluded from a lack of correlation between obesity and energy derived from potato. In general, countries with a high proportion of energy intake from the basic staple foods, including potato, in general and on average, have fewer obese inhabitants.

Table 1.2 shows primary data of the top 21 producing potato countries. The largest producer of potato tubers is China with over 90 million tons and Kazakhstan with 3.55 million tons the smallest producer in this range. The USA have the highest GDP with USD 65289 per annum and Pakistan (USD 1285) the lowest. China and India are the countries with the largest population of over 1.3 billion each and Belarus with fewer than 10 million inhabitants is the smallest country in this respect. The largest importers of frozen potato products, French fries mainly, are the USA with over 1 million tons per annum from Canada mainly and the United Kingdom that mainly imports from Belgium and the Netherlands. The largest exporters of frozen potato products are Belgium (2.5 million tons), the Netherlands (2.0 Mt), Canada (1.1 Mt) and the USA with 1.0 million tons exported per annum.

The last column in Table 1.2 shows the number of quick-service restaurants (QSR: McDonalds, KFC, Starbucks, Pizza Hut and Subway Quick only). Of the countries mentioned, the USA and Canada have over 200 QSRs per million inhabitants, the European counties less than 100 and a few countries have none.

Table 1.2. FAOSTAT, Worldbank, Worldometer and Chartsbin primary data of the top 21 potato producing and consuming countries (2018 – 2021 data). Ranking based on national annual production, GDP = gross domestic product in USD/annum, QSR = quick service restaurant

Rank	Country	Tuber production Million t FAOSTAT (2019)	GDP USD/ annum Worldbank (2020)	Population × 1000 World-ometer (2021)	Import Frozen × 1000 t FAOSTAT (2018)	Export frozen × 1000 t FAOSTAT (2018)	QSRs per 1 million per country Chartsbin (2021)
1	China	92.21	10262	1394016	288.9	26.9	7.1
2	India	48.60	2100	1326093	0.01	21.4	1.2
3	Ukraine	22.21	3659	43922	17.9	0.3	1.8
4	Russia	29.59	11585	141722	125.3	4.3	10.1
5	USA	20.02	65298	332639	1016.5	1011.5	224.7
6	Bangladesh	10.22	1856	162650	1.52	0.28	0.2
7	Germany	11.27	46445	80160	317.6	349.8	29.6
8	France	7.34	40493	67848	644.9	376.0	33.2
9	Poland	9.17	15693	38282	107.6	201.7	17.9

Rank	Country	Tuber production Million t FAOSTAT (2019)	GDP USD/ annum Worldbank (2020)	Population × 1000 World-ometer (2021)	Import Frozen × 1000 t FAOSTAT (2018)	Export frozen × 1000 t FAOSTAT (2018)	QSRs per 1 million per country Chartsbin (2021)
10	Netherlands	7.39	52331	17280	436.2	2039.6	29.2
11	Belarus	6.41	6663	9478	6.51	0.59	0.8
12	Canada	4.41	46195	37694	51.6	1086.4	200.1
13	Iran	5.10	5550	84923	0	19.5	0
14	Peru	4.78	6978	31914	31.4	0.2	9.5
15	United Kingdom	6.22	42330	65756	669.5	95.8	82.4
16	Egypt	4.33	3019	104124	1.45	45.7	3.8
17	Algeria	4.61	3974	42942	0.216	0	0
18	Pakistan	4.14	1285	233500	8.12	44.3	1.0
19	Turkey	4.80	9126	82017	0.7	36.2	8.3
20	Kazakhstan	3.55	9812	19092	10.2	0.01	0.9
21	Belgium	4.03	47518	11626	213.6	2507.3	16.7

With the primary data in Table 1.2, calculations were carried out to detect saliences and dependencies among them (Table 1.3). The production per capita is not the same, it is higher than consumption per capita because part of the crop is saved as propagation material for the next planting season, here and there non-food products are made and some countries export a significant proportion as seed such as The Netherlands, UK (Scotland), France and Canada and as processed products especially frozen French fries (Netherlands, Belgium, Canada). This is corroborated by data from Table 1.1, where the daily intake of energy from potato is shown. Inhabitants of most potato countries derive between 400 and 600 MJ/day (at 350 kJ/100 g, corresponding to 115 and 171 g potato) from potato, high per capita producers (and exporters) such as Belgium, The Netherlands and Canada included. There are also countries, especially in central and Eastern Europe where the main staple food is potato such as Ukraine with 1012 kJ/day, Belarus (1378) and Russia (865). For a Western European country, potato consumption is relatively high in the United Kingdom with 739 kJ/day, corresponding to about 200 g of tubers per day.

Table 1.3. Secondary data of the top 21 potato producing and consuming countries (2018 data) derived from Table 2. correlation matrix at the bottom, GDP = gross domestic product in USD/annum, QSR = quick service restaurant

Rank	Country	Production kg/capita/ Annum	Production kg/capita/ annum/1000 USD GDP	Frozen (Imports-Exports) × 1000 t	Frozen (Imports-Exports) × 1000 t/1000 USD GDP	QSR/GDP (× 1000)
Code		A	B	C	D	E
1	China	66.1	6.44	262	25.53	0.69
2	India	36.6	17.43	-21.39	-10.19	0.57
3	Ukraine	505.7	138.21	17.6	4.81	0.49
4	Russia	208.8	18.02	121	10.44	0.87
5	USA	60.2	0.92	5	0.08	3.44
6	Bangladesh	62.8	33.84	1.24	0.67	0.11
7	Germany	140.6	3.03	-32.2	-0.69	0.64
8	France	108.2	2.67	268.9	6.64	0.82
9	Poland	239.5	15.26	-94.1	-6.00	1.14

Rank	Country	Production kg/capita/ Annum	Production kg/capita/ annum/1000 USD GDP	Frozen (Imports-Exports) × 1000 t	Frozen (Imports-Exports) × 1000 t/1000 USD GDP	QSR/GDP (× 1000)
Code		**A**	**B**	**C**	**D**	**E**
10	Netherlands	427.7	8.17	-1603.4	-30.64	0.56
11	Belarus	676.3	101.50	5.92	0.89	0.12
12	Canada	117.0	2.53	-1034.8	-22.40	4.33
13	Iran	60.1	10.83	-19.5	-3.51	0.00
14	Peru	149.8	21.47	31.2	4.47	1.36
15	United K	94.6	2.23	573.7	13.55	1.95
16	Egypt	41.6	13.78	-44.25	-14.66	1.26
17	Algeria	107.4	27.03	0.216	0.05	0.00
18	Pakistan	17.7	13.77	-36.18	-28.16	0.78
19	Turkey	58.5	6.41	-35.5	-3.89	0.91
20	Kazakhstan	185.9	18.95	10.19	1.04	0.09
21	Belgium	346.6	7.29	-2293.7	-48.27	0.35

0.513	**AB**	Matrix of coefficients of determination (R^2)					
0.121	AC	0.018	BC				
0.021	AD	0.029	BD	**0.715**	**CD**		
0.032	AE	**0.518**	**BE**	0.016	CE	0.004	DE

The strong positive relationship between production per capita and production per unit GDP is only due to the two outliers Ukraine and Belarus, exempting these two points the trend is slightly negative indicative of better-off countries producing less potato per capita. The correlation between the import and export of frozen products is obvious; the more a country exports, the less it imports. The strong (R^2= 0.518) relationship between the national income (GDP) and the number of quick-service restaurants (QSR) shows that affordability is a major factor. The differences between countries with similar high GDPs in Northern Europe and North America are considerable. It illustrates the cultural preferences as on the European continent the number of QSR is about 30, then in the UK, it is 85 and it is over 200 per million across the Atlantic.

Figure 1.2 from Rabobank (2019) shows a positive relationship between the income of inhabitants of countries expressed as GDP per capita and the average quantity of frozen potato products consumed. The general trend is that consumption increases with higher incomes but with a large variation. The four outliers above the line are Australia, Canada, New Zealand and the United Kingdom, the two below the line are Hongkong and Switzerland with a high income but low frozen products intake.

Austrians with a GDP per capita of USD 45,000 consume close to 3 kg of frozen potato products against Australians with a similar GDP who consume over 18 kg. From Figure 1.1 it is concluded that the countries above the trendline include the four countries with the highest production and exportation of frozen foods, namely the Netherlands, Belgium, the USA and Canada, and countries with above-average numbers of quick-service restaurants (fast food outlets, ChartsBin 2021), namely Canada, Australia and New Zealand with, respectively, one McDonalds, KFC, Starbucks, Pizza Hut and Subway per 5356, 7598 and 7731 inhabitants against one per 12462 in the United Kingdom and one per 15013 in the Netherlands.

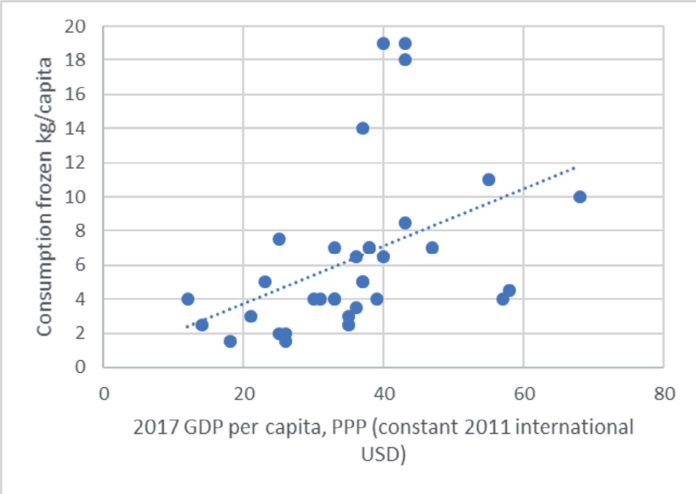


Figure 1.1. GDP per capita vs. frozen processed potato consumption. Source, Rabobank, 2019

Processing maintains tuber production

Global consumption of potato is about 1 kg per person per week with an increase in Asia and Africa and a decrease of prepared fresh tubers in the rest of the world, where processing took an important place. So in monetary terms, consumer expenses on potato have increased relatedly (Factsheet, 2017). The contribution of potato and its products to the energy and protein balance in diets and health (Chandrasekara and Kumar, 2016) accordingly differs in the environments where the role of the crop is that of food, cash or industrial crop, convenient or snack food. Besides the beneficial aspects of the contribution to food availability and intake, when consumed as fried products, it leads to obesity, especially among low-income consumers in high-income societies (Borch et al. 2016; Blakely 2019). Consumers replacing fresh tubers with potato-derived products have stabilized potato production in many countries such as the USA and the Netherlands or even increased it, such as Belgium (Table 1.4), whereas in countries where processing is of lesser importance, the decline in consumption and production was more substantial. Processing data per country are not available, but production in 1980 is estimated at around one-fifth of current production levels. Belgium processing more tubers than its national production because manufacturers there import from neighboring countries. France has a relatively modest processing capacity (14 % of total production is processed) compared to neighboring Belgium (173 %) and the Netherlands (70 %). Even so in France, total fresh tuber production not for processing into food products increased contrary to trends in other European countries because of an increase in fresh table potato exports. In Germany, the decline was by far not compensated by processing, a situation stronger still in Poland where the decline in production is due to feeding animals

Cottage industry, chips production

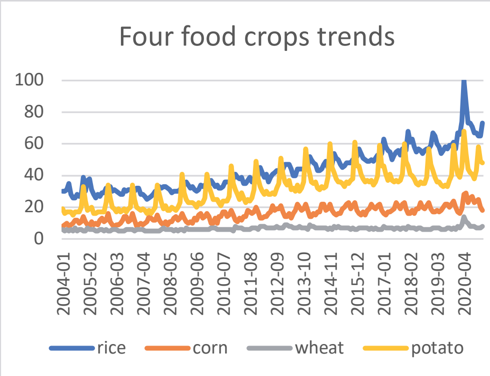
with potato. In Japan 90 % of the potato products are imported and annually 35,000 t raw potatoes for chips production are imported. In the UK, the need for processing tubers did not weigh up against the decline in table potatoes. Consumption of fresh tubers declined from 1250 g per week in 1980 to 500 g in 2010 with now about 50 % of the crop eaten in processed form. Total potato consumption has not declined strongly. The USA represent an example with Belgium where processing enhanced total tuber production.

Table 1.4. Illustration of countries where a decline in fresh tuber purchase by consumers is, or is not, compensated by demand from the processing industry

Item	Year	Belgium	France	Germany	Japan	Nether-lands	Poland	UK	USA
Production Mt/yr	1980	2.02	6.62	17.15	3.42	6.27	26.39	7.10	13.79
Production Mt/yr	2019	3.05	8.57	10.60	2.17	6.96	6.48	5.25	19.18
Processed Mt/y	2019	5.29	1.20	3.73	0.61[1]	3.86[2]	1.39	1.70	15.23
Source		Belgapom 2020	UNPT, 2020	Destatis, 2021	USDA-Gain 2020	VAVI, 2020	NVO, 2020	Fresh Plaza, 2021	NASS, 2020
1: 2017 data, 2: 2 million t raw for the starch industry not included									

Societal interest in processed potatoes

Potato has the introduction of new products in common with only one major cereal: corn (maize), also from the new world following the Colombian Exchange and brought to the rest of the world. Both now rank in the top four volume-food crops produced worldwide. In 2019 (FAOSTAT, 2020), growers produced 1.185 Mt of corn, 766 Mt of wheat, 755 Mt of paddy rice and 370 Mt of potato. Considering that the bulk of the corn production goes into non-food products (feed, fuel), potato is considered the third global food crop.



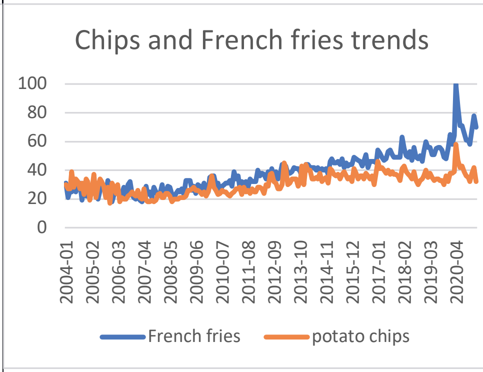


Figure 1.2. Google trends in interest in four food crops and two potato products from April 2004 until April 2020, relative to the highest value at the ordinate(100)

Hits in the internet search engine Google of the four main food crops of the single word for the crop give the highest number for rice, roughly twice as many as for the other three commodities (Table 1.5). This is also viewed in Figure 1.2, which also gives trends of hits for the two major products made of tubers: French fries and chips. This is likely because rice is consumed as such whereas bread from wheat is eaten; bread approaches the number of hits for rice. The requirement that the two words are in a sequence in the searches ("potato processing") reduces the number of hits by one fifth for potato and wheat and by one third for rice and corn indicative that bread (641 million hits) and French fries (61 million) are less frequently associated with wheat and potatoes than rice and corn food stuffs with rice and corn. The picture changes considerably when the number of hits is related to the relative global importance of the crop, expressed as the total number of hectares grown: 18 million hectares of potato versus 215 million hectares of wheat. Then potato receives 5 times more hits than rice instead of half, similar conclusions are drawn for "potato products" and "potato processing". The number of hits for bread per million ha of wheat is 3.0 and the figure is 3.4 for French fries per million ha of potato crop, so the same order of magnitude. When relating hits to the dry matter production of the four crops, a similar picture arises. It is apparent that the societal interest in the potato and its products by far exceeds that of its relative importance as a food crop. The versatility of the tuber crop is one of the reasons. Where wheat mainly goes to bakeries producing bread with various bran concentrations and baking procedures, rice to consumers and the bulk of corn is turned into sugar, feed and fuel, potato is consumed fresh and is processed into an array of frozen products, snacks and modified starches with specific applications. Moreover, potato products have a typical appreciated

Table 1.5. Number of hits of the four main food crops: total, total divided by the area of the crop grown and totals divided by the annual dry matter production

Crop		**Potato**	**Wheat**	**Rice**	**Corn**
Total number of hits	Crop[1] × 1 million	362	307[a]	790	401
	"Crop Product"[2] × 1000	752[b]	783[a]	2940	1410
	"Crop Processing"[3] × 1000	440	277	626	195
Global area × 1 million ha		18	215	162	196
Number of hits per million hectare	Crop[1] × 1 million	20	1.4	4.9	2.0
	"Crop Product"[2] × 1000	42	3.6	18	7.2
	"Crop Processing"[3] × 1000	24	1.3	3.9	1.0
Global production fresh × 1 million ton		370	755	765	1148
Global production dry matter[c] × 1 million ton		74	604	612	918
Number of hits per million ton dry matter	Crop[1] × 1 million	4.89	0.51	1.29	0.44
	"Crop Product"[2] × 1000	10.1	1.30	4.80	1.54
	"Crop Processing"[3] × 1000	5.95	0.46	1.02	0.21
Inserted key words in Google 1: name of the crop e.g. *potato,* 2: crop-product combination e.g. *"rice product"* 3: crop-processing combination e.g. *"corn processing"*					
a: bread 641 million b: French fries 61 million					
c: assuming potato contains 20 % and cereals 80 % dry matter					

smell and taste that differ considerably from cereal crops. For consumer products, the typical corn smell and taste are usually removed from the oil and starch to give it more appeal. Several not ground, so not flour-based potato products, contain unaltered potato structures as seen in tubers, French fries and chips, which have a specific appreciated mouth feel. There is special societal and industrial interest in manufacturing products of the wet potato crop compared to dry cereals because of the multitude of dehydration issues with potato rather than the few milling issues with cereals. Besides, many potato products need to be chilled or frozen, which also gives rise to increased collective attention as becomes evident from the number of hits on the Google internet search machine.

Contents of the thesis

Objectives of the thesis

The previous sections: 1) Energy from potato and other important staples, 2) Key economic potato related data, 3) Processing maintains tuber production and 4) Societal interest in processed potatoes, under the heading "Global Perspectives" clearly demonstrate the scope, importance and interest of potato processing and its products. These introductory paragraphs also delimit the domain of this thesis as henceforward these particular subjects of societal interest will not be touched upon again. Another delimitation is that the food industry using potato products (starch, flour, granulate) as a binder, thickener and for the production of potato pellets, noodles and rice, is not considered among the potato processors. An exception is made for potato-based extruded and expanded snacks and stackable chips because of their exchangeability with conventional chips.

The umbrella domain of "Processing Potato" confines itself in general to the three principle domains of interconnected participants, namely those of growers, processors and cooks. They cultivate, manufacture and cook in the cooperation domain to make classes of tubers, products and dishes through classes of practices, operations and preparations, respectively, within the productivity domain. Information among participants is conveyed in one domain, production of tubers in another. The efficiency domain is subjects products to efficacies and losses and the food domain contains classes of dishes, of sensory perceptions and contain and nutrients. All this takes place to benefit the community, assuring sustainability and taking societal boundary conditions into account in the society domain.

At the onset of research, this general description of the super-domain was written but the nature of the domains and their classes, let alone their attributes, was unknown, simply because it was never researched, described and published in any detail before. Hence the overall aim of this thesis is to capture the domain of processing potatoes in society in a coherent manner allowing qualitative and quantitative evaluation of the findings. More specifically:

- The ontology of potato processing and products needs to be defined and concepts need to be elucidated;
- The categories and hierarchy of domains and sub-domains (or super-domains and domains) require formulation and delimitation;
- Each domain must be captured in manageable parts and needs to be caught in tables introducing the concepts of classes and their attributes;
- A major objective is to quantify the degree to which the attributes apply to the classes;
- A following purpose is the grouping of classes and attributes into closely related clusters so as to be able to focus in fewer and condensed classes in follow-up in research and practice.

The chosen approach of classes and attributes calls for a coherent approach. Specifically for the research “On Processing Potato”, a Four-Tier Analysis, enlightened in the next section (Methodology) was developed and tested with the following aims:

- To find out if methodological triangulation in the condensation of a domain is an adequate approach;
- To apply theoretical and environmental triangulation in a few illustrations;
- To test the practicality and adequacy of transformation of qualitative information of attributes into quantitative information with the aid of heatmaps;
- To learn if the use of dendrograms to create a hierarchical clustering results in a meaningful grouping of classes.

The general objective of the thesis is to capture the super-domain of processing potatoes in society in relevant domains with therein appropriate classes and their apt qualitative attributes through methodological triangulation and derive conclusions through heatmapping and clustering. Specifically for each of the domains cooperation, manufacturing, productivity, food and society, the following research questions arise:

COOPERATION

- Are kitchen operations a justified starting point for industrial processing?
- What are the requirements of tubers for various products?
- When and why were products made in factories rather than in kitchens?
- What are the advantages of deploying products in kitchens?

MANUFACTURING

- Which variety of potato products is found in a supermarket?

- Can they be classified meaningfully according to common processes?
- In factories, which operations take place for the different processes?

PRODUCTIVITY

- Which structures are required to regulate supply and demand?
- Which factors determine yield and processing quality of tubers as raw material?
- Which factors determine recovery of finished product from raw and reduce losses?
- How efficiently are resources used on farms, in factories and in kitchens?

NUTRITION

- Which variety of potato dishes exists and which ones are manufactured?
- Which sensory perceptions apply to potato and its products?
- What is the nutrient composition of tubers and of potato products?
- What are the perspectives for the industry according to consumer trends?

SOCIETY

- What are the benefits of processing for society?
- How is sustainability assured on farms, in factories, in communities and on the plate?
- Which policy, economic, social, technological, environmental and legal matters are associated with the potato processing sector?

Methodology: Four-Tier Analysis

In brief

To answer the research questions, a "Four-Tier Analysis", explicitly developed for this thesis, processes data in four steps. First, a domain is briefly formulated, defined, and delimited. Next, following methodological triangulation a summary **Table A** is made of the classes subject of investigation and their attributes. Next in **Table B,** a heatmap is produced listing the classes with their qualitative

I. Research questions related to a domain are articulated
II. A subdomain is described and its classes and their attribute expressed: **formulation**
III. Data are assembled through method triangulation (literature, websites, enquiries with experts, experience)
IV. For all classes the summary Table A is drawn based on these data: **condensation**
V. An increase in the level of detail of classes and attributes creates a blank Table B
VI. For each attribute a degree to which it is applicable for the class, a score from 1 to 5 and corresponding colors are ascribed. This yields the heatmap Table B including the average value of scores of classes and attributes: **quantification**
VII. When theoretical triangulation from a position or environmental triangulation from a different environment is applied, more than one heat map is produced
VIII. The significance of the map and averages is noted and interpreted
IX. A dendrogram, Table C, is created through a web based program, and its grouping interpreted: **clustering**
X. Results are formulated and readied for practice or for a reiteration of the steps II-IX above

attributes that apply quantitatively to a varying ponderable degree. Environmental and theoretical triangulation apply where the setting of the industry or the perspectives of parties differ, respectively. Producing a dendrogram in **Table C** allows clustering of the classes and attributes allowing perception and deliberation. The methodology, perception arrived at, and deliberations are summarized in the box below and explained in detail in the following sections that also provide an illustrative case.

Data assembly

The thesis is written as five literature reviews with heatmaps and cluster diagrams added through additional sources of information and experience. The thesis' subject, super-domain and title is "On Processing Potato" which encompasses the processing potato (raw material: breeding, growing, handling, delivery) and the processes and operations in factories (reception of raw to packing) and operations in kitchens by cooks and quality aspects important for and appreciated by consumers. The domain is thereby delimited, it includes the environmental and appropriate social aspects of processing potato but it was decided to exclude health and economic aspects such as pricing and trade as perceived too remote from the core topic, also because of the manifold socio-economic interactions with non-topical issues. The domains are selected based on the research questions about: the ontology of the domains, the variety and need of operations in kitchens and factories, specs, efficiency and production of raw and products and on the sensory and nutritional quality of the latter while taking repercussions of the social and environmental surroundings into account. The attributes are not exhaustive by far but also closely associated with the research questions, so properties of process of processes regard temperatures and use of water for instance and not their costs and how long they take as being irrelevant for answering the research question.

The sources of data pertinent to answering the research questions, through appropriate domains with their classes and the degree their attributes apply is given in Table 1.6. The setting of the industry from production of raw to consumption of product derived meal components is from subsistence farming, cottage industry and low income consumers to corporate farming, globally operating companies and well to do consumers. Observations and experience of the author are mainly from 45 years of practice and visits on farms, factories, shops, kitchens and restaurants where also information was gathered through interviews with key informants and intentional and targeted conversations without a stringent pattern in questions or reporting. The internet yielded additional information especially on nutritional aspects and companies' ambitions.

This thesis is not based on experiments that independent researchers are able to replicate. Straightforwardly replicable, however, are:

1. Choice of the classes in each domain resulting in the same classes as were selected in the three to four domains of each of the chapters;
2. Choice of the same diversity of attributes (properties);
3. Choice of the value (score) for each property as to the degree the property applies to each class.

Then the heat maps, dendrograms and clustering will appear exactly as shown in the procedures of the domains in the chapters. With other objectives in mind than finding answers to the research questions of this thesis, other researchers with different data sources as mentioned in Table 1.6 or with different information from the same type of source, possibly will add or reduce classes and attributes and award different scores. The outcome thereof then satisfies their objectives without altering those presented in this thesis.

Table 1.6. Origin of data of the classes mentioned in the thesis and the degree their attributes are of relevance to them

dark green	light green	cream	light orange	dark orange
Most relevant				Irrelevant

Origin of data	Nature of information						
	Observing setting	Observing operations	Professional literature	Scientific literature	Interviews, talks	Websites	Databases
Hands-on experience of the author on parental clonal seed potato production farm	dark green	dark green	dark green	dark orange	dark green	dark orange	dark orange
Participation in academic research projects ranging from the molecular (DuRPh) to the global systems (climate change) level	light orange	cream	light orange	dark green	cream	cream	cream
Monitoring and judging raw material related R&D of internationally operating potato processing companies in 16 different countries	light green	dark green	light orange	cream	dark green	light orange	light orange
Farm visits related to development, performance of raw material regarding meeting specs resource use efficiency and CO_2 emission	light green	dark green	dark orange	dark orange	dark green	dark orange	dark orange
Potato processing factories and their quality labs visited, performance of raw and processes discussed in ten of the counties mentioned above	cream	dark green	dark orange	dark orange	dark green	dark orange	dark orange
Tubers and products observed in shops and markets, variety, quality and prices compared in most countries visited	dark green	cream	dark orange	dark orange	cream	dark orange	dark orange
Potato components of meals in restaurants noted and usually questions asked to the kitchen on their origin	dark green	dark green	dark orange	dark orange	light green	dark orange	dark orange
Managing and/or consulting national potato R&D programs in 33 different countries (4 overlap with row above)	dark green	dark green	cream	cream	dark green	light orange	light orange
Conferences attended and presentations given (over 30, in over 20 countries (10 overlap with rows above)	cream	dark orange	dark orange	dark green	cream	dark orange	dark orange
Participation in potato related advisory committees of public services and the industry in the Netherlands and abroad	light orange	light orange	cream	dark green	dark green	cream	light orange
Data gathering to specifically answer the research questions of this thesis	dark orange	dark orange	dark orange	dark green	dark green	dark green	dark green

Iteration or exit

Once a research question is articulated that will yield new knowledge, the domain that produces this evidence is formulated. As illustration serves the question: when did products (classes) originate and for which reason (attribute). The domain then formulated is "Potato Origin" with classes of "products" and "When first made?", "Where" and "Why" as attributes. The delimitation consists of the description that the first time mention of the recipe only does not suffice. The methodological triangulation of quantitative and qualitative data (Flick 2018) that follows, consists of the research methods: observations, interviews, scientific and professional literature, consulting databases and websites and calculations.

After formulation of the domain in the 'Four-Tier Analysis' specifically developed for the current study, data undergo A) assembling (condensation), B) mapping (quantification) and C) grouping (clustering) of data. The consequences thereof undergo deliberations and perception, leading to results as shown in Figure 4. The analysis shown in Figure 1.3, is reiterated when, perceiving the results, additional data are needed or the research question requires to be amended.

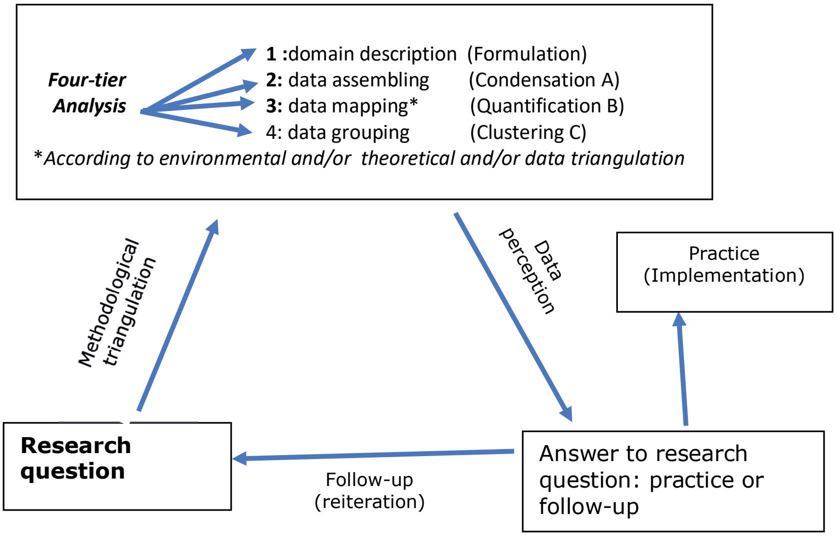


Figure 1.3. Route of questions, analysis and answers

Four-Tier Analysis

To arrive at examined material ready to be perceived and discussed, a Four-Tier Analysis is followed as shown in the flow diagram below (Figure 1.4) and, once the domain is formulated, consists of:

A. Collecting and organizing qualitative data of classes and their attributes. These data are either qualitative (fanciness of French fries, skills needed to make them) or quantitative (frying temperature, oil concentration) and have different origins. Through 'method triangulation' they corroborate each other and remove bias (Flick 2018). In the current research, most observations consist of the experiences of the author working in science and industry, illustrated in the section "Data assembly" above and summarized in the Potato handbook (Haverkort 2018). Interviews comprised formal ones to explicitly elicit societal intelligence on processing potato from key industry players such as chief executive, agricultural, sustainability and communication officers and exchanges with technical staff of the industry on specific technical issues, such as efficiencies and losses.

Table A. Organization of data
METHODOLOGICAL TRIANGULATION

QUALITATIVE INFORMATION
Examples
- Observations
- Interviews
- Literature
- Internet

QUANTITATIVE INFORMATION
Examples
- Data bases
- Calculations
- Scientific literature
- Google hits

Table B. Mapping of data
THEORETICAL AND ENVIRONMENTAL TRIANGULATION

Table x. Extent to which the attribute applies to a class in a heat map

Instance	**Attribute**		
	a	**b**	**c**
1	1	**4**	
2	**2**	**5**	
3	**3**		

Table C. Clustering of data

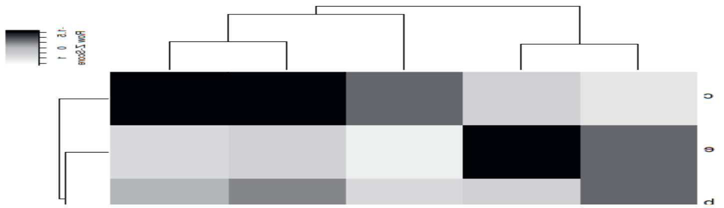


Figure 1.4. Scheme representing the Four-Tier Analysis (how methodological triangulation is used in this thesis)

Literature yields both quantitative and qualitative data and so does the internet through websites and hits. To keep the number of references within limits, often a most recent source or a most illustrative one is taken up in the text and list of references. A most recent one upon consultation offers the possibility to view less recent ones cited there. Most illustrative usually are reviews on a specific subject exposing it from multiple perspectives. Data bases such as from FAO, and WHO referred to in the tables and interpretation through calculations are sources of quantitative information. Table A lists classes with their attributes and where use was made of published material, references are supplied.

B. Definitions are from the science and terminology of ontologies: a domain contains classes. A class, say “French fries” is a class of all “things” (a term used in ontologies) that meet the criteria of French fries. Instances of this class are Flemish cut or MacFry (MacDonald’s specs). Attributes specifically describe classes, with a name and a value. Attributes and classes are dependent. Attributes more (green) or less (red) apply to a class. This exactly is the interpretation of the result of identifying classes and attributes. Once data are compiled and ordered in Table A, the classes that are subject of investigation are listed in the rows and their attributes in the columns (‘methodological triangulation’, i.e., deploying data from different methods in a single investigation (Denzin and Lincoln 1998) producing Table B. As illustration serve frozen French fries processes with instances 1) cutting, 2) blanching, and 3) par-frying and with attributes the requirements of a) water, b) oil and c) energy. Next, the extent to which water, oil and energy are needed for each class cutting, blanching and frying is indicated by a range from 1 (little with a dark red color) to 5 (much with a dark green color). Some attributes are quantitative and unambiguous such as the temperature at which a process takes place during freeze-drying (below 0°C, green color, value 5), starch production (ambient °C), blanching (70°) boiling (100°C) and frying (170°C, red color, value 1). Somewhat more arbitrary are qualitative attributes such as the skill needed to cut: dark red, value 1 or to blanch and par-fry: light green value 4. The values given to an attribute follow from the gathering and triangulation of the data (Denzin and Lincoln 1998); ‘theoretical triangulation’ takes the position into account, so a consumer will attach greater value to the product when it costs less whereas the producer will attach a greater value when the buyer pays a higher price. Similarly ‘environmental triangulation’ as an illustration distinguishes local versus global where for instance drying potato slices in sun and wind is important in an Indonesian village (value 5) but not at all at the global level (value 1).

C. The fourth tier of the research approach in “On Processing Potato” is the creation of a dendrogram to establish hierarchical clusters of both the classes that are subject to examination and their attributes. Therefore the heatmap of Table B is downloaded into the online heatmapper (heatmapper.ca, Babicki et al. 2016), set at “Average Linkage” and “Euclidean Distance Measurement Method”. In a dendrogram, Table C, the classes are always in the rows and the attributes in the columns. A cluster of attributes is grouped by connecting horizontal lines which show they have similar properties. The length of the vertical lines is indicative of the degree of similarity: the shorter the line the greater the analogy.

Illustrative case

To demonstrate the Four-Tier Analysis based on triangulation, a simplified example with a few classes of actors is shown with a few attributes. The research question is: what kind of information is shared among links in the supply chain? The domain is formulated and delimited as: all participants exchanging potato material and information; suppliers of services and material are excluded. From various methods of data gathering explained in the accompanying text, provided with references to the origin, a summary Table A is composed. The summaries of the data assembling (Table A) let a complex narrative be condensed into a simple description of a domain into a group of instances (individuals), a class where all instances share the same attributes. In the Four-Tier Analysis, Table A is not exhaustive but in general terms describes which classes, among others, are present in a subdomain under scrutinization and what kind of attributes in general apply to them, without detailing to what degree. The glossary at the end of this thesis assists those unfamiliar with potato processing and its jargon.

Table A. Description of the classes of actors with their attributes about preferences and information

Class	Preferences	Information	Concerns
Consumer	Taste, origin, health	Share with cook, friends	New products
Cook	Convenience, ease, safety,	Performance	Ingredients
Retailer	Rapid turn-over	Product requirements	Shelf life
Processor	Optimized recovery	Availability of raw	Quality of raw material
Grower	Meeting specifications	Decision support, seed	Environment

The heatmap (Table B) produced here is a cluster heatmap with a fixed grid cell size with in each row classes of a domain and in each column their attributes. The color refers to the degree the attribute applies to the class (Wilkinson and Friendly 2009). It delivers a quick qualitative information evaluation as the focus is drawn to dominant color concentrations in the map, permitting preliminary deliberations and conclusions on issues of classes and attributes. The average value of scores permits

Table B. Heatmap of the classes of actors and the importance they attach to considerations as their attributes

5	4	3	2	1

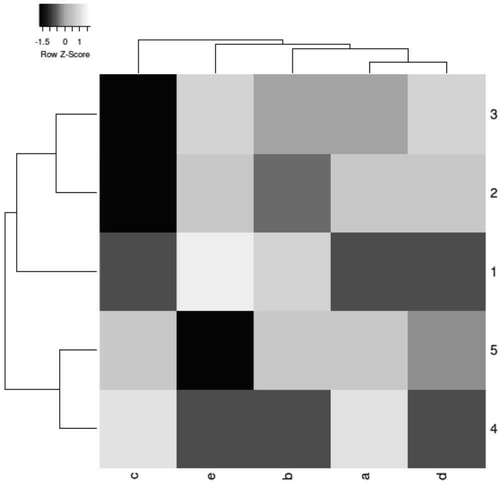
Very important	a	Necessity to meet specs[1]	Not important
	b	Environment-friendly production of raw	
	c	Information on the supply of raw[2]	
	d	Access to performance of peers	
	e	Interest in new products	

	Class	a	B	c	d	e	Average
1	Consumer of potato dish	1	2	1	1	5	2.0
2	Cook in the kitchen	5	3	1	5	5	3.8
3	Shop selling the product	3	3	1	4	4	3.0
4	Processing factory	5	4	5	4	4	4.4
5	Grower of tubers	5	5	5	4	2	4.2
	Average	3.8	3.4	2.6	3.6	4.0	3.5

1 Specifications of raw, finished and dish
2 Quantity and quality of the raw material tubers going to the factory

a quantitative evaluation of where classes find attributes of importance and which attributes are of relevance for classes. Table B is constructed where the classes are supplied with a number (1-5) and the attributes with letters (a-e), each allocated a value per class ranking from 1-5 shown with a corresponding color from dark red to dark green. For example, consumers have no interest in the specs that raw growers have to meet (cell a1, value 1) and cooks are very much interested to learn from peers (cell d2, value 5). The values given to the attributes are qualitative and somewhat prone to bias but the great difference among the classes and of the attributes allotting a neighboring shade of red or green will not much change the order of the columns and rows, so row c remains to consist of attributes only of interest to growers and factories and row four showing that factories have interest in most attributes (an average of scores of 4.4) and consumers the least (2.0) with only some assurance that tuber production spared the environment and a desire for new products. Of the attributes, the supply of raw is only of interest for growers and processors and all classes, albeit to a varying degree, find new products important.

Table C. Dendrogram of the classes (1-5, Table B) and their attributes (a-e, Table B)



The heatmaps are at the base of dendrograms that show a hierarchical clustering of both classes (ordinate) and attributes (abscissae). Groups (clusters, subsets) of classes share more attributes among them than with members of another group. This approach permits a further condensation and focus for future explorations, research and development and communication. The closer the classes or attributes are in a subset, the less effort is needed in communication and reiterations.

Clustering of actors shows:

- Two clusters: one with growers and processors, and one with the other actors
- The twins growers (**5**) and processors (**4**) have many attributes in common as emanates from their short distance from the ordinate; the same holds for cooks and shops
- Consumers (**1**) have most in common with cooks and shops but at a larger distance.

Clustering of attributes shows:

- The twins **a** (meeting specs) and **d** (information from peers) that have the lack of interest of consumers in common are one cluster
- At an ever greater distance from these groups are the attributes **b, e** and **c**

Note: the relative larger distances plotted for the classes than for the attributes are not indicative of a greater similarity of the attributes. It is just how the heatmapper.ca does the plotting. Exchanging rows and columns in Table B presents a dendrogram with relative larger distances for the attributes.

Selection of classes, attributes and numerical values

The classes of subjects in the thesis are many, but not exhaustive: tubers, products and dishes, farmers, processors and cooks, operations, handlings and processes, efficiencies, losses and wastes, legislation, technology, environment and legal issues. All these classes of subjects are divided into subclasses or lumped into super classes. Frozen products for instance are part of the super-class fried products, which includes a variety of snacks and is divided into sub-classes such as French fries and formed products. Classes or sub-classes have instances, those of French fries are strait and crinkle-cut, battered and unbattered to name a few. These, however, are considered subclasses of French fries when supplied with attributes of instances such as a bag of frozen French fries Flemish cut of 1 kg in the supermarket at street x in city y.

Next, each class, superclass or subclass is supplied with a number of relevant attributes (descriptors, properties, particularities). The class of Frozen French fries, among others, has attributes such as shape, size, additives, flavors, concentrations of dry matter, oil and vitamin C. Data collection on classes and attributes are the key objects in the approach of the chapters. When tabling classes in rows they always belong to the same category so classes are only a list by way of illustration of products, process, operations or actors. The attributes in the columns apply to a greater or lesser degree to each class: the attribute flavor is very applicable to chips but much less to baked tubers. In general, the list of classes in the rows of Tables B is rather complete, although an investigator with a specific interest may delete a few and add other ones. The number of attributes is complete to a somewhat lesser extent and the selection is rather prone to arbitrariness. Here too, a researcher is free to change the selection. Some of the values from 1-5 of the attribute are indisputable: baking is hottest (5) and freeze-drying is coldest (1), but others are less obvious and simply assumed (consumers are more interested in new products than growers. Here anyone interested in suggesting a different value can do so as well. Selection of different classes, attributes and values yields a different heat map, open to new perceptions and conclusions. When the heatmap completed with values 1 – 5 in MS Excel is uploaded to the online heatmapper (www.heatmapper.ca), it produces a new dendrogram with new hierarchical groupings of classes and attributes. This process adds value to this thesis as other times, locations and persons are targeted, data triangulation becomes in effect.

The Tables A, formulating a domain (its classes and their attributes) are leading and are input for the Tables B (heatmaps). The text (with references) in a section pertaining to a Table A, intentionally does not mention or treat all classes and all attributes but merely serves as illustration of how elements of the domain are gathered without being as exhaustive as the table A itself. The thesis is written as a monograph. The chapters are written as surveys with state of art presentation of 17 domains, their classes and the attributes thereof. For The "discussion" of these findings for each domain is represented intrinsically in the Four-Tier Analysis, by awarding scores, producing and verbally interpreting heatmaps (Tables B) and dendrograms (Tables C). This representation and analysis is an internal discussion of the findings presented. A separate discussion by comparing the findings of the Tables A,B.C with literature is not possible for lack of previous scientific literature of most domains. Nor is the methodology (the Four-Tier Analysis amenable to "discussion" as this aspect has also been uniquely developed within the framework of the thesis. Therefore the deliberations and conclusions at the end of each chapter intentionally do not embody a discussion but serve as an overview to grasp the contents. Table 7.1 (in the General Discussion) serves the same purpose. There are limitations to the Four-Tier Analysis, however, situations where other approaches are more apt. The final part of the General Discussion treats this aspect.

Structure of the thesis

Following the General Introduction in Chapter 1, the thesis (Table 1.7) in the second chapter describes the ontology of the super-domain and the domains of the participants, i.e., growers, processors and cooks/consumers. Special interest is given to the history of processing starting with Inca practices

Table 1.7. Schematic overview of the seven chapters of the thesis

Chapter 1. GENERAL INTRODUCTION		
Domains		
Cultivation **Growers** making tubers	Manufacturing **Processors** making products	Utilization **Cooks** making dishes
Chapter 2 COOPERATION: tubers, products and kitchen operations		
Growing product specific tubers	Copying kitchen preparations from antiquity till present	Making dishes from tubers and products
Chapter 3 MANUFACTURING: products, processes and operations		
Meeting specs of tubers for specific product	All actions from delivery of raw to packing	Convenience from using products
Chapter 4 PRODUCTIVITY: supply chain, performance and efficiency		
Genotype, environment, management	Recovery of finished products per unit weight of raw	Water, energy efficiencies, avoidance of losses
Chapter 5 NUTRITION: dishes, senses and nutrients		
Genotype, environment, management	Operations and additives for taste, smell, looks and feel	Choice of healthy products and meal composition
Chapter 6 SOCIETY: benefits, stewardship and surroundings		
Regulated supply, restricted use of resources, chemicals	Value addition, subjected to policy, food culture, buying power	Awareness of health, choice, environment, affordability
Chapter 7. GENERAL DISCUSSION		

observed by Spanish chroniclers in the early 16th century and ending with the newest snacks introduced to the market early this century. Next, the super-domain of manufacturing is described with its three domains, i.e., products (available in a supermarket), processes (such as heating, cooling) and operations (such as washing and frying), each containing classes (such as processes) with attributes (such as frying). In the fourth, interaction among the actors in the supply chain, efficiencies and losses in farming, processing and cooking are subject of investigation. Chapter 5 illustrates a worldwide inventory of potato dishes and products they contain and discusses the quality of potato products in terms of taste and nutrients. Chapter 6 analyses social interest in processing potato, its benefits, its sustainability approaches and the political, economic, social, technical, environmental and legal (PESTEL) aspects concerning growers, processors and users. The final Chapter 7 discusses the findings not per chapter but from the point of view of the umbrella domain On Processing Potato.

Each of the Chapters 2-6 starts with an inception, mainly comprised of three or more research questions. Next, the Four-Tier Analysis is deployed rigorously: each domain is formulated and delimited, condensed to a list of classes with their attributes followed by a heatmap and a dendrogram. A chapter concludes with a deliberation section discussing the responses to the research questions.

Chapter 2.

COOPERATION
Domains of tubers, products and kitchen operations

Slightly modified published in Potato Research as:

Haverkort AJ, Linnemann AR, Struik PC, Wiskerke JSC, 2022. On Processing Potato. 1. Survey of the ontology, history and participating actors.
https://doi.org/10.1007/s11540-022-09562-z

Abstract

The processing potato ontology includes the three domains of tubers produced by growers, products made by processors and kitchen operations of cooks producing dishes. The latter consists of three subdomains: kitchen operations, resulting dishes and consumer preferences for products. Preparing meals with potato as ingredients dates from the time of the domestication of the crop in the Andes region. It involves washing, peeling, partitioning in smaller sections and heating to gelatinize the otherwise, for non-ruminants indigestible starch. Since the Columbian Exchange both the crop and processing expanded globally. The history of potato processing starts with the pre-historic pre-Columbian era when drying as a means to preserve and render the tuber less bulky and making flour and alcoholic drinks were common practice. Once the crop was a global food crop, processing established, initially into an array of nourishments for seafaring and military purposes and later for aviation, convenience and to satisfy hedonistic needs.

The domains are studied through a Four-Tier Analysis: first a description and delimitation of the domain is made, next allocation of classes with their attributes followed by awarding a value to an attribute as to the degree it applies to the class, yielding a heatmap and fourthly, a dendrogram is produced that shows clustering of classes and of attributes with similar features.

Inception and research questions

The cooperation domain, describes classes and their attributes of tubers grown by growers, products made by processors, kitchen operations performed by cooks and dishes made of products by cooks according to preferences of consumers. The intricate relationships between eaters of potato dishes, cooks, retail, processors, growers of tubers for raw material, seed potato growers and breeders is a unique social phenomenon in food supply chains. In scientific literature to date this super-domain has not been formulated, not been delimited, classes not identified and properties not attributed nor supplied with values to allow a quantitative evaluation and grouping. More specifically a number of research questions are articulated below. The super-domain of processing potato has domains, or similarly a domain has sub-domains. The relevant domains are mentioned, what kind of classes they contain and what kind of attributes they have in general.

Research question about growing classes of tubers

Both for cooking in kitchens and for industrial transformation tubers need to be produced by growers. It requires to be described which classes of tubers are needed by the industry, the efforts in producing them and what their specifications are for use in processing with different finished product in mind. Are the specs different when articulated by another party or in another environment?

Research question about manufacturing of products

Over time the number of manufactured products available for consumers increased. The domain of products has classes of types that with time came to the market for specific technical and social reasons. In what order and why were they made?

Research question about kitchen operations

Fresh tubers, purchased with the aim of a dish in mind, are washed in kitchens, usually peeled, whether or not cut and heated to end up among others as French fries of gratins. Historically, manufactured potato products were derived from kitchen preparations for several reasons and became available on markets. What are these kitchen operations? What kind of dishes do they lead to?, what skills, appliances and energy is needed?

Research question about preparation of dishes from products

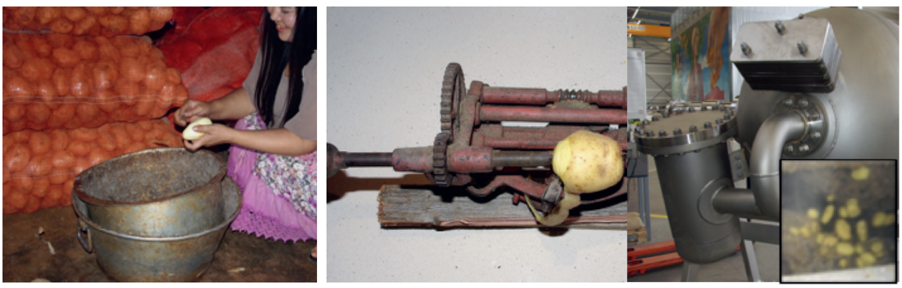
Which readymade potato products are made into what kind of dishes in kitchens? What are the properties of these classes of dishes and apply these properties differently in developing and developed market situations ?

Research question about categories and preferences of consumers

It has not been documented what the attitude of the different consumers is when needing or being confronted with the wide array of potato products. Consumers are not just one group but are a diverse population. What are their different interests depending on their attitude as determined by economic position, taste, habits and on the purpose of buying? Is there variation in buying products for routine cooking or for a special occasion varying from a snack between meals or preparing a dinner party?

Ontology and delimitation of the potato processing domain

The potato ontology (Haverkort et al. 2005; Haverkort and Top 2011) describes the domain of tuber production, tuber handling and storage of tubers to be processed. An ontology is helpful to organize data in a systematic way as to enable interested entities to question the database. The sub-domain tuber production has three sub-sub-domains, “Planting Material” (variety and seed), “Growing Environment” (climate and soil) and “Crop Management” (fertilizer, biocides and water). An instance in the ontology of planting material is Seed_tuber with attributes Variety Agria (with known lateness, resistances and tolerances, Size (between 35 and 50 mm), Health Class A Label (with known proportions of pests and diseases and origin). An instance of Environment as illustration is Cropping_time with attributes planting and harvest date and daily maximum and minimum temperatures, rainfall, evapotranspiration, solar radiation and soil moisture recordings. An instance of Management is Irrigation with attributes frequency and quantity (dates and mm per application). One of the basic concepts of potato production is a potato field as part of a farm (other crops in a rotation), with its layout (coordinates), its climate (weather data), soil (water and fertility data), its treatments (tillage, planting, fertilization, crop protection, harvesting) and its potato crop with properties such as variety, yield and quality. In Figure 2.1., these subjects and underlying data are represented schematically. Decision support systems (DSS) and crop observations assisting growers in



Peeling: hand, device, steam

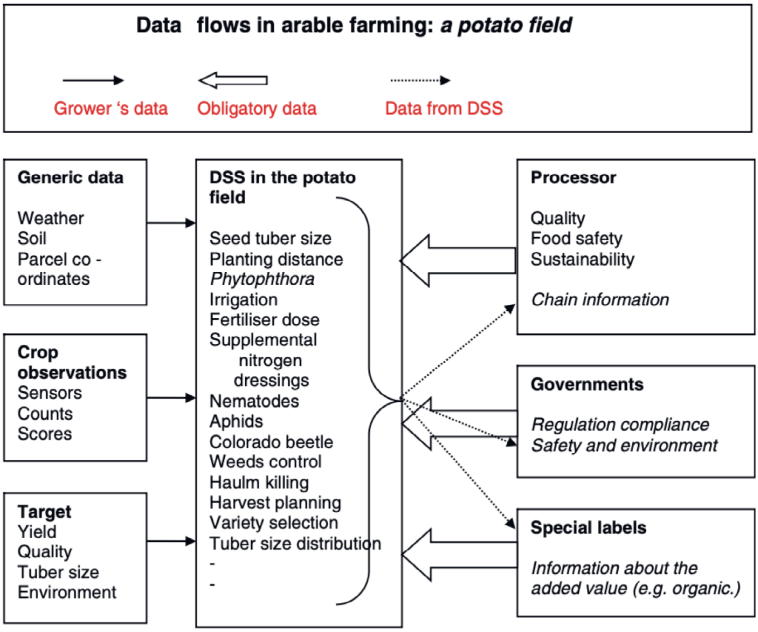


Figure 2.1. Data flows in a potato field (from Haverkort et al. 2005).

intervening in the crop, yield the bulk of the data. Processors, governments and special labels impose specifications and compliance to the growers and also retrieve information from them, especially processors want to know about water quantity and quality, mineral fertilization and biocides used. They add their own observations which are shared with the grower such as yield, tare, size, dry matter and reducing sugars concentrations and defects (green, cut and rotted tubers). The 2005 and 2011 potato ontology articles did not include aspects of the crop once leaving the farm but here, Figure 2.2 as examples, concepts of the potato ontology are shown. The super-domain Plant_parts has a domain Tubers with Processing_tubers as one of the siblings and French_fries_tubers a sibling thereof. Similarly the superclass Production_processes has siblings among them the class Potato_products_production _processes with three subclasses among them Physical_processes with one of the sub-subclasses Heating with a sub-sub-subclasses Heating_in_hot air with a sub-sub-sub-subclass Baking. An instance in the comprehensive potato ontology is a bag of chips with attributes production date and time, weight, seasoning, proportion water, salt and oil, frying time and temperature, blanching time and temperature, quality characteristics of the raw material (variety, size, defects, tare, dry matter concentration, fry color and origin). The origin goes back to the field where grown with all data recorded as represented in Figure 2.1.

a

- Leaves
- Stems
- Roots
- Tubers
  - Seed tubers
  - Table tubers
  - Feed tubers
  - Processing tubers
    - Rejected tubers
      - Green tubers
      - Low solids tubers
      - Tubers with hollow hearts
      - Tubers too large or too small
    - Accepted tubers
      - Blanched tubers
      - Fried tubers
        - French fries tubers
        - Chips tubers
      - Baked tubers
      - Dehydrated tubers
        - Tubers for flour
        - Tubers for flakes
        - Tubers for granulates
        - Tubers for starch

b

- Seed tuber production processes
- Table potato production processes
- Potato products production processes
  - Mechanical processes
    - Washing
    - Peeling
    - Cutting
    - Mashing
      - Dough making
      - Forming
  - Physical processes
    - Dehydration
      - Ambient temperatures
        - Starch production processes
        - Dried slice production processes
      - Low temperatures
        - Cottage industry freeze drying
        - Factory industry freeze drying
          - Ambient pressure
          - Low pressure, vacuum
    - Heating
      - In water
        - Blanching
        - Boiling
      - In oil
        - Par-frying
        - Deep fring
        - Pan frying
      - In hot air
        - Baking
        - Roasting
  - Chemical processes
    - Hydrolyzing

c

- Nutriments
  - Nutriments for animals
  - Nutriments for humans
    - Nutriments from powder in liquids
      - Sauces
      - Soups
        - Pea soup
        - Vegetable soup
    - Nutriments from mash
      - Cooked
        - Stews
        - Side dishes
      - Fried
        - Fresh mash
          - Croquette
          - Pomme dauphine
        - Dough based
          - Not pelletized (stackable chips)
          - Pelletized (Expanded chips)
    - Nutriments from tuber (parts)
      - Cooked
        - Gratin
        - Boiled tuber
      - Fried
        - French fries
        - Chips
      - Baked
        - Jacket potato

Figure 2.2. Part of the potato ontology with classes of tubers of raw material made by growers (a), of operations by processors (b) potato products used by cooks or consumed (c)

The super-domain "Processing Potato" consists of three sibling domains. The first one is "Potato tubers" with attributes of production up to delivery of the raw material at the processing plant. It is followed by the domain of "Products" that are made by processors and is concluded by the "Kitchen Operations Domain" with two related sibling domains, that of "Dishes made from products" and "consumers with their preferences"

Domain of tubers serving as raw material for different products

Formulation of the tuber domain

Production (P) of a quantity of tubers per unit area and of a specific quality takes place with a genotype (species, variety), in an environment (summer, winter rainfed, irrigated, long day, short day) and crop management (low and high input, conventional or organic). The genetic aspects (G) include the adaptability to the environment in field and store, resistance to prevailing biotic factors, pests and diseases, and tolerance of abiotic factors such as drought and salinity. Also more societal interests such as the suitability to make desired finished products, which among others depends on mealiness, structure, size and shape, to a great extent depend on the genetic make-up of the planted material.

Table 2.1A. Description of the tubers domain

Raw material tuber	Pre-planting specifications	Storage and handling regime
Starch tuber	[1]Tare, small tubers, TGA starch	Hardly stored, ambient for few months only, ungraded, no sprout control
Flour tuber	[2]No small tubers, defects, reducing sugars	[5]Rather low temperature (6°C), ungraded, sprout control
French fries tuber	[3]Size, shape, defects, fry color	Rather low temperature (6°C), graded sprout control
Baking tuber	Firm skin, size, nutty taste, buttery texture	Rather low temperature (6°C), graded sprout control
Crisping tuber	[4]Meeting many specs, very low in reducing sugars	Not too low temperature (10°C) to avoid formation of reducing sugars, graded, sprout control, washed upon delivery
Chilled tuber	[2]As for flour tubers, no odor, no greening	Rather low temperature (6°C), graded sprout control
Baby tuber	Small sized, waxy	Rather low temperature (6°C), graded, sprout control, (washed upon delivery)
Fresh market	Without skin blemish	Rather low temperature (6°C), graded, sprout control
Seed tuber	Disease free (according to class)	[6]Low temperature (3°C), graded

1: Only specification is high solids, so no quality requirement allowing not too subtle management storage
2: Varieties usual dual purpose for use as e.g. French fries and flour, low temperature storage for long period
3: Specific varieties with breeding rights, adequate solids, low reducing sugars, large, long tubers
4: Specific varieties with breeding rights, low yielding, high solids, very low in sugars, storage at not low temperatures
5: The lower the storage temperature the higher the concentration of reducing sugars and the darker colored is the fried product (Chie et al. 2006) because of acrylamide formation
6: Seed tubers are stored at temperatures as low as possible to postpone sprouting. Sometimes low ethylene doses are of assistance

The environment (E) where the crop is planted is composed of an above-ground compartment and a below ground compartment. Above-ground the crop is subjected to the atmospheric conditions including the intensity and duration of solar radiation that determine the growth rate, daily maximum and minimum temperatures that determine the development rate, and precipitation and evapotranspiration that are part of the water balance that limits growth when negative. Conditions in the soil that matter are rooting depth and water holding capacity (influenced by granular composition and organic matter) that determine the water availability and soil fertility , the presence of minerals and organic matter. A planted crop in a given environment is subject to management (M), the cultivation practices of the grower who does the tilling, manages the supply of water and minerals and protects the crop against weeds, pests and diseases. This way of describing production is often written as a 'formula', P=G x E x M of which Rietema (2015) supplied an example. Another approach of the domain is through the expression of yield levels of the crop. The highest, potential, yields, are obtained when the yield defining factors (solar radiation and temperature) are deployed optimally, when the crop is provided with all water and nutrients it needs, (growth determining factors) and not hampered by growth reducing factors (weeds, pests and diseases). All tubers, so also in the subclasses, until harvest have been subject to these conditions.

Table 2.1A distinguishes the various tubers for processing (and as illustration, also for seed and fresh market) the pre-planting specifications (specs is the term used by the industry) they have to meet and a few handling and storage aspects. Chapter 4 enters into more detail on these aspects. The specs of the tubers of the harvested crops are stipulated by the manufactures and depend on the products made: starch (Grezel 2015), flour (AVIKO 2021a), French fries (AVIKO 2021a), baked tubers (PotatoesUSA 2021), chips (USDA 2011) and chilled tuber parts (AVIKO 2021). Starch potatoes are ground so their shape and defects hardly matter and the starch factories only operate a few months per year so no expensive storage is needed. Just a heap covered with plastic and straw in a corner of the field suffices. To compete with the major starch source corn, the raw tuber material of the starch crop needs to be produced at the lowest possible costs. This is made possible through the absence of specs other than a high starch concentration and low transport costs. Fields are less than 100 km from the factory. Potato flour is made in specialized factories but also is a by-product of the French fries and crisping industry where slivers, not of use for the final product, are cooked, dried and made into flakes or flour. Here a wide range of sizes is acceptable and not many other specs are required. Tuber destined for French fries production need to have flesh with a creamy color in most parts of the world, but are white fleshed in the USA and most Commonwealth countries. The taste matters too and the tubers need to be long and large to create the highest yield in the factory with minimal losses. These restrictions lead to a high cost of production to which storage and transport costs up to a few hundred kilometers are added. The most stringent requirements apply to tubers for crisping. Small and round with a high dry matter concentration but with very low reducing sugar concentration, so they should not be stored at temperatures lower than 10°C. Crisping factories are near population centers where they are consumed so tubers are often transported for many hundreds of kilometers up to over 1000 km. Baby tubers for canning and chilled, result from grading, from scooping with a melon baller from large tubers or are grown for this purpose. Then densely planted crops of a variety that produce many small tubers with a firm waxy structure are harvested before tubers become too large. In Table 2.1A two categories of tubers are not processed but have many interfaces with growers of raw material such as seed tubers used as planting material of raw and fresh market tubers for dual purpose crops.

Quantification of the attributes of tuber classes

The nine classes of raw material are supplied with 11 attributes that to a lesser or greater degree apply to the classes. The attributes are explained in the previous ('formulation') section or go without saying such as size or are addressed in subsequent chapters like recovery: proportion of raw ending up as processed finished product, or readied as tubers for seed of the fresh market. Variety specificity captures pre-planting the specifications mentioned in Table 2.1A.

Table 2.1B. Heatmap of 9 classes of tubers and 11 attributes, awarded a higher score the more they apply to a class

High value			Low value
	a	Losses in handling	
	b	Storage requirements	
	c	Recovery in factory, market, seed	
	d	Variety specificity	
	e	Overall rigor, growers' skill	
	f	Value addition on farms	
	g	Value addition in factory, market	
	h	Year round delivery	
	i	Maximum distance to factory, market	
	j	Dry matter concentration	
	k	Size	

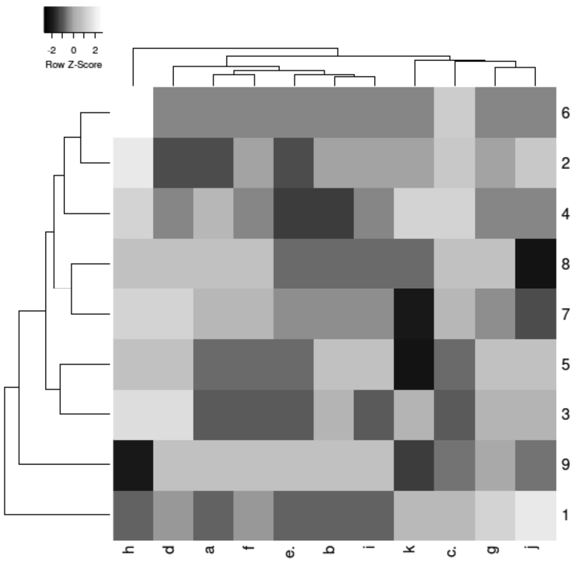
	Raw material classes, tubers destined for:	a	b	c	d	e	f	g	h	i	j	k	Av.
1	Starch												2.2
2	Flour												3.1
3	French fries												3.7
4	Baking												3.5
5	Chips												4.5
6	Chilled products												3.3
7	Baby tubers												3.4
8	Fresh market												3.5
9	Seed potatoes												3.9
	Average	3.3	3.2	3.8	3.8	2.9	3.4	3.7	4.0	3.2	3.4	3.0	3.4

The heatmap in Table 2.1B indicates that in general size should be average with the exception of tubers for baking that need to be very large and baby tubers which have to be very small. Also tubers for frying are large ones and seed tubers are sized well below average. Year round delivery is valid for most tubers except seed tubers that are only delivered for a limited period before planting and starch tubers that are not delivered after the factory closes some six months after the first loads arrive. The average of scores of all attributes is lowest for starch that has a high score for dry matter concentration and also for value addition in the factory (because of the low value of the raw material. Losses are considerable as not all non-starch matter such as proteins and fiber is recovered at higher than feed value. A very high average of scores is for chipping tubers (4.5), twice that of starch tubers (2.2). Here high losses in handling and expensive storage requirements are awarded a high score although they are conceived negative. If desired so they may be given a negative score as is done for two scenarios in Table 2.2B but the advantage of losses in handling (grading) and costs in storing (refrigeration) is a higher price of the tubers upon delivery.

Clustering of the classes of tubers and their attributes

The dendrogram in Table 2.1C does not reveal a clear clustering of tubers but it is clear that the class of starch tubers are apart from the other ones. Seed tubers too are relatively remote from the other classes. Tubers destined for making flour and chilled product, twins, have much in common. Baby tubers and fresh market tubers also and tubers as raw material for French fries and chips although at a larger distance. Clustering the attributes reveals that year round delivery stands alone with two clusters remaining, the left one with value addition assured at high recovery from tubers with the right size and dry matter concentration. The middle clusters concerns farm matters with variety specificity at some distance.

Table 2.1C Dendrogram of tubers for different products and markets and of their details Codes of products (1-8) and details (1-k) in Table 2.1b)



Domain of potato products

Formulation of classes of products

Potato products appear in dry (flour, chips), liquid (beer, vodka), more or less as moist as the fresh tuber used as raw material (baked, blanched and chilled) or semi-dehydrated (French fries and formed). Some products are easily prepared in a cottage industry setting, others need complex equipment, to make popped chips for instance. Some products are ready to eat (biscuits and snacks), others only need be heated (gratins) or still allow many further kitchen operations if so desired (flour, chilled).

Then there is also the appearance of the product over time. Cieza de Leon, Spanish chronicler, in 1538 according to Burton (1966) citing Penrose (1864) and Laufer (1983) wrote: *"Their principal sustenance is papas....These they dry in the sun and keep from one harvest to the other. And they call this papa after it is dried, chuno (chunu); and among them it is esteemed and held precious......and if* *there is a dearth of natural water to make their crops grow they suffer from lack of food and work unless they are provided with this sustenance of dried papas....".* Burton (1966) citing Cobo (1653) translated by Safford (1925) described how Chuño was prepared: *"The tubers are gathered at the beginning of the cold season, in May or June, spread on the ground and exposed, for a period of twelve or fifteen days, to the sun during the day, and the frost at night. At the end of this time they are somewhat shriveled, but still watery. In order to get rid of the water, they are trampled upon and left for fifteen or twenty days longer to the action of the sun and frost, at length becoming as dry and light as a cork, very dense and hard and so reduced in bulk that from four or five fanegas of fresh tubers there only results one fanega of chunyo".* When *chunyo* is left in water for two months and dried it results in white *moray*.

Three hundred years later a contemporary description of conventional use in the twentieth century was given by Rodriguez (1974). Chuño is produced by exposing tubers on rocks at high altitude (more than 4000 m above sea level) to – 10°C at night and + 30°C during the day for one week. The product is dry, dark colored, storable for years and less bulky to transport than fresh tubers. Also as an advantage over fresh tubers, the concentration of glycoalkaloids is halved (Christiansen, 1977). It is eaten, after reconstitution, in stews (Woolfe, 1987). When soaked in water for two months the color becomes white and the glycoalkaloids concentration then is further reduced to about 10% of the original tuber. In the country of origin chuño is also called tunta or moray. Traditionally tunta was ground to produce a fine flour according to Burton (1966) citing Cobo (1653): "producing a flour finer than that of wheat of which the Spanish women (no mention of the Inca's using such flour) baked biscuits and sweetmeats. This is a first time mention of a recipe (beside fermenting to make beer) based on a potato ingredient. Papa seca (Woolfe 1987) is produced by peeling, crumbling and sun drying of boiled potato. Chicha, beer, is made by fermenting potato pulp with water. Distilling chicha produces chakta. The peoples of the Andes before the arrival of the Spanish around 1500 AD, hundreds maybe thousands of years earlier (Salaman 1970) mastered six processes still applied in modern times: boiling, freeze drying (chuño), production of flour (almidon) and making a flakes like food stuff (papa seca), brewing and distilling (chicha and chakta). It is not known at which scale processing took place, in the household, at cottage level or in larger holdings. The use of chuño by armies in great quantities and transported over long distances (Salaman 1970) makes it plausible that large scale industry type of processing took place. These pre-Columbian means of potato preparation and those mentioned first time in recipes and industrial processes outside the region of origin are summarized in Table 2.A2.

Dumplings, pommes parisiennes adobe croquettes

Delimitation of the subdomain: peeling and packing not included

One group of products not part of the products domain described here is that of Potato Peeling and Packing Companies (Table 2.2A1. information compiled from the web sites of a few selected pre-peeled potato companies (PPPC 2021). They are excluded because heating or dehydration is not one of the processes the products have been subjected to, yet they are briefly touched upon in this section. PPPC's offer peeled (unless skin-on wedges), whole (often baby tubers) and cut tubers to outlets that do not wash, peel and cut but need fresh tuber (parts). These raw tubers or parts cannot be frozen (Mondy and Chandra 1979) as only heated tuber parts are frozen and still be fit for human consumption. They are supplied to customers on a (few) weekly basis fresh, packed in absence of oxygen and chilled to a few degrees above zero. Large scale processors have their own washing, peeling and cutting facilities so usually only smaller outlets directly serving consumers are users of peeled (and cut) fresh tubers and their parts.

Table 2.2A1. Pre-peeled and packed tubers: operations, products and users

Processes	Intermediate and final products	Users
Washing	Washed, peeled and trimmed whole tubers	Food service: diners, frietkots, restaurants, cafeterias, caterers, institutional kitchens
Peeling		
Trimming		
Cutting	Cut in halves and wedges and various French fries shapes (slim, thick, long, short, strait, crinkled)	
Additives	Preserved product with anti-oxidant (ascorbic acid), firming agent ($CaCl_2$)	
Deoxidization	Removal of oxygen (vacuum, nitrogen only)	
Packing	Wrapping in plastic bags various sizes	

Condensation of the attribute history

The first mention of a processed potato product outside the region of origin and other than cooking books as recipes in the household , according to Burton (1966) was by Parmentier in 1781. Ships had provisions of biscuits made from dough of boiled potatoes and served as an antiscorbutic to avoid scurvy and they occupy less space than tubers and when reconstituted and boiled, produce food similar to potato itself. In the same period, 1784, Fraser (2018) observed that the product potato flour on ships, remains well preserved. Herlihy (2012) in her book and Begg (1998) in his on the history of vodka mention that by 1790 potato was used as an ingredient for fermentation and distillation because then it represented a lower cost raw material than cereals. Currently it is a more expensive source of carbohydrate than cereals so potato derived vodka and akvavit are expensive niche products.

By 1830, baked potatoes also called jacket potatoes were sold by hawkers in the streets of London (Walton 2014) baked over embers or in portable tin ovens.

Preservation of food in a cottage industry fashion by drying as the chuño example in the Andean region shows, is age old. Another example of such a preservation method at the household level to sell to customers is drying slices of raw potato placed on iron mesh by exposure to sun and wind as is seen in Indonesia. Industrial freeze drying takes place since early last century (Fellows 2017).

Snacks: extruded-expanded, stackable chips, sticks

Upon reconstitution these products still need to be heated to permit starch to gelatinize. When dried in hot air, whereby the tubers loose water through evaporation following cooking, the starch is gelatinized already. Canning to preserve was invented by the Frenchman Nicolas Appert in 1810 (Anonymous 1963) to provide the Napoleonic armies with preserved food that needed little processing. First glass jars were used but by 1815 tins were in use in the USA.

Ricing, pressing cooked potato through a perforated metal sheet yielding a vermicelli -like substance was patented by Fitzgerald and Silver in 1887 in the USA. Riced potatoes are used as a mash and also as an ingredient of hash brown or rösti (The Wall Street Journal 2018). Burton (1966) cites sources in 1943 and 1945 describing how the riced product is dried and commercialized.

Hash browns are small cakes made of riced or diced potato, some onion and shortening and fried. The name comes from hashed and browned and was first mentioned in a 1895 cook book by Maria Parloa. Large frozen French fries companies also make frozen hash browns that cooks fry or bake in the kitchen.

The first time a starch factory opened in the USA was in 1831 in New Hampshire USA (Brautlecht 1940) and in 1833. In Europe it was in the Vosges region in France (Charton 1868) at the time competing with corn starch in the USA and with wheat starch in Europe. From the start starch had several uses and in Europe for a long time potato starch was the raw material for vodka production before lower costs starches took over. Modification of wheat and corn starch took already place by 1831 (Brown and Heron 1925) by adding vinegar to increase its solubility so it is assumed that potato starch modification started then as well. According to Willard (1959) flour for animal consumption was commercially produced as of 1901 when a German patent was filed for drum drying and subsequent grinding of unpeeled cooked potato. By 1917 the process was refined for human consumption producing flakes (unground) and flour (ground).

The first chips, anecdotally, were made by cook George Crum when preparing a meal for railway tycoon Vanderbilt who complained that his French fries were cut too thick (Daugherty 2021). Chips (Crisps in the United Kingdom) are thin slices of tuber fried in oil until the sizzling stops when all water is evaporated. They are loosely packed in aluminum coated polyethene bags with controlled atmosphere to avoid the oil to deteriorate, salted or with a wide array of flavors with many countries having a preferred taste. In 2008 the Tri-Sum company in Leominster, Massachusetts USA (Radvon 2008) and in 2010 Mikesell's company in Dayton, Ohio USA (Dayton 2010), both claimed to be the oldest chips factories

Feustel (1959) citing Harrington and Griffiths (1950) mentions "potato puffs", an experimental product that did not make it to the market. It is oil free made by flash heating small blanched slices or dices resulting in pillow shaped forms.

In 1945, Snow Flake Canning company, based in Brunswick (Maine USA) a branch of HC Baxter and brothers, was the first to produce frozen potato products according to a source in Talburt and Smith (1957). According to the Los Angeles Times archives the first frozen French fries were sold by the Birds Eye Company in Caribou, Maine in 1947. The process was invented by O.P. Pierson at the H C Baxter laboratory in Hartland in Maine. Somewhat later the Simplot and McCain (Stoffman 2007) companies started producing and continue to do so until today. Ebeling (2005) states that President Jefferson, formerly ambassador in Paris introduced them to the USA in 1802 with his French cook Honoré Julien. The first mention of French fries is in the French journal “Le Gastronome” in 1830 mentioning “how nice it is to see the Parisians and their *pommes de terre frites and* vendors of hot herrings and oven baked pears....” (Anonymus 1830). Croquettes as a savory meat based snack were described among others as early as 1851 by Haezebroeck. It is not known when potato versions with mashed potatoes were introduced to kitchens but processing of frozen formed products took off in the mid-20th century along frozen French fries, as all these frozen products needed a frozen food chain in factories, shops and homes which all relatively rapidly became mainstream in developed countries after WWII. The first written record about French fries in the Netherlands is an advertisement in the daily *Bredase Courant* in 1856. Around 1950 blanched tubers or parts were chilled and distributed to restaurants where time was saved (Kirkman 2007), by companies that started with chilled French fries and later moved to frozen ones (AVIKO 2021). Chilled or frozen chains need to be in place before related products are distributed. Nowadays chilled products, par-boiled or par-fried small uncut tubers or cut tuber parts, in plastic sealed bags are available in most supermarkets for home preparation.

Complete frozen cooked dishes initially manufactured for passengers of airplanes passengers in 1945 (Tressler and Evers 1957) and the military, contain a variety of possible potato products, among them boiled tubers, French fries and puffs. Distributed through super markets potato containing dinners hold a wider range of frozen potato products and include cooked tuber parts, hash browns and baked gratins: sliced or scalloped tubers in a sauce.

Granules, potato flour that contains intact potato cells, so has a more grainy texture than flour and makes a distinct mash, was produced first in Idaho by the RT French Company in 1952 by boiling cooled blanched tuber, mix it with tubers dried before and, flash drying the result.

Potato patties introduced to the US market in 1953 (Anonymous 1957) consist of blanched, cooled shredded or chopped slivers and other by-products of French fries manufacturing with flour and seasoning, formed and frozen. Other by-products of the French fries industry (Feustel and Kueneman 1959) introduced in the 1950s are frozen ‘mashed or whipped potato’ as steam cooked dices mashed and mixed with milk, mashed or whipped (contains more air) divided in equal packages and frozen. If riced then frozen and marketed as a shredded product. When egg and margarine is added and the creamy mixture shaped into a spiral form the product is sold as ‘potato whirls’.

Stackable chips, Pringles® for instance, are baked potato cookies originally produced by Proctor and Gamble. The chips are punched from rolled dough containing 42 % potato flour (Snack History 2021). They all have the same saddle shape so are stackable in a carton or can. The patent with inventor Alexander Liepa was granted in 1967. Application US05/493,821 summarizes “A potato chip product and process wherein a dough is prepared from dehydrated cooked potatoes and water and subsequently fried. The dough has an iodine index of from about 0.01 to about 6 and a lipid content of from 0 to about 6 %, by weight”

Extrusion of corn dough at high temperature and pressure followed by heating which leads to expansion by steam formation of the water trapped in gelatinized starch was first commercialized for breakfast cereals in 1946 (Adekola 2016). In the 1960s, similar processes with potato dough made from flakes yielded aerated snacks. Puffed chips are made of potato flour with cereal or soya flour baked at high temperature and pressure, upon release of pressure they puff. The company Popchips produces them since 2007.

Table 2.2A2. First time mention of a manufactured potato product (block) and mentioned in descriptions of recipes (italics)

Time	**Product/*dish***	**operations/process(es)**	**Social satisfaction**
Before 1500	*Chuño negro*	*Inca method of freeze drying*	*Storable, transportable, removes glycoalkaloids*
	Chuño blanco (moray, tunta)	*Chuño left in water for two months, dried*	*Taste, aspect, low in glycoalkaloids*
	Almidon de papa	*Ground tunta*	*Thickener*
	Papa seca	*Sun drying of boiled potato*	*Ingredient*
	Tocosh	*Fermenting and drying potato pulp*	*Antibiotic and thickener*
	Chicha	*Brewing beer from potato*	*Low alcoholic beverage*
	Chakta	*Distilling chicha*	*High alcoholic beverage*
1653	*Biscuits, sweetmeats*	*Baked from dough of ground moray*	*Finer than wheat flour*
1781	Potato biscuits	Prepared from dough of boiled tubers	Antiscorbutic
1784	Flour	Unknown, used on ships so must have been processed	The flour "keeps sound" on ships (contrary to tubers)
1790	Alcohol distilled (vodka, akvavit)	Hydrolyzing, fermenting and distilling	Cheaper raw than cereals for vodka at the time
1802	*French fries*	*Brought to the USA by Jefferson*	*History*
1805	*Mash*	*Mentioned in The Art of Cookery Made Plain and Easy by H, Glasse*	*Household kitchen preparation*
1810	Canned	Peeled with water in jar or tin sealed and boiled	Preservation, provide armies
1817	*Chips/crisps*	*Mentioned in "The cook's oracle" by William Kitchener*	*Household kitchen preparation*
1831	Starch	Grinding, sieving, washing, drying	Initially competing with corn, now specialty starch
1831	Modified starch	Acidification with vinegar	Increased solubility
1840	*Baked potato*	*Heated in embers or oven*	*Initially street food*
1851	*Croquette*	*Flavored potato dough with crust, fried*	*Side dish*
1853	Chips	Invented by George Crum at Saratoga springs (anecdote, legend)	Snack
1887	*Ricing*	*Pressing potatoes through a perforated metal sheet*	*Household application*
1895	*Hash browns*	*Julienned, flavored formed and fried or baked patties*	*Household kitchen preparation*
1901	Flour	Cooking, drying, grinding	Storable, multi-purpose use
1908/1910	Chips	Thin slices fried till all water is evaporated	Snack
1917	Flakes	Cooking, drum drying	Improved processing techniques

Time	**Product/*dish***	**operations/process(es)**	**Social satisfaction**
1942	Instant mash (Granulate)	Mixing wet mash with dry mash, avoiding cells to burst	Rendle, 1942 UK patent
1943	Dry riced potato	Boiled, extruded vermicelli-like and dried	Easy reconstitution
1944	Frozen French fries	Peeling, cutting, blanching, par frying, freezing	Conservation
1945	Frozen dinner	Precooked dinners containing potato	To feed airline passengers
1950	Rissole potatoes	Peeling, blanching and frying of small uncut tubers	Variety on the plate, convenience
1950	Frozen mashed/whipped	Cooked dices and mashed or whipped (more air) with milk	Variety on the plate, convenience
1950	Potato whirls	Mashed tubers, seasoned and passed through a piping bag	Variety on the plate, convenience
1950	Chilled	Peeled cut blanched chilled pieces packed in plastic	Time saving in kitchens of restaurants
1950	Potato puffs	Small blanched flash heated potato morsels	Snack, experimental, never caught on
1953	Potato patties	Blanched, shredded wheat flour added seasoned forms, baked	Variety on the plate, convenience
1955	Granules	Mash mixed with previously dried potato than flash dried	Gives grainy appreciated texture to mash from flour.
1960's	Extrusion and expansion	Pelletizing and expanding by frying in oil or baking in hot air	From puffed breakfast cereals to snacks
1967	Stackable chips, cookies (Pringles®)	baked potato cookies punched from rolled dough containing 42 % potato flour	Stackable, space saving, easy opening re-closable can
2007	Puffed chips	Dough of potato baked under high pressure and temperature	Contain about 50 % less fat than regular potato chips

The products listed in order of historic appearance in time in Table 2A2 are grouped into products with similar properties in Table 2.2B.

From oldest (Chuño) to youngest (popchips)

Appearance of companies

Table 2.2A3 lists a number of companies, their products and when founded. The data were taken from their websites and are not exhaustive. It illustrates that potato starch companies are the oldest. The Polish starch company may be the oldest but the Emslandgroup and Avebe were established from a combination of already existing smaller companies. The oldest chipping companies exists some 100 years and frozen potato products date from the early 1950's in the USA. Starch currently has its base in continental Europe, chips had it in the UK, currently in many countries and frozen products started in North America, but now has an equal base in Europe.

Table 2.2A3. List of currently existing old potato companies and year of establishment (from companies' websites)

Company	**Year**	**Country**	**Product**
Agrarfrost	1992	Germany	Frozen
Avebe	1919	Netherlands	Starch
Agristo	1992	Belgium	Frozen
Aviko	1962	Netherlands	Frozen
FritoLay	1932	USA	Chips
Frozen Express	1994	Colombia	Frozen
Cavendsish Farms	1980	Canada	Frozen
Clarebout	1988	Belgium	Frozen
Ecofrost	2003	Belgium	Frozen
Emslandgroup	1928	Germany	Starch
Farmfrites	1971	Netherlands	Frozen
JR Simplot	1953	USA	Frozen
Lamb Weston	1960	USA	Frozen
McCain	1957	Canada	Frozen
Smith Snack food	1910	UK	Chips
Trzemmeszno	1883	Poland	Starch
Tri-Sum	1908	USA	Starch
Wernsing	1962	Germany	Frozen
Wise Food	1921	USA	Chips
Utz Brand	1921	USA	Chips

Intermediate and finished products

Native potato starch is an intermediate product (with attributes rasping, sieving, washing and drying (BeMillet et al. 2009)). Blanched tubers with one attribute in common, blanching, is another intermediate product. Finished products from the intermediate native starch are modified starches with attribute modification. Blanched tubers and cut parts are made into storable sterilized products in cans or jars (moist) or storable dried tuber pieces (Doymaz 2011). When mashed from blanched tubers formed products (PotatoPro 2021) are made or flakes when dried (Cui et al. 2018). Par-fried blanched tuber parts make French fries and chips when sliced and fried (Van Loon 2005). Large blanched tubers are readied for baking (AHDB 2021). Hydrolyzing, fermentation and distillation yields vodka (Xu et al. 2016).

Drum dried flakes, flour when milled, mash when cooked

A list of intermediate and finished products and their processes and/or operations as attributes is presented in Table 2.2A4. This table includes the principle operations from grinding to drying but is far from exhaustive as for instance additives are not included nor the wide spectrum of finished products regarding shape and flavor. This is expanded in Chapter 3 on procedures between delivery of tubers at the factory up to leaving it as packed finished product.

Table 2.2A4. List of Intermediate and finished products

Intermediate product	Operations	Finished product	Operations
Native starch	Grinding, cold dehydration	Modified starches	Modification
Flakes	Heating, warm dehydration	Flour	Grinding
Blanched tuber	Cutting, heating	Chilled tuber (parts)	Cooling
Par-boiled French fries	Cutting, heating	French fries	Par-frying, freezing
Mash	Heating, mashing	Formed products	Par-frying, freezing
Dough	Mash with mix	Stackable chips	Rolling, punching, frying
Raw thin slices	Cutting	Chips	Frying
Raw whole tuber	Grading large size	Jacket potato	Baking
Cuts of raw tuber	Cutting	Dried tuber parts	Drying
Beer	Grinding, fermenting	Vodka	Distillation
Raw baby tubers	Grading small size	Canned tubers	Canning, sterilization

Quantification of the attributes of the product classes.

This paragraph serves as illustration of deliberations of scores given to the attributes in Table 2.2B, not exhaustive by far. The temperature at which processes take place are highest for fried products, about 170°C and lowest, ambient, for manufacturing native starch and some (not all) modified starches. Boiling and distillation is done at 100°C. After washing, peeling and cutting, water is used in starch production to wash the starch after sieving, to blanch tuber parts before chilling, mashing or par-frying and to produce potato beer before distilling it into vodka. The temperature at which a process takes place is not equivalent to the amount of energy it takes to make the product, as that is more linked to the quantity of water evaporated from the tuber and its parts, reflected in its water content. Powders and snacks contain less than 10% water, and tubers and parts, blanched chilled

Formed: pancake, samosa, rösti (hash brown)

products and jacket potato that are only heated, contain as much water as fresh tubers. To produce flakes, tubers are boiled, mashed, dried and ground: four processes in total. For chilled products tubers are cut, blanched and cooled. Formed products have the attributes of flakes (often at their base) with forming and par-frying on top. This is a number of processes comparable to that of making modified starches and distilling into vodka. In developing countries some products are prepared in a cottage setting (chips in polyethene bags supplied with a telephone number sold in local shops and markets) or as street food (French fries prepared, sold and consumed on the sidewalk). Obviously products that require sophisticated equipment and many steps to prepare do not come into consideration for cottage industry such as powdered ones and their derivatives, formed products. Chips and French fries are most common and in some developing markets producers dry tuber discs in sun and wind in their yard. Some products only have one application, French fries and formed potato products are a side dish, chips are a side dish, a snack and can be accompanied by a dip. Modified starches, and to a lesser extent flakes, are used as a thickener, binder, structurer and for mashes. Dried or chilled tuber parts are used to make boiled, fried, mashed and many more side dishes as they have the same properties as fresh tubers.

Table 2.2B distinguishes product-process combinations that are dominant in large scale industrial settings but some dominate in cottage industry. Chips and stackable chips share similar features but their market introductions differ widely. Drying as a means of preservation reflected in the percentage of water is oldest and freezing one of the younger techniques, with processes aimed at hedonistic satisfaction in the middle. Complexity, need of equipment and skills, increases with time. Dehydration through natural means is and old technique and so are brewing and distillation, but refrigeration requires more recently acquired knowledge and engineering. The shelf life of snacks is more or less equal to fresh tubers, a few months but blanched chilled products only last for a few weeks in the fridge. All other processes yield products with a longer storability than tubers. This with two exceptions, beer brewed in a traditional fashion in the Andes needs to be consumed within a few days whereas canned potato beer stores for over a year. The other exception is that chips made in the cottage industry packed in material exposed to light and in ambient atmosphere in warm (sub)tropical conditions rapidly deteriorate with oil becoming rancid compared to chips manufactured and packed in aluminum coated plastic in controlled, nitrogen only, atmosphere. All potato products bought save

Table 2.2B. Heat map of 23 manufactured products (from Tables 2.2A2 and 2.2.A4) and 16 attributes. Bold underlined ***attributes*** *following theoretical triangulation are also given a low score because considered unfavorable in a second run*

Much, high	a	**Age of product**	i	**Intricateness of packing**	Little, low
	b	Shelf life, storability	j	Size of package or lot	
	c	Time saving in the kitchen,	k	Number of servings from a package	
	d	Relative global market size	l	Storage temperature	
	e	Relative impact on national economy	m	Street food potential (ELAB:	
	f	Impact on local economy	n	**Price of product per kg**	
	g	Availability in developing markets	o	**Energy use in kitchen**	
	h	Range of different uses, in kitchens	p	**Water use in kitchen**	

Product		a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	Average	
Freeze dried tuber chuño	1																	3.6	**3.5**
Ambient air dried slices	2																	3.4	**3.6**
Hot air dried slices, cubes	3																	3.3	**3.2**
Beer (chicha, traditional	4																	2.6	**3.1**
Distilled chakta, vodka	5																	3.4	**3.3**
Potato Biscuits	6																	2.9	**3.3**
Flour, flakes, granules	7																	3.4	**3.2**
Canned	8																	2.6	**2.5**
Starch	9																	3.2	**3.5**
Modified starches	10																	3.4	**3.4**
Chips	11																	3.4	**3.5**
Stackable chips	12																	2.8	**3.1**
Extruded, expanded pellets	13																	2.8	**3.1**
Dry riced potato	14																	2.9	**2.9**
(Frozen) French fries	15																	3.4	**3.5**
Frozen, formed	16																	3.0	**3.0**
Frozen potato dishes	17																	2.9	**2.9**
(Frozen) rissole potatoes	18																	3.1	**3.1**
Frozen baked potato	19																	3.1	**3.1**
(Frozen) hash browns	20																	3.1	**3.1**
Freeze dried (industrial)	21																	3.0	**2.9**
Chilled blanched tuber	22																	2.8	**2.9**
Puffed chips	23																	2.7	**3.1**
	Average	2.9	3.6	4.2	2.7	3.7	2.9	3.4	2.7	3.5	3.4	3.4	2.4	2.7	[illegible]	3.2	1.8	3.1	
		3.1	**3.6**	**4.2**	**2.7**	**3.7**	**2.9**	**3.4**	**2.7**	**2.5**	**3.4**	**3.4**	**2.4**	**2.7**	**3.1**	**2.8**	**4.1**		**3.2**

time over preparation by the cook in the kitchen, although for dried products that need reconstitution for several hours the time gain is less than for the other ones. The last column gives an indication of the market size of the various products: small for dried tuber pieces, intermediate for powders, chilled and formed products and large for chips and French fries. All values (dark green is 5, dark red = 1) are relative, mutually comparing the products diverging from the average (yellow = 3). For the product age, chips and starch are taken as average, over 100 years old with flour being older and French fries as a commercial product being younger. A product may be made with more operations, another with fewer but requiring more sophisticated equipment. The impact in local economy can be considerable (Idaho, Andes) but moderate at the global scale. Packing is simple (bulk) or technically demanding (canning). If a company wants to extend activities to other regions where potatoes are grown, the product needs to be socially acceptable, the technique transferrable and some basic infrastructure needs to be in place such as shops and houses with fridges and freezers. Theoretical triangulation takes place by allocating high and low scores from two different position: an old product receives a high score (more years), a product that needs many operations also receives a high score, so do products that need much water and energy. Table 2.2B, however, **<u>in bold and underlined</u>** also offers the possibility to allocate low scores to attributes considered unfavorable. In a theoretical triangulation iteration colors, hence values, take opposite values from the average then the values for dark green, light green, yellow, light red and dark red are 1, 2, 3, 4 and 5 resulting in different averages, but also to a different clustering.

The range of averages of the values of the attributes per product is not very wide and ranges from 2.6 for chicha to 3.6 for chuño, both happening to be traditional Andean food stuffs. The top five averages of scores in the heatmap in Table 2.2B are chuño airdried slices in hot and cold air and flour, four dry products having in common high scores for use of water and energy in the kitchen. The products with lowest scores are chicha and canned (both wet) and the snacks mainly for low scores of water and energy use in the kitchen. The average of scores of attributes across all products is highest for convenience, time saved when bought rather than cooked in the kitchen. The lowest score is for water use in the kitchen as most products in kitchens, chuño excepted, need no washing. And some products (flour, chilled blanched tubers) need a little water for heating.

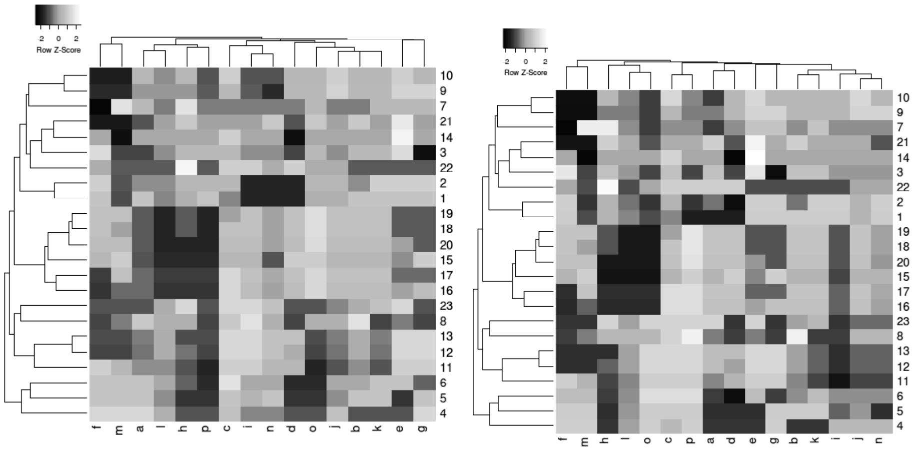
Awarding a high value to some aspects means the higher the better averages of scores. The products with averages over 3.0 are all dry products and French fries and the lowest is for canned tubers. Averages over the products are still high for convenience but where low water use received a low score in the first evaluation it becomes and asset in the second one and increased from 1.8 to 4.1, a similar appreciation as for convenience. Intricateness of packing loses points as more layers of plastic, as illustration, presumably are not favoured. A high average score is only meaningful if all attributes have a positive connotation which is the case in the second evaluation (**<u>in bold and underlined)</u>**.

Clustering of products

Table 2.2C demonstrates the clustering with a high score for all attributes where a high value applies (left) and when given a low value for some attributes the clustering appears at the right. The top cluster in the right side dendrogram, with three members has the close twins starch and modified starch with another powder, flour, at quite some distance. Below there is a cluster with air and freeze dried products but includes the class of chilled blanched ones. The classes of frozen products is one coherent cluster in the middle. The snacks and drinks are in the lower not so coherent cluster, seen the large distance between the members with the exception of the close twins stackable and extruded chips.

In the dendrograms in Table 2.2C the clustering of the products is identical. Mirroring (flipping) around the average (1 becomes 5 and 2 becomes 4) does not change the position in the cluster hierarchy. Clustering of the attributes in the top diagram reveals 5 clusters. Street food potential and influence on local economy obviously are a twins and so are age and storage temperature, the oldest products having in common that they

Table 2.2C. Dendrogram of products (1-23 table 2.2B) and their attributes (a-r Table 2.2B) Left: with a high score for all attributes, Right: with a low score for attributes considered unfavorable



are only stored at ambient conditions. More uses of a product is associated with more water added which also has some logic. Snacks and fried products have only one destiny and there is no water involved. Availability in a market and its influence on the economy is a twin and the more convenient a product is the more expensive.

The clustering at the right shows more relevant smaller clusters than at the left. Availability and economic impact are twins in both dendrograms and so are street food and local economy, next to a cluster with three members packing, number of uses and energy use. Water use and time saving are together, logically because the most convenient, fried, products need no water for cooking. Age and market size are twins: the oldest products now represent the smallest markets. Storability is clustered with the number of servings from a package and larger sized packages contain products with a lower price per unit weight. The new triangulation creates more clusters which potentially lead to more reiterations in future exercises.

The kitchen operations domain

Formulation of the domain kitchen operations

Originally, before cottage or industrial manufacturing of potato products took place, and still in kitchens where some meal components do not consist of purchased products, dishes are made starting with fresh tubers. Multiple operations are carried out by the cook before a dish is served to the eater. Kitchens vary in size, skills of the cook and sophistication of appliances whether they are in a household, restaurant, diner, hospital, prison or at a caterer in a university. Washing is either done by hand or by a washing/peeling machine and frying in a pan or a professional deep fryer. A kitchen in an advanced economy often has more space, (cold) storage possibilities and equipment but not necessarily more skills of cooks as absence induces resourcefulness. Central in all kitchens are the options to heat the tubers or parts thereof by boiling, microwaving, frying, or baking. Potato needs to be heated to make it digestible for non-ruminants (Sharma et al. 2008), among them humans. So all processes at home involve at least one step, whereby the tubers or parts thereof are subjected to high temperatures up to 100°C. Above this temperature the water inside the tuber starts to boil thereby avoiding a higher temperature. Only when frying in heated oil, the water content decreases to such low levels that the tissue as of 150°C becomes crunchy and discolors, turns yellow, golden or brown. At home, i. e. in a non-industrial setting unprocessed tubers, harvested at own farm, garden or allotment or purchased. At markets, greengrocers or supermarket they are sold washed or unwashed, packed or in bulk.

Condensation of the kitchen operations domain

When making an inventory of all operations taking place in kitchens, there are mechanical operations where the tuber material or a substance thereof derived, change shape but during which the physical and chemical properties are not altered. Next there is the physical treatment the tuber and its parts undergo: heating which is done in hot water (boiling), hot oil (frying) or hot air (baking). The array of mechanical and heat involved operations is summarized in Table 2.3A. The table also shows where the operations lead to. When tubers are bought unwashed, so only brushed on the farm or the packing station, before preparation they are washed in kitchens and peeled, unless a skin-on dish is desired such as wedges and baked whole tubers, jacket potato. Peeled fresh tubers are not cut when small and ready to boil, otherwise cut into various shapes, finger shaped for French fries, sliced for several applications or thin slices to make into chips or scallop. With a melon baller baby potatoes for pan frying are imitated. Grating raw tubers yields shreds, fritters for use in hash browns or potato pan cakes. Therefore the shreds are formed with other ingredients, frequently with onion. Also cooked tubers can be subjected to mechanical treatments, most often to mashing to be consumed as a meal ingredient, or as riced potato when passed through a ricer. Riced potato may also be formed into hash browns and mashed into balls or croquettes that subsequently are baked or fried. The operations and their attributes are summarized and quantified through rating of the degree an attribute applies to the class. This table also serves as an introduction to Chapter 3 where some factory operations are not unlike the kitchen operations described here.

Heating to decompose the starch granules, gelatinization, takes place with hot water, steam, microwaves or a sauce (gratin), hot air (oven) or oil. Adding water is not a necessity as the tubers contain sufficient water themselves: 75-80%. Heating implies whole tubers or tubers cut into pieces: chips, cubes, slices or shreds. Blanching involves subjecting tubers or cuts to a hot water treatment without thoroughly cooking them. It is done by heating to almost 100°C for a few minutes or to much lower temperatures for a prolonged period. This is done to stop enzyme activities that would discolor the tuber parts (Severini et al. 2003) awaiting further use, it improves the structure of fried food (Liu and Scanlon 2007) and the texture of boiled whole tubers when blanched first (Abu-Ghannam and Crowley 2006). When boiling in water or above steam at higher than blanching temperatures (at 100°C at sea level) for up to half an hour depending on variety, tuber age and desired texture, the tuber is ready to be consumed, either mashed or not. Microwaving has the same effect as boiling in water. Wilson et al. (2002) observed that first the internal temperature rises to 100°C whereby the starch gelatinizes within 3 minutes. Subsequently water evaporates to soften the tuber to make it ready for eating. Baking slices in a sauce, gratins and scalloped tubers has the same effect on the tuber parts as

Table 2.3A. Preparation of potato tubers in kitchens

Attribute	Operation	Description	Meal ingredient
Mechanical treatments	Washing	Brushing with water to remove adhering soil	Skin-on tuber for baking whole tubers or frying wedges, heating needed
	Peeling and trimming	Removal of the skin and outer layer of the tuber with a knife of vegetable peeler (peeling), additional cutting of deep eyes and defects (trimming)	Tubers need to be heated before consumption
	Cutting	Dividing tubers in parts: wedges, chips, slices or cubes. Round parts (imitating baby potatoes) are created by scooping balls with a melon baller	Tuber parts need to be heated (boiling frying) before being eaten
	Shredding, grating	Creating strings (shreds) of raw tuber with a grater,	Ingredient for hash brown, rösti or pancake, heating needed
	Mashing, ricing	Production of a mash of boiled tuber with a masher or (electric) beater (mashing), of riced tuber with a ricer (ricing)	Side dish, stew (hotchpot) when mixed with vegetables, ingredient of homemade gnocchi, waffles and bread
	Forming	Shaping shreds or mash in patty, ball or other forms before baking or frying	Hash browns and rösti from shreds, croquette from mash
Hot water treatment	Blanching	Tubers placed in cold water, heated till boiling, cooled rapidly to avoid continuation of the process.	This before freezing or frying to stop enzyme activity and preserve structure before cooking such as frying
	Boiling in water (or steaming)	Tubers submerged tubers in cold water in a pan, heated till boiling for 15 to 30 minutes depending on potato variety and kitchen use	Side dish, ingredient of soup or followed by pan frying or mashing. A salad ingredient when cut into slices or cubes and cooled
	Boiling in the microwave	Tubers placed in a bowl microwaved for about 8 minutes, effect is similar to boiling	
	Baking au gratin	Slices of tubers of about 5 mm thickness spread in an oven dish embedded in a creamy sauce covered with cheese baked for 40 minutes at 180°C	Main dish
	Baking, scalloped	Very thinly sliced tubers of around 2 mm embedded in a roux with spices and/or meat and/or vegetables	
Hot air treatment	Baking whole or cuts	Whole tubers with many parallel incisions (Hasselback) or none but incised longitudinally and filled as dish (Jacket potato)	Side dish or main course
	Baking in clay	Tuber wrapped in an envelope of clay baked in (hot ashes of a fire in the open.	Side dish, primitive, camping
	Roasting	Pieces of spiced tubers tossed with oil put in the oven for 40 minutes at 190°C.	Side dish
Hot oil treatment	Deep frying (French fries)	Frying raw or blanched cut pieces in oil at 180°C for a few minutes	Side dish
	Deep frying (formed)	Frying raw (hash browns) or mashed (croquettes) formed ingredients	Side dish
	Deep frying (Chips/ chips)	Frying thin slices of about 2 mm in oil at 180°C for a few minutes till all water has disappeared	Snack
	Pan frying	Frying pre-cooked or blanched tuber parts, slices usually, in an open pan lubricated with oil	Side dish

boiling in hot water and takes about the same time. Tubers subjected to hot air are baked in the oven for 30 minutes at 180°C, whole, with slits or not (hasselback and jacket potato respectively) or cut up, spiced and oiled in a pan and roasted. A leisure way is wrapping a tuber in clay and heat it in hot ashes of a camp fire.

Hot oil treatments, frying results crispy outside French fries, hash browns and croquettes and pan fried potatoes. The tuber parts (Pedreschi 2012) have two distinguished zones: on the outside a dry crispy exterior where the oil is concentrated and a cooked interior without oil. The coloring and flavor development (Cerny 2008) take place in the Maillard reaction, a non-enzymatic browning when heating carbohydrates with specific amino acids form pigment. Also at high temperatures during frying, the reducing sugars glucose and fructose with the amino acid asparagine form acrylamide which is considered an unfavorable component (Halford et al. 2012)Boiling washed and peeled tubers in water regarding complexity of equipment (a heat source and a pan) is considered the standard with washing, peeling and cutting requiring simpler equipment (basin, knife). Blanching and pan frying need similar appliances as boiling and for other means of preparation cooks use more demanding electric appliances such as an oven, microwave and deep oil and air fryers. These usually are found in kitchens in developed countries and with well-off citizens in developing countries but not in those of other people in developing countries. Shaping of dauphine potatoes is don with a piping bag which is not readily available is most kitchens. Washing tubers requires most water but all other processes except boiling need no or hardly any water. Potato needs to be heated before consumption so all means of cooking require energy. Six minutes in the microwave requires one third of energy compared to boiling 25 minutes on an electric stove (Korzeniowska 2019) and baking in the oven for 45 minutes takes twice more energy than boiling. Using gas stoves it takes the same amount of time but producing electricity first takes three times more energy. Labor and convenience are two communicating vessels, the more time it takes to prepare in the kitchen, the more convenient it is to use a manufactured product. Similarly, more sophisticated kitchen equipment is associated with greater cooking skills.

Quantification of the attributes of kitchen operations

The number of classes of kitchen operations has been condensed to 18 in Table 2.3B and supplied with 9 attributes and valued. The lowest average for all classes has the attribute water need, indicative of few operations requiring water. Only the class of washing operations (with a few of its instances, soaking, brushing by hand, washing machine) uses a considerable amount of water and in the food serve abrasive peeling in a water fed peeler uses water.

Chips

Table 2.3B. Heatmap of 18 classes of kitchen operations of potato with 9 attributes

High, much	a	Kitchen appliance requirement
	b	Need for water
	c	Temperature of process
	d	Energy requirement
	e	Labor requirement
	f	Cooking skills required
	g	Product costs when purchased
	h	Represents an introduction of new dishes
	i	Important in developing markets
Low, little		

Classes of operations		a	b	c	d	e	f	g	h	i	x̄
Washing	1										2.3
Peeling	2										2.2
Cutting	3										1.9
Shredding	4										2.6
Mashing, ricing	5										2.7
Forming, shaping	6										2.8
Blanching	7										3.2
Boiling in water	8										3.8
Microwaving	9										3.0
Baking au gratin	10										4.0
Baking, scalloped	11										4.1
Baking (Jacket)	12										3.8
Baking in clay	13										4.0
Roasting	14										4.0
French frying	15										4.2
Deep frying forms	16										4.0
Deep frying chips	17										4.3
Pan frying	18										3.2
	Average	3.8	1.9	3.4	3.3	4.2	3.3	4.0	3.7	2.6	

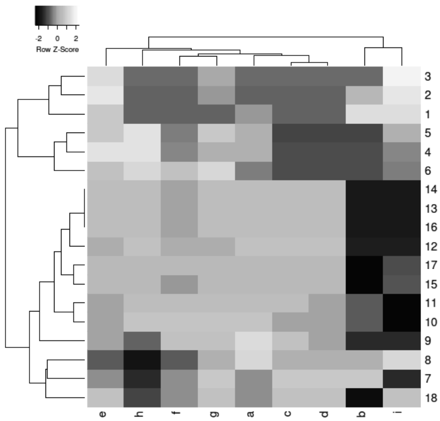
There is also a little bit of water added to the tubers for boiling and blanching and there is some in the sauce of gratins. Another relatively low average of scores is for the importance of the operations for developing markets when oven prepared dishes are not very common but where frying is quite common. The highest average is for labor requirement with only boiling in water and microwaving taking the least labor. The opposite of labor intensity is convenience when the product is bought in a shop. This is well possible in developed markets but many products need to be transported and shelved, chilled or frozen so are not available in such markets. The costs of the products when bought are considerable for most of them.

The average of scores per class of operations is lowest for cutting with only substance for the labor it takes and the relevance of this particular process in developing markets. The high temperature processes baking and frying all have high averages of scores of their attributes: they are all very much need energy, skills and equipment.

Clustering of operations in kitchens

The dendrogram in Table 2.3C displays two clear clusters. The top one consists of all mechanical processes that do not involve heating the tubers. It comprises two subclusters, the top concerns operations with intact tubers: the twins peeling and cutting with washing at some distance, the subcluster thereunder deals with tuber particles, the twins shredding and mashing with forming (making croquettes, hash browns) at some distance. All other operations are in the lower cluster with the identical triplet baking in clay, roasting and deep frying of forms, and the close twins frying French fries and chips and preparing the regular gratin with the scalloped one.

Table 2.3C. Dendrogram of processes in kitchens (codes a-i and 1-18 in Table 2.3B.)



The attributes show two clusters. The rather distant twins high water need and suitability for developing markets that has some logic as the low water requiring heat treatments are not the most suitable ones for developing conditions. Another, this time very similar twins, are cooking temperature and energy need.

Domain of dishes

Formulation of the domain

The second aspect of the kitchen domain is the sphere around consumers that buy and use processed potato products, nutrition, as component of dishes and meals. The powders serve as thickeners in soups and sauces or are made into a mash. If granulate is added the structure of the mash approaches that made of boiled tubers. Par-boiled tubers packed and chilled have a wide range of applications, comparable to fresh tubers peeled and boiled in kitchens. They are mashed, formed, deep or pan-fried as French fried or sautéed tubers. Hash browns are made of julienned blanched tubers, French fries from par-boiled cut tubers frozen or chilled. Jacket potato (but for the topping) and gratins are complete dishes itself rather than ingredients but still need to be baked in the oven. Snacks and drinks are not in need of any preparation in the kitchen and only chips in some cultural settings serve as a side dish in a meal. With the exception of a few non-food applications, the majority of potato derived products find their ways to kitchens where food is prepared by cooks for themselves, consumers, eaters, guests. Classes of products are many. Chapter 3 shows a list of almost 200 potato products found in one supermarket on a particular day. Chapter 4 displays a list of over 150 potato dishes from many countries and illustrates how purchased products replace part of the ingredients and in many cases still allowing thew cook to approach the original. That chapter also demonstrates how ingredients such as minerals, vitamins and antioxidants increase or decrease during processing. Chapter 6 makes it clear how much time is saved in the kitchen if a product is bought rather than starting with fresh tubers. The subject of the dishes domain is treated from two angles, an environmental triangulation from the position of a well-developed market with affluent clients, say North America, and from a position of a new market for potato products with less well-off clients, say India.

Condensation of the dishes domain

The classes of dishes prepared from purchased products are listed in Table 2.4A, with attributes of the products and of preparation. These attributes do not vary among users, they are products' own. Other attributes of the dishes made of the ingredients (products), however, are viewed differently in well-off societies than in less well of ones. For consumers in the latter, prices of products and costs of fuel for cooking are more relevant for a decision to buy. They usually have less products available in their markets and view products and dishes made thereof fancy to eat in restaurants or with guests. Where consumers have a wider array of tastes and preferences, in well-off societies, potato products are considered less fancy. In developing markets, time dedicated to cooking is more amply available, the availability of appliances plays a role, as well as means to arrive at high enough temperatures for baking. In developing markets an absence of a chilled or frozen infrastructure in shops and houses plays a role in potential products and in losses. Health image and cultural influences also differ in societies.

Table 2. 4A. Description of aspects of the dishes domain (cooking dishes from products)

<table>
<tr><th rowspan="3">Classes of dishes</th><th colspan="7">Attributes</th></tr>
<tr><th colspan="3">Of purchased food ingredients</th><th colspan="4">Of preparing the dish in kitchens</th></tr>
<tr><th>Classes of purchased product</th><th>Storage Temperature</th><th>Package</th><th>Liquid added</th><th>Heating</th><th>Ready to eat</th><th>Complex</th></tr>
<tr><td rowspan="2">Sauce</td><td>Starch</td><td>Ambient</td><td rowspan="6">Paper, carton</td><td rowspan="7">Yes</td><td rowspan="6">Boil</td><td rowspan="9">No</td><td rowspan="4">Some-how</td></tr>
<tr><td>Flour</td><td>Ambient</td></tr>
<tr><td rowspan="2">Soup</td><td>Starch</td><td>Ambient</td></tr>
<tr><td>Dehydrated tuber</td><td>Ambient</td></tr>
<tr><td rowspan="2">Mash</td><td>Flour</td><td>Ambient</td><td rowspan="2">A bit</td></tr>
<tr><td>Granulate</td><td>Ambient</td></tr>
<tr><td>Side dish</td><td>Par-boiled tuber (chilled, canned)</td><td>Chilled or canned</td><td>Plastic, CA*</td><td>Many***</td><td>Quite</td></tr>
<tr><td rowspan="2">Hash brown</td><td rowspan="2">Julienned and formed tuber</td><td>Chilled</td><td>Plastic, CA</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Frozen</td><td>Plastic</td></tr>
</table>

Classes of dishes	Attributes						
	Of purchased food ingredients			Of preparing the dish in kitchens			
	Classes of purchased product	Storage Temperature	Package	Liquid added	Heating	Ready to eat	Complex
Croquettes, balls	Formed products	Frozen	Plastic		Fry		Quite
French fries	Par-fried French fries	Chilled	Plastic, CA				
		Frozen	Plastic	No			
Pommes sautéed	Roasted tuber pieces	Chilled frozen	Plastic, CA				
			Plastic				
Jacket potato	Baked tuber	Frozen	Plastic		Bake		
Gratin	Gratin	Frozen	Tray				
Snacks	Chips	Ambient	Plastic, CA**				
	Stackable chips	Ambient	Carton tube		None	Yes	Not
	Expanded chips	Ambient	Plastic, CA**				
Drinks	Beer	Ambient					
	Vodka	Ambient					

*Controlled atmosphere (vacuum) , ** Controlled atmosphere (Nitrogen only)
*** Baking, frying, cooking, microwaving, roasting, mashing, forming

Quantification of dishes aspects

The results of heatmapping the dishes made from potato products and their attributes are represented in Table 2.4B. Of the products the average of scores is lowest for soups (2.0) with the highest score only for eating Potage Parmentier, potato soup, in a restaurant. Gratin has the highest average of scores (3.1) because of its fanciness and that not all groups in society are likely buying and serving gratins and scallops. Drinks and snacks have relatively low scores as ready to consume upon freeing the contents has few issues. There is much more variation in the averages of the scores of the attributes. The costs of energy for cooking and the presence of cold chains are not issues at all in affluent societies, nor is the complexity of appliances as most kitchen dispose of an oven, microwave and deep fryer. The highest average is for fanciness of the products. Many of them are considered chic to serve, baked potato and vodka from potato for example, French fries and snacks, however, are rather ordinary food. Also consumers in developed markets are price conscious and attach much importance to convenience. A high sum (3.4) is for the availability, with the exception of potato-based alcoholic drinks, most products abound in shops.

Table 2.4B. Heatmap of 13 classes of dishes made of purchased products and 13 attributes

High, much			Low, little
	a	Price	
	b	Availability, variety in shops	
	c	Fancy product, when serving to guests	
	d	Time saved by buying the product is important	
	e	Cooking temperature (e.g., baking)	
	f	Cost of energy use in cooking (gas, electricity, wood)	
	g	Complexity appliances	
	h	To like eating this out in restaurants	
	i	Issue of low temperature of product in shops	
	j	Risk of loss in pantry	
	k	Risk of loss on plate	
	l	Esteem, health image (calorie content)	
	m	Susceptible for cultural preferences	

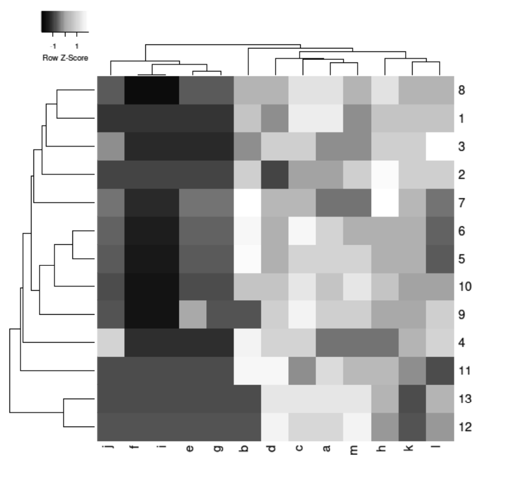
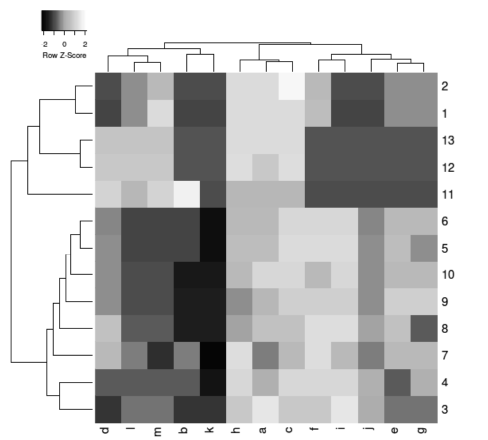
	Dishes classes		a	b	c	d	e	f	g	h	i	j	k	l	m	Av.
Developed market	Sauce	1														2.2
	Soup	2														2.0
	Mash, from flour	3														2.2
	Side dish, tuber	4														2.6
	Hash brown	5														2.8
	Croquettes,	6														2.8
	French fries	7														2.5
	Pommes sautéed	8														2.7
	Jacket potato	9														2.9
	Gratin	10														3.1
	Snacks	11														2.3
	Beer	12														2.2
	Vodka	13														2.5
	Average		3.5	3.4	3.8	3.5	1.5	1.0	1.5	3.2	1.0	1.8	2.6	2.8	3.3	2.5
Developing market	Sauce	1														2.3
	Soup	2														2.3
	Mash, frozen	3														2.8
	Side dish, chill	4														2.8
	Hash brown	5														3.3
	Croquettes,	6														3.4
	French fries	7														3.5
	Pommes sautéed	8														3.1
	Jacket potato	9														3.4
	Gratin	10														3.3
	Snacks	11														2.4
	Beer	12														2.5
	Vodka	13														2.6
	Average		4.0	1.7	4.5	2.8	2.8	3.5	2.6	4.0	3.3	2.2	1.0	2.5	2.7	2.9

The situation in less well-off markets varies (average of averages 2.5) from that in affluent societies as is made clear in Table 2.4B, bottom (2.9), showing that more points of consideration matter. Fried and baked products (snacks excepted) in developing settings has issues because of lacking of cold chains in shops and appliances in kitchens. The averages of scores for 13 attributes is highest for fanciness (4.5), treating guests with an exotic dish and, obviously the costs of food is more important. Low scores are for availability of potato products and for wasting food at the table. Where 'rich' cooks do not take the fuel bill into consideration, 'poor' cooks do, with a stove heated with gas from a tank or charcoal from a bag.

Clustering of the dishes domain

The dendrogram on the left in Table 2.4C shows three distinct clusters. At the bottom the two drinks and at the top sauce and sauteed are twins at a large distance and further remote soup, mash and French fries that all have relatively low scores in common. Of the remainder the twins at short distance consists of the formed products from mash (croquettes) and from shreds (hash browns). The attributes are distributed over three clusters. On the left the non-issues regarding shelf and kitchen temperatures, losses and appliances with two (almost) identical twins. The cluster on the right with three members regard the luxury issues worry about calories, not emptying the plate and eating out in restaurants. The attributes of the cluster in the middle relate to the products directly such as price, availability and convenience.

Table 2.4C. Dendrogram of consumer use of products. Codes for products (1-13) and attributes (a-m) in Table 2.4B.

setting in developed markets	setting in developing markets
	

The products in the diagram on the right in Table 2.4C show two distinct clusters with on top the considered expensive or luxury ones sauces, soups drinks and at some distance, snacks. The lower cluster presents two twins hash browns and croquettes and mash and chilled tubers. The attributes demonstrate three clusters, on the left five members with low scores with two twins, concerns about preferences and calories with convenience at some distance clustered with the twins low availability losses on the plate. The middle cluster comprises luxury concerns, price, fanciness and eating dishes in a restaurant. The remainder five are in the cluster left that deals with technical aspects appliances and temperature requirements.

The difference in clustering when potato products are not readily available, considered expensive and exotic is that more products gather in a luxury section. The attributes are more or less clustered along the same lines in both situations but for different reasons: what is a cluster of major concern for the disadvantaged (technology) is one with low scores for the privileged.

Consumer preference domain

Formulation of the domain

Consumers when buying food products consider three aspects: what they expect, what they experience and what they trust (Brunso et al, 2002 in their description of the Total Quality Model). Expectations are related to the shopping situation such as being in a hurry or shopping for leisure, price, size and expected taste and convenience. Experiences are the ease of preparation in the kitchen, the taste and fulfilment which are at the base of buying the product again. Credence features cannot be experiences before or after purchase, they have to be trusted such as health claims, information regarding some ingredients and labels such as organic or GM-free. Consumers are living in rural areas, small or large cities and old or young both directing their behavior from traditional to innovative. They vary from low to high income and accordingly are increasingly health conscientious and pandering less to indulgence. Interest in price, product information and the origin of the tubers also segregates the class of consumers in the various classes uninvolved, careless, conservative, rational and adventurous consumers.

Condensation of the consumer preference domain

Diverse types of consumers attach varying importance to the three aspects and their underlying characteristics. Among others Brunso et al. (2002) distinguish four groups of consumers, purchasers interested in low prices, those who go after the preferred taste, those who prefer light products and consumers giving priority to ecologically friendly products. Other classes of consumers are indulgence seekers, snacks especially and, ones having to prepare a special meal. Ethnic and cultural background also play a role with for instance hash brown having a place in a cooked breakfast not enjoyed by all cultural groups and certain flavors on chips have preference such as paprika in Europe and barbeque in North America. Zarantonello and Schmitt (2010) and Deseret (1995) differentiate groups of consumers including holistic, inner directed and utilitarian and Deseret (1995) enumerates eight groups some of them do (principle oriented) or do not (achievers) coincide with the preferences mentioned in Table 2.5A. When it comes to segregating consumers into recognizable classes with comparable characteristics for, for instance, targeted new food product development, it is important to realize that the classification of a consumer in a particular group can vary with varying circumstances. Suppose a normally price-conscious consumer organizes a festive dinner party, in that case, he may decide to buy more expensive products than (s)he would normally buy.

Table 2.5A. Consumers domain, description of classes with their preferences and attitudes as attributes

Selected consumer preference class	Properties expressed in key words regarding preference and social situation of the consumer	Selected source
Convenience seeker	Uninvolved: Convenience is important, not interested in cooking, quality. Likes snacks, low income, young, low education, single, city	Brunso et al. 2002
After innovation	Careless: same as uninvolved but likes new product higher educated, city	
Conservative	Conservative: Traditional, convenience not important, taste and health and stability, oldest, least educated, rural	
Information seeker	Rational: Product information and price, use list, self-fulfillment, security, relatively many women with families in medium sized cities	
Bold	Adventurous: love intrepid cooking, food, quality, not convenience, younger than average, large families, big cities	
Price conscious	Price is the main property of interest	Maehle et al. 2015; Kongstad and Giacolone 2020; MacFadden and Huffman 2017
Taste conscious	Flavor is the main property of interest	
Health content conscious	Health concern such as energy content is the main property of interest, but also salt and acrylamide count	
Eco label conscious	Environmentally friendly production is of greatest interest	
After indulgence	Satisfying, fulfilling a need to eat tasty food, not necessarily at meals	Fona, 2021
Special occasion in mind	Special festive occasion dinner for guests, fancy (side)dish (	Allrecipes 2021
Culture driven	Consumers with a targeted ethnic or cultural background preferring specific products occasionally at specific (festive times)	Ethnic foods 2021

`

Quantification of the consumer preferences domain

Condensation of the consumer preferences domain (Table 2.5A) produces 12 classes presented in Table 2.5B ranging from convenience seeking to culture driven. The preferences in themselves are not overlapping but consumers usually have more than one preference. Attributes in the heatmap in table 2.5B are properties of the classes of consumers: the degree of interest they show in buying these 16 products.

It becomes immediately clear that adventurous consumers, as far as cooking is concerned are not enthusiastic about purchasing processed potato products (an average of 2.1 only) with the exception of flour to make a mash for further preparation into dishes and dry products such as gnocchi. Of all products there are only few that are preferred by consumers seeking indulge, snacks especially. Innovative cooks are not likely to choose French fries, flour or almost ready to eat canned or chilled tubers or cuts. Fried products including snacks are least fancy. Consumers seeking convenience obviously get the highest mean score of 4.1 because there are many convenient products available and listed. Buying baked tubers yields least convenience and the more sophisticated the product, the more time is saved if bought. Low priced products are favored and so are many different products by different cultural groups. Pan fried potatoes are popular in Germany, baked in the United Kingdom and expanded snacks are supplied with flavorings that target a variety of ethnicities and cultures.

Table 2.5B. Twelve classes of consumers with 16 attributes, their degree to which they prefer the product

Legend: Much preferred | a-p | Preference | Not much preferred

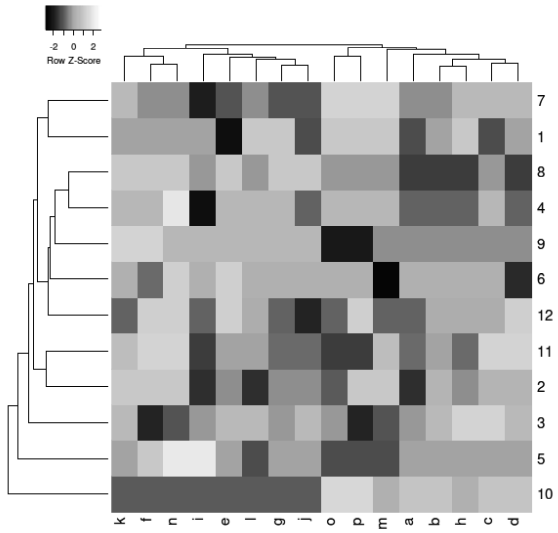
Nr	Class of consumers seeking	French fries	Wedges	Rissole	Roasted	Baked	Hasselback	Formed mash	Formed shreds	Mash from flour	Blanched chilled	Vegetable mixes	Canned	Gratin	Dry products	Chips	Expanded snacks	
		a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	Av
1	Convenience																	4.1
2	Innovation																	3.4
3	Tradition																	3.3
4	Information																	3.6
5	Adventure																	2.1
6	Price																	3.8
7	Taste																	3.3
8	Environment																	3.1
9	Health																	3.4
10	Indulgence																	2.5
11	Fanciness																	3.0
12	Culture																	3.8
	Average	2.8	3.3	3.8	3.5	3.3	3.6	3.1	3.3	2.6	2.8	3.7	3.1	3.3	3.9	3.1	3.3	3.3

Of the attributes, consumer preferences, the average of the scores ranges from 2.6 for mash made of flour to 3.9 for dry products that need reconstitution and heating . The most widely produced product, frozen French fries, also receives a low score because it is moderate on convenience in household kitchens (still needs deep frying and equipment), not considered an innovation nor fancy. It is especially popular in food service. The heatmap and sum of scores for preferences give information of how different consumers appreciate diverse and distinct products but are not indicative of the total quantity purchased in shops, prepared in kitchens and consumed.

Clustering consumers as is seen in the dendrogram of Table 2.5C show the closest association between seekers of information and worriers about the environment with consumers concerned about their health in the same triplet. Consumers who are after taste and convenience have much in common and so have customers that look for innovative products and those for fancy ones. Indulgent consumers of snacks are a separate group not closely coupled to any other one.

Clustering preferences yields the closest association among wedges and hash browns (fried formed shreds). Other twins are preferences for croquettes (fried formed dough) and blanched canned or chilled tubers, chips and expanded pellets and roast and rissole potato. The niche products hasselback and gnocchi are twins and closely associated with vegetable mixes, another product not bought by many consumers. Just right of this cluster with preferences for niche products is a cluster with preferences for products that have in common that they do not contain fat (with the exception of croquettes) and a cluster that contains preferences for fat containing products.

Table 2.5C. Dendrogram of all classes of consumers (1-12 see Table 2.4B) with attributes their degree to which they prefer the products a-p, Table 2.5B)



Deliberation and conclusions

In the inception section of this chapter research questions were asked about the ontology and description of the domain 'on processing potato'. Subsequently, after the ontological description of the domain and it elements, of tubers serving as raw material, of products manufactured classes of operations in kitchens, their use by cooks and finally the preferences of consumers were enumerated and supplied with attributes. Below the newness of the findings per domain is put forward. The merits of the Four Tier Analysis and the adequacy of answering the research questions is dealt with in the Final Discussion (Chapter 7). The Potato Processing Ontology is introduced in this chapter, all domains treated, however, are not found in this chapter but are included in the next four chapters and summarized in Table 7.1 in the general discussion.

Tubers

Nine classes of tubers were distinguished of which two are not intend to be processed: seed tubers and fresh market tubers. The specifications differ strongly but all can be used as attributes in a scale from 1 to 5. Tubers for chipping need to be round and for making French fries they need to be long as illustration. The average of scores for potatoes destined for chips production is twice that of starch but no social consequence can be attached. The classes of tubers only have own attributes or specs: specific sizes, shapes, dry matter and reducing sugar concentrations and storage requirements to name a few and these are the same in lowland summers as highland winters. So no environmental triangulation was possible and specs are also the same when articulated by growers or processors, making theoretical triangulation unnecessary. Clustering demonstrates that starch and seed tubers stand alone, the rest in a cluster and the attributes are in two groups, those most concerning growers and those more of interest for processors.

Products

Some products were made well before the tuber spread to Europe and the rest of the world in the 16th century, freeze dried chuño, flour and drinks. Industrial scale starch production started in the 19th century. Chips were introduced early 20th century but a real boom of new products started in the second world war until some ten years thereafter. Then large globally operating North American companies were established. This was triggered by needing to supply armed forces and airline passengers and made possible by the cold chain, freezing, from factory to kitchen. Other triggers were new and tasty products (snacks), convenience (time saving) and prolonging the storage period (frozen products) of the crop through products. Theoretical triangulation was done on 23 products and 18 attributes carried out with a difference in appreciation (a high score indicative of a high degree of the attribute applies to the class) becomes a low one (because a high score is considered undesirable). Of the attributes concerned their score is flipped around 3 (as illustration a score of 1 becomes a 5). The order of products from low to high sums of scores changes and also that of the attributes although convenience has the highest score in both theoretical triangulations. This procedure did not at all influence the hierarchy of clustering of the classes but it refined the clustering of the attributes into more and smaller and easier to grasp small clusters, twins most often, as illustration: concerning developing market, number of uses of product, convenience, age and market and price and size.

Kitchen operations

In kitchens, 18 classes of operations are distinguished and supplied with attributes including the requirements of appliances, skills, energy and time. Six of the classes concern mechanical operations, the other twelve regard several means of heating. The highest average of scores was for baking a gratin and the lowest for peeling. No theoretical triangulation took place as it is assumed that all operations are a necessity so if an operations in kitchens needs more water or energy than another cooks have fewer opportunities than processors to fine tune operations than processors have. Of all operations there are only two that require water, washing and boiling, so logically this attribute receives a low average of scores summarized over all classes. Having to buy at a price rather than carrying out the operation in the kitchen is valid for most operations so this attribute receives the highest average of scores. Two distinct clusters of classes are observed: mechanical and heat involved operations.

Dishes from products

The 13 classes of dishes made from purchased products and their 13 attributes were subjected to two environmental triangulations. One from the perspective of an affluent society where potato and its products abound, where kitchens are well supplied and consumers have ample buying power. The other analysis is from the point of view of a less well-off society, in a warmer environment with less potato (if at all) and products available, a cold chain often lacks and money is scant. In the second situation the average of averages of scores is higher than in the first as in general there are more issues and the order of the averages of attributes per class and over the classes changes. The clustering also alters, with more products moving to the luxury cluster. The clustering of the attributes did not change much but the attributes expressing unconcern for the affluent worry the destitute.

Consumer preferences

The least attractive product is flour to make mash in the kitchen and rissoles the most striking. Of the classes of consumers, the adventure seekers have least interest in buying products and convenience seekers the most. Fried products (French fries and chips) are considered least fancy so French fries prepared from a manufactured frozen product are not likely to appear at a posh dinner party. Scientific literature also hints at where certain consumers abound, rural elderly are culture driven and women with children in mid-sized cities seek information on ingredients and health.

Chapter 3.

MANUFACTURING
Domains of products, processes and factory operations

Slightly modified article published by Potato Research as:

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Abstract

In supermarkets in the Netherlands, well over 150 potato products are displayed. They can be distinguished by heating characteristics (boiled or fried), appearance (e.g., intact tuber pieces or formed hash browns), dehydrated (e.g., snacks and flour) and storage temperature (e.g., ambient and frozen). Fancier products (frozen formed versus chilled blanched) require more processes and operations in factories, are more expensive; consumers appreciate them because they offer more convenience. Heatmapping and hierarchical clustering were carried out twice within the domain of classes of products and their attributes. In a theoretical triangulation consumers give high scores to low prices and a wide range of products, tastes and sizes where processors give these attributes a low score. Processes in factories include dehydration, heating, cooling and transformation. Examples of the latter are modification of starch to increase the range of applications in the food industry, forming of mash and shreds to produce croquettes and hash browns and expansion to make snacks. Processes require operations such as washing, cutting, blanching and packing. In total, between the arrival of the tubers at the gate and leaving as packed products to outlets, 66 operations are distinguished. French fries undergo some 30 operations and to produce flakes, 8 suffice. Heatmapping and hierarchical clustering differentiate a group of physical operations (with attributes associated with heating and cooling that require much energy) and mechanical ones (related to separation, grading, sorting for instance and size reduction of which shredding is an example that require little energy). The wide range of operations in large factories, reducing the moisture content and longtime storage at low temperatures distinguishes potato from wheat that has fewer operations while increasing the moisture content in relatively small bakeries and the product, bread, stored for about one day in ambient conditions.

Inception and research questions

In shops, especially supermarkets in affluent societies, a wide variety of processed food products is found. The majority of products as far as shelf space is concerned is based on the four main staple foods, wheat, corn, rice and potato. Wheat products, bread, cookies, pastries dominate in most markets and in Asian countries there is also emphasis on rice and in European and North American countries on potato. Potatoes, unlike most vegetables need to be cooked before consumption, as its starch cannot be digested by non-ruminants such as humans (Narwojsz et al. 2020). When eaten raw it is not affected by the stomach and upper intestines and in the colon its starch is fermented, producing gas leading to flatulence (Birt et al. 2013). When heated, the tubers, their cell walls and amyloplasts disintegrate, and the starch granules (Singh et al. 2005) absorb water, gelatinize and become digestible. In starch potato factories all starch related processes take place at low temperatures so the resulting native starch and modifications thereof, need to be reconstituted with water and heated. Also freeze-dried products need to be boiled upon reconstitution with water.

Just one procedure prepares food from freshly harvested tubers, washing. It is often followed by peeling and cutting but not necessarily for all side dishes. Subsequently, tubers or parts thereof are boiled in kitchens, on occasion mashed, fried or baked and eaten as such. Deep frying potato cuts, (French fries) is also one of the preparations in kitchens at homes, institutions and restaurants. Starch extraction at home is done only sporadically to make glue, but the industrial extraction already took place as of the middle of the 19th century (Chapter 2). The processing industry delivers all products that cooks can prepare in the kitchen, dry ones including flour, chips and gnocchi, baked such as jacket potatoes and hasselback, blanched for instance baby potatoes and slices packed or canned and fried ones including French fries, formed products and chips.

Cereals, notably wheat, rice and corn, when harvested contain about 15% moisture (Tahir et al. 2007) and to make an edible meal component, water needs to be added. With the tuber crop potato containing 80% water, adding water is not needed, heating suffices, although some is used at blanching, boiling and steaming. Cereal starches are digestible without heating in water, whereas moist potato starch needs to be heated, which is another feature distinguishing these two sources of food. Table 3.1. shows the four main food crops, the operations needed to prepare a meal component from the main product and the by-products (Phetmanyseng et al. 2019; Liu et al. 2015; Rausch et al. 2019). Boiled potato and rice and bread are meal accompaniments whereas corn starch is an ingredient of sauces and soups, a thickener. The majority of potato tubers, globally, is purchased fresh from shops and markets and prepared in the kitchen. All cereals, rice and wheat and corn, however, are processed in factories (mills) and the products grain, flour or starch used as ingredients. All four crops can

Table 3.1. Principal minimal factory and kitchen operations, beside cleaning to produce food from the harvested crop

Crop	**Factory operations**	**By-products**	**Main product**	**Basic operations to make a meal component**
Potato				Boiling
Rice	Dry milling	Husk, bran, germ	White rice	Boiling
Wheat	Dry milling	Bran, embryo	Flour	Adding water and yeast, baking
Corn	Steeping, wet milling	Gluten, fiber, germ	Starch	Add hot water

produce flour from ground whole kernels or boiled and dried tubers. But also pure starch is derived when protein and fiber are washed out. Of the four crops, the bulk of corn is processed into starch, of potato and wheat a considerable proportion and of rice a negligible part. This because globally, corn starch is produced at the lowest costs and rice starch at the highest. Not all starches are readily soluble in water, nor applicable for a wide range of uses in the food industry. Therefore they are subjected to a range of treatments, modifications.

Although no primary processing of potato is needed to make a basic side dish, the number of processes and underlying operations the tuber is subjected to in kitchens, is considerable as was shown in Chapter 2. The products in supermarkets have undergone many of these and some considerably more.

In line with the general objective of the thesis, this chapter seeks to capture the relevant subdomains with classes of products, classes of processes they went through and the classes of operations that underly the processes and their respective attributes. The latter are scored as to the degree they apply to the classes and where possible through theoretical or environmental triangulation. Where Chapter 2 took the most important participants into account (growers, processors, cooks and consumers), does this Chapter 3 focus on products available for cooks and the processes and operations that create them. To disentangle the myriad of products, processes and operations that helps to elucidate the particular issues within the domain of potato-based food processing the following research question are put forward.

Research question about variety of products in supermarkets

In supermarkets many potatoes, potato products and potato derived products are shelved at ambient, cold and freezing temperatures often of more brands and several weight classes. This demarcated domain of potato products in supermarket has not been analyzed in detail through an inventory and description of its groups of products, subclasses. The latter have experienced similar processes with their descriptors. What information does this analysis yield, and what is its relevance?

Research question about processes

Potato products on sale are moist (blanched and chilled) or dry (flour), still have some of the tuber structure intact (French fries) or not (gnocchi), some have been fried (chips) or never experiences any temperature above ambient (native starch). Some products are not for sale in supermarkets as they go to the food industry directly or are an ingredient in potato-based food, such as granulate and modified starches. The questions arise which classes and subclasses of basic processes lay at the base of products and how to meaningfully classify and supply them with attributes in a delimited domain? Which intermediate products go to the food industry and what are their functionalities? Are there specific requirements and demands made on the tubers serving as raw material, do processes vary in use of water and energy and which processes require the product to be stored at below ambient temperatures.

Research question about operations

Processes, such as dehydration lead to starch and frying to chips, involve many operations taking place in factories. Some products probably undergo few operations such as skin-on baked tubers, but of most products, consumers have no idea what they went through. The domain of operations in potato processing plants with all classes of operations taking place and their descriptors, attributes, has not systematically been defined. Nor is it made visible which classes and subclasses of products undergo specific operation and for what purpose. A systematic allocation of attributes to operations in order to distinguish groups according to necessities as illustration, as heating or water use, has not been carried out so has not been judged on its merits.

The domain of potato products on sale

Formulation of the products domain

The small town Wageningen in the Netherlands of about 40,000 inhabitants has six supermarkets where mainly food is sold. The posh ones contain a bakery, a butchery, a greengrocery and all have shelves with packed and canned food, fridge compartments with chilled food and frozen compartments with deep frozen food. In December 2020 one particular supermarket, rather classy brand Jumbo, was visited and the potato products observed. The greengrocery department sells 13 fresh tuber products. The choices are waxy or floury tubers, general use or specific use for French fries preparation, ordinary or gourmet potatoes, conventional or organic or environment conscious, regular sized or baby potatoes. This particular shop displayed the cultivar name (cv) beside quality characteristics such as waxy, floury and suitability for making French fries. Not all shops do this. The domain of potato products on the market here is limited to the products found in one supermarket thought to be representative of larger and smaller ones and situated in larger and smaller cities in developed and less developed markets, provided they have a cold chain: freezing and chilled compartments. Its list is expected to not exhaustedly represent the products made in many factories, on sale in many supermarkets.

Condensation of the supermarket products domain

The supermarket (Table 3.2A1) had 30 chilled products on display, 42 when considering that some products were sold at two different weights e.g. at 200 and 500 g. Some chilled products appear as dishes in a tray, gratins, ready to place in the oven or microwave. Others appear in plastic bags loosely packed. Only few of the same quality characteristics as shown in the fresh tuber displays, appear in

Table 3.2A1. Potato products in a supermarket (Jumbo Supermarket at Wageningen, The Netherlands) on a single day in December 2020)

Nr	Type	Category	Description	Nr	Type	Category	Description
				Nr			
				76	Formed		Skin-on wedges
1	Fresh	Waxy	cv Regina 5 kg	77			Mash
2			cv Mozart 3 kg	78			Cubes
3		Organic	cv Vitabelle 2 kg	79			Dices
4		French fries	cv Alegria 5 kg	80		Aviko brand	Mini croquettes
5			cv Alegria 2 kg	81			Bistro
6		Floury	cv Milva, 3 kg	82			Rösti mini
7			cv Milva, 1 kg	83			Rondjes
8		Waxy	cv Loreley, 3 kg	84			Rösti mix
9			cv Loreley , 1kg	85			Rösti bacon/onion
10		Trade mark	Conscious 1kg	86	Dishes	Jumbo Brand	Burgundian
11			Baby potatoes cv Suzanne0,5 kg	87			Netherlands
12			Red Gourmands cv Cherrie, 0,75 kg	88		Aviko brand	Swiss Rösti
13			Yellow Gourmands cv Lavie, 0,75 kg	89			Netherlands
	Chilled Tray or bag			90			Greek
14		Casserole	Patates gyros	91			Gratin
15			Casserole Gratin				
16			Casserole Hasselback	92	Dry	Gnocchi dumplings	..di patate. 500 g bag
17			Casserole Rosemary				
18		French fries	Air fryer fries	93		Gnocchi	.. di patate 500 g oven tart
19			Fryer fries	94	Flour	Maggi brand	Mash natural
20			Skin-on farmers' fries	95			Natural a la minute
21		Whole tubers	Oma(Grandmother)	96			Hotchpot (stew)
22			Waxy	97			Crème fraiche
23			Hotchpot (stew)	98		Jumbo brand	Natural
24			Floury	99			A la minute
25			Pan fry		Snacks		
26		Pan fry sections	Skin-on natural	100		Jumbo brand	Ribbed paprika 250 g, (335g)
27			Peeled natural	101			Ribbed natural 250 g, 335 g
28			Seasoned bell pepper	102			Sticks natural 150 g
29			Skin-on Paprika	103			Sticks paprika 150
30			Skin-on curry	104			Undulated popper /salt

Nr	Type	Category	Description	Nr	Type	Category	Description
31			Skin-on Provençal	105			Undulated sweet chili 150
32		Discs	Small	106			Garlic
33			Large	107		Organic	Biologisch paprika 125
34			Section	108		Lays brand Super Chips	Natural 200/280 g
35			Ham and onion	109			Paprikal 200/280 g
36			Duopack (2 x 350 g)	110			Ketchup 200/280 g
37		Cubes and baby tubers	Cubes	111			Jopiepatat 200/280
38			Natural 200 g 500 g	112		Lays brand	Undulated natural 147 g
39			Bistro 200 500 g	113			Bolognese 200/280
40			Gyro	114			Light 170 g
41			Burgundian	115			Sour cream
42			Pan fry fine cut	116			Cheese union
43			Texas barbeque	117			Strong Chili
44			Duopack 2 x 250 g				Strong hot chicken wings
45	F fr	Jumbo brand	Patates Frites 2 kg	118			Sensations Mexican pepper
				119	Snacks		Sensations Red sweet paprika
46			Patates Frites 1 kg	120			Sensations Japanese wasabi
47			Flemish fries	121		Enrico	Natural, paper bag 110 g
48			Super Cruncy	122			Spanish, paper bag
49			Oven	123			Cucharada (pringle type)
50			Ribbed	124			Cucharada paprika
51		Organic	Bio	125		Kettle	Sea salt 150 g
52		Aviko brand	Pommes frites 2 kg	126			Sea salt and pepper
53			Pommes frites 1 kg	127			Paprika
54			French fries 2 kg	128			Salt and vinegar
55			French fries 1 kg	129			Sweet chili
56			Flemish fries	130		Chio	Salt, kettel 150 g
57			Granny's	131		Tyrell	Furrows 150
58			Oven	132		Torres	Black truffle 40 g E 1.65
59			Crinkle fries	133			Iberian ham 40 g
60			Sunny fries	134		Croky brand	Paprika 125/270 g
61			Raspatat (Formed)	135			Bolognese 125/270 g
62		Beyer-lander brand	Rapid airfry	136			Super frites Paprika 150
63			Crinkle fries	137			Super frites Naturel 150
64			Strait no coating	138	Stackable snacks	Pringles 165 and 70 g tubes	Original, paprika, sour cream-onion, hot&spicy, roast beef, Texas bbq, flame, Cheese-onion, salt&vinegar
65			Strait with coating				
66		Lamb Weston brand	Rustic strait				
67			Ziggy crinkle				
68			Twister	146			
69	Formed	Jumbo brand	Small croquettes	147	Baby food potato base in jars 120-300 g	Olvarit	Beans, carrots, broccoli, pumpking, mixed (organic)
70			Wafers	151			
71			Roses	152		Hippo	Mushrooms, chicken
72			Balls	153			
73			Bistro balls	154		Nestlé	Pumpkin (organic)
74			Pom Duchesse	155		Jumbo	Spinach
75			Sections				Beans
				157			Carrot

this department: waxy or floury and use as French fries or mash. No mention of the variety used is shown. But other characteristics are added: skin-on or not, whole tubers or parts thereof (slices, cubes, dices, French fries cut). The size of sections and slices are itemized and seasoning and spices added with reference to national tastes such as 'French bistros' and 'Burgundy' and 'Mexican barbeque'. The assortment of French fries and related items consisted of 23 products of 4 different companies, one of them the private Jumbo label. Among them regular, crinkle, with and without coating and rapid airfry. Of some products it is not readily obvious in what they differ from the other ones such as 'Granny's' and 'Sunny'. Raspatats are French fries not made of cut tubers but of dough shaped as French fries cuts and battered. Their shape, bite and taste is very consistent.

The supermarket had 16 frozen formed potato products for sale, most of them private label and one brand. Croquettes being the most popular on offer, the rest consists of balls, wafer, patties, pomme duchesse, baby potatoes, look alike dices and cubes and rösti (hash browns). Frozen dishes with potato contain other vegetables such as carrots and bell peppers with mushrooms and ham (Burgundian) or potato sections with gyros pork, zucchini and bell pepper (Greek) and there are more. A gratin (Gratin Dauphinois) consists of thin tuber slices in cream and baked, this also is a readymade potato dish.

Dry potato dish ingredients registered in the inventory, numbering seven, were gnocchi and flour to prepare mash with options natural and a la minute (more soluble), ingredients added (creme fraiche) or with a more original potato mouth feel with granulate added.

The shelves displayed 52 dry snacks (chips) when adding products available in two weight classes of 11 brands. Of the 52 chips products 9 consisted of stackable chips of a single brand, Pringles. The snacks differ in shape so as to the size of the slices, their shape flat, ribbed or undulated and slices (majority), similar stackable copies or thin sticks. The seasoning is the most varied characteristic, 19 different combinations, with 'natural' dominant, only salt added, and typical for the Netherlands market 'paprika' (bell pepper) is very popular. 'Organic' (1 out of 37) is a trait of these snacks and so is 'light' (also 1 out of 37). The latter contains about 20% fat rather than the 30% in regular products. The package also is a feature wherein products are distinguished: by large and small bags and made of polyethene (the majority) or of paper. How chips are prepared also shows on the wrapping in a continuous process on a frying belt, dominant, or in batches, so called 'kettle chips' and made of intact tubers. More than the other products the prices per kg showed variation with an over tenfold difference between the private label Jumbo, natural, large bag of 335 g at €3.37 per kg, versus the Torres brand 'Black truffle' taste in a 40 g bag priced at €41.25 per kg. Formed and stackable made of potato dough there were 10 (14 if varying sizes are distinguished) different products of a single brand: Pringles. Extruded and expanded potato-based products numbered 16 distinguished by brand, taste and shape (heart, bear, rings sticks, screw).

This supermarket did not sell canned tubers nor potato soups but there was one jar of 390 ml containing a potato-based sauce for use in the oven (Aardappel Anders) and 11 types of potato containing baby food in jars of 4 brands, 2 of them also offering organic products.

Cuts: waver regular, crinkle

This single supermarket in the Netherlands is representative in a wider context as the range of products found there are similar in other settings. There, the range may be smaller or wider with less or more products within the same category (snacks for instance) and with different sizes and flavors.

Potato products found in supermarkets can be distinguished in frozen, chilled and stored under ambient conditions. The bulk of manufactured potato food products globally is frozen to -18°C at the factory, distributed refrigerated, exposed in freezers in shops and at home or restaurants placed in freezers again or thawed and prepared. Table 3.3A2 shows the five main categories of frozen products: they are:

- Cut products in a variety of shapes and size (French Fries Machine, 2021; Couture, 2017) either battered or not battered and par-fried. In the kitchen the par-fried potato parts are fried for a few minutes and served. Also air-fry and oven heating preparations exist whereby the product contains more fat than the non-oven ones but the final dish less. The bulk of products is made of white or cream flesh colored tubers but niche products are made of colored tubers (Lachman et al. 2016).
- Boiled products, mashed to fit the product (stiffer for balls than for puffs), seasoned and shaped in various forms. Kitchen preparation possibilities as with fried potato cuts with pan-frying added for potato pan cake (Kiremko 2021; McCain 2021; LambWeston 2021)
- Shredded or julienned products, often onion added for rösti and hash browns (Kaczay 2016), type and proportion of binder varies. Preparation in kitchens as for cut and for formed products with a larger proportion pan fried
- Baked products (Potatoes USA 2021) consist of tubers whole, slit, scooped or baked in a sauce (gratin) or pre-pan-fried. In the kitchen these products are baked whether or not with a filling, baked in an aluminum casserole in which they are usually commercialized or pan fried in case of rissole.
- Heated tuber parts in watery environments at near or boiling temperatures (blanching, steaming, boiling) yield an array of products, mashed among them. Blanching followed by IQF (individually quick fried) produces frozen ingredients for dishes in kitchens. Dumplings consist of dough with non-potato ingredients prepared by boiling in water in kitchens (Lisinska and Leszczynski 1989; Maine Potatoes 2021; Zaheer and Akhtar 2014).

Many frozen products are also available in a chilled version. These are not frozen to -18˚C but cooled to 4˚C. Table 3.2A2 also summarizes these product categories and subcategories. Some products are packed in plastic in vacuum to evacuate all oxygen, pasteurized (Peng et al. 2017) at 96˚C degrees and can then be stored for weeks or sterilized at 100°C or higher (Ramesh 2003) and can then be stored for many months. Vacuum packing is only done with products that allow compression without losing shape such as French fries and then usually only packed in larger than household packages of 1 or 2 kg but in 5 kg or larger packs for outlets. Display in vacuum is not considered attractive, so most products

Wrapping: tray, loose, vacuum

are loosely packed in plastic bags with print in controlled atmosphere, nitrogen only. For formed products chilling is not possible as when they are unfrozen they loose their form. Some formed products are placed in plastic or aluminum trays to be baked in the oven. Potatoes in cans or glass jars need no chilling as they are sterilized, similarly to potato dishes (soups for instance) sold in tins or bags.

Fully dehydrated potato products (Table 3.2A2) need no refrigeration nor cooling and can be stored for many months in controlled atmosphere such as potato snacks where the oil risks to become rancid. Also light is detrimental for the quality of the oi, reason why these products outside the cottage

Table 3.2A2: Classes of products stored 1), Frozen only, 2) Frozen and chilled, 3) Chilled only, 4) Ambient conditions

Class	Nr	Subclass	Description	Factory preparation
Cut, blanched and fried	2	Strait cut	Cuts of tubers of about 9 mm x 9 mm x 6 cm	Peeled tubers are cut into one of the many shapes, blanched at 70˚C for 5 minutes, dried, par-fried in oil at 170 ˚C and frozen at – 18˚C. Kitchen: fry for 5 minutes at 180˚C
	1	Curly cut	Spiral shaped cuts 2.5 cm long, 1.5 diameter	
	1	Crinkle cut	Corrugated with dimensions of regular cut	
	1	MacFry	6 mm x 6 mm x 7 cm	
	2	Flemish cut	12 mm x 12 mm x 5 cm	
	1	Wedges	Wedge shaped 5 cm long, usually skin-on	
	1	Tater drums	Cylinder shaped 1.5 cm diameter 2.5 cm length	
	1	Lattice cut	Basket weave pattern, roundish 4 cm diameter	
	2	Various	Dippers, shells, skins, shoestrings	
	1	Twister	Spiraled curls 2 cm diameter 3 cm long	
Cut, fried	4	Chips	Thin crispy slices, often flavored	(Un)peeled thin slices, fried
Dough formed, fried	1	Patties	5 cm diameter potato cookies	Dough from fresh mash or flour, formed, fried
	2	Croquettes	Battered round 2.5 cm diameter, 5 cm long	
	1	French fries	Dough shaped in French fries regular cut	
	1	Whipped	Puffed dough (wheat flour added) with egg	
Shredded tuber, shaped and fried	1	Cake	As hash brown but with dough instead of shreds	Forms are made from potato mash: mashed boiled tubers or from reconstituted flakes, seasoned, shaped to form the desired product, par-fried and frozen same as French fries
		Pancake	Dough ingredient of flatter and larger hash brown	
	1	Hash brown	2 cm thick patty shaped seasoned shreds	
	1	Rösti	Pan sized hash brown, if not same as hash brown	
	1	Pancake	Thinner and larger than hash brown	
		Tater tots	Small hash browns with corn starch binder ('53)	
Baked	1	Jacket P.	Whole tuber	

Class	Nr	Subclass	Description	Factory preparation
	1	Stuffed	Whole tuber slit, filled	Shredded, diced or chopped tuber parts shapes 1.5 cm thick of various shapes
	2	Rissole	Small tubers 3 cm diameter boiled pre-pan-fried	
	2	Au gratin	Slices, in tray (casserole) ready to bake	
	1	Half shells	Unpeeled whole 6 cm tubers, flesh scooped	Oven prepared whole or scooped or sliced tubers, some with filling. Gratin contains slices in a creamy sauce, rissole is pan fried
	2	Mash	Mashed boiled tuber (parts)	
	1	Dices	IQF 2cm x 2 cm dices (Individually Quick Frozen)	
	1	Shreds	IQF 2 mm x 2 mm x 4 cm shreds	
	2	Dumplings	2.5 cm dough balls with wheat, egg (gnocchi, knödel)	
Blanched or boiled	4	Tubers	Baby tubers (if cut: scooped with a melon baller)	Whole or scooped
	2	French fries	Various cuts	Shapes see fried above
	3	Slices	About 6 mm thick slices par-boiled	Cutting, blanching
	4	Liquid dish	Potato-based soup, sauce or stew, pasteurized	Food industry, babyfood
	4	Slices	About 6 mm thick dry slices	Peeled and cut
	4	Cubes	About 1.5 cm^3 dry cubes	Partly for food industry
	4	Flakes	Flour, flakes, granules ready to (drum)dry	Peeled, blanched
	4	Snacks	(stackable), (popped), (expanded) chips	Potato for taste and structure
Dried	4	Slices	About 6 mm thick dry slices	Air dried in cottage industry
	4	Cubes	2 cm x 2 cm	Freeze dried under vacuum
	4	Pellets	Various shapes and sizes	Par-boiled, mashed dried
	4	Expanded	Snacks from pellets	Expansion upon frying, baking
	4	Powders	Flakes, flour, granulate	Drum drying

industry environment are packed in aluminum coated polyethene bags, or the stackable ones in tins or cartons. Dehydrated slices, cubes and flour contain no oil nor seasonings and are packed with ambient air in permeable paper and carton packages.

Quantification of the supermarket products domain

The eight potato product categories found in supermarkets , fresh tubers, chilled tubers and parts, frozen French fries, formed products, dishes, dehydrated, snacks and baked tubers are listed in Table 3.2B against 11 attributes. The range or variety of products within a category is the first one, the variety being low with only two flour types but high for chips. Similarly products have an average price level per kilogram and range of prices around it, of weight of the packages in which shelved, and of tastes as there are many in chips and other snacks with a wide variety of flavors available. A product is more fancy if not eaten at a regular basis but as a more exceptional treat consumed at memorable occasions when guest are there, or in a slow service restaurant. A product is more convenient when it takes more time to prepare a dish in the kitchen based on purchased fresh tubers. Vacuum packed chilled slices are a most densely packed, chips most loosely. The number of manufacturing operations a product goes through is derived from Table 3.4A2. The appreciation of the attributes of the products depends on the point of view from the user or the producer. Consumers want a choice from many products, processors are more interested in a narrower range as it requires less finetuning of operations and packaging in the plant. For some attributes user and producer have opposite aims as is shown in Table 3.2B: array, weight, numbers of shapes and tastes. Here the values in Table 3.2B, lower part, are mirrored around the average value 3. One exception is made to flipping the scores: both consumers and processors prefer low prices of fresh tubers for cooks to prepare and for processors to use as raw material. Consumers have no knowledge nor interest in the factory operations so this column is left blank in Table 3.2B. Snacks have the highest average values of the attributes with only a low score for density of packing as they are loosely stacked and a medium value for fanciness. Flour is dry and stored at room temperature and is densely packed, only two high scores with the other attributes receiving low scores only. The average value of an attribute over all product classes is highest for convenience. Only fresh tubers and flour receive a low score as it takes time to make a substantial dish from them. Only a few products, powders and dishes are densely packed hence a low score for this attribute.

When looking at the products from processors' point of view some inversions take place. For them the class of dry products emerges with the highest score for which they have to accept the consumer low scores for price range and convenience. The average value for snacks drops from 4.4 to

Table 3.2B Heatmap of 8 classes of potato derived food products in supermarkets with 11 attributes values from the consumer point of view (top) and from the processors point of view (bottom)

High value			Low value
	a	**Range of products**	
	b	Price range	
	c	Shelf temperature	
	d	**Weight range of package**	
	e	**Number of different shapes**	
	f	**Number of different tastes**	
	g	Fanciness	
	h	Convenience	
	i	Stacking density	
	j	Number of operations in factory (Table 3.9a)	
	k	**Price per unit weight**	

			a	b	c	d	e	f	g	h	i	j	k	Av
CONSUMER	Fresh	1												2.6
	Chilled	2												3.1
	French fries	3												2.8
	Formed	4												2.9
	Dishes*	5												2.7
	Dry**	6												1.9
	Snacks***	7												4.0
	Baked tubers	8												1.6
	Average of 1-8		3.3	2.8	2.8	3.3	2.5	2.6	2.6	4.0	2.3		1.0	2.7
PROCESSOR	**Fresh**	**1**												**2.5**
	Chilled	**2**												**2.7**
	French fries	**3**												**2.8**
	Formed	**4**												**3.1**
	Dishes*	**5**												**4.3**
	Dry**	**6**												**4.0**
	Snacks***	**7**												**2.9**
	Baked tubers	**8**												**3.0**
	Average of 1-8		**2.8**	**2.8**	**2.8**	**2.8**	**3.5**	**3.4**	**3.1**	**3.5**	**2.3**	**3.5**	**4.5**	**3.2**

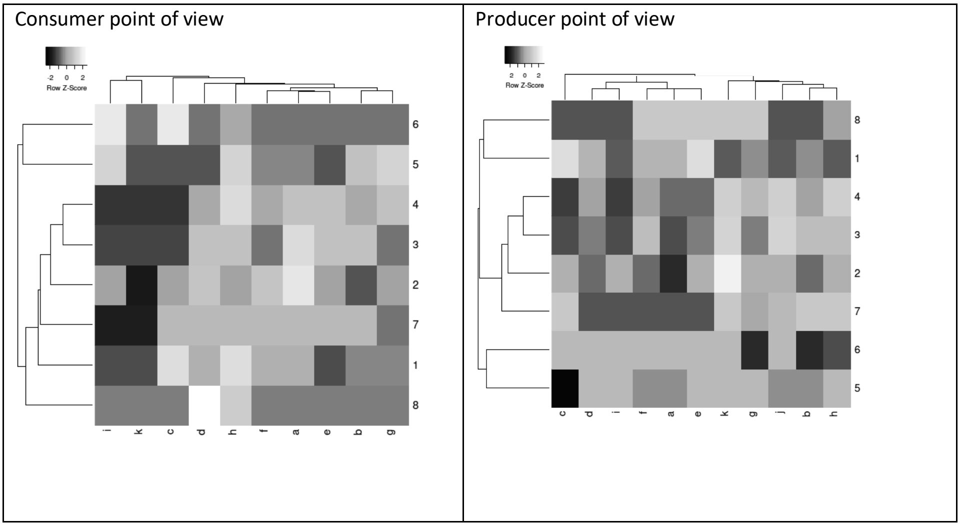
*Gratins, soups, sauces, stews, baby-food
**Flakes, flour
***Fried, baked, popped chips and expanded snacks

2.9, comparable to fresh tubers from the consumers point of view. Dishes are also valued by processors for their added value with one disadvantage: they have to be shelved frozen. Where consumers are willing to pay, are accepting the price, processors, in this exercise are thought to go for higher prices for all products preferably with fewer shapes, flavor and operations in the plants.

Clustering of products in supermarkets

The cluster hierarchy of the classes from the consumers' point of view is revealed in Table 3.2C (left). Two clusters are distinguished: the twins at large distance dishes and dry products are separated from the other product that hold the close twins French fries and formed products. Baked tubers stand alone and are most remote from all other products. The attributes show four groups. Price and fanciness are coupled, so are ranges, shapes and tastes of products. Stacking density and price per unit weight have some relationship and shelf temperature stands alone.

Table 3.2C. Dendrogram of potato products. The categories 1-8 and their attributes a-j are displayed in Table 3.2B.



Grouping from the processer's perspective (Table 3.2C, right) shows three distinct clusters. Fresh and baked tubers add the lowest values so appear together in the top cluster. The dry products and the 'moist' gratins are in almost all aspects each other's opposite poles which puts them together in the bottom cluster. The fried products are also inseparable and are clustered with chilled and snacks here mostly because of a shared particularity: wide range of available products within the category. The hierarchy of the attributes altered somewhat with theoretical triangulation. From the processors outlook a cluster order is more perceptible. Shelf life stands alone beside the twins package range and stacking density and the triplet price and ranges of products and shapes. The remainder is grouped less evidently.

The domain of basic processes in transformation of tubers

Formulation of the processes domain

The raw material, tubers entering the processing facility, is grown on fields planted with seed tubers and supplied with nutrients, biocides, irrigation water and harvested (Haverkort 2018). In case of organic farming, nutrients and biocides are not synthetic. For starch production all tubers suit, but for other destinations they are graded to meet the specifications of the product: small round tubers for chips and large long ones for French fries. Sorting consists of removal of unsuitable tubers presenting defects such as green skins and cuts. Washing is done on-farm in some instances for crisping potatoes but then they cannot be stored and are delivered to the factory directly. The majority of tubers is stored for one to many months with temperature, relative humidity and concentration of carbon dioxide regulated. Transport to the factory takes place under frost-free conditions and for very long hauls in warm condition they are refrigerated. Once arrived at the processing plant, tubers are destoned and washed and subjected to subsequent operations. Many operations are mechanical such as washing, conveying, cutting and take place at ambient temperatures but especially for the food industry operations involve heating. Processing potato is making products such as illustrated in the third section of this chapter through a sequence of operations demonstrated in the second section. In this first section the principle classes of processes (dehydration, conversion, blanching, frying and baking) are underpinned by the required operations and the resulting main classes of products supplied with operations related attributes.

Condensation of the processes domain

Table 3.3A1 gives an overview of the processes and (intermediate) products implied in starch (BeMiller et al. 2009) and food production from washed tubers. The three main components of starch potato tubers upon grinding are starch, protein and fiber and their destination is revealed. The lowest value is the fiber, usually silage and destined as feed for cows. Some facilities extract food grade fiber used in the food industry to give structure, bite, feel and satiety to food products (Potato Fiber 2021). A higher value is attributed to the denaturalized protein that can be used as feed for non-ruminants such as pigs but is not marketable for human consumption. Denaturalization (Ralet and Guéguen 2000) takes place by heating the fruit water, the liquid remaining after settling of the starch the bottom of the vessel. Extracting protein in cool conditions by means of chromatography yields natural protein, comparable to that in whey, is used in the food industry (Lokra et al. 2008). The bulk of the dry matter of tubers is starch, considered native before modification into products for the food and non-food industry. Starch also is the main component of the final food products beside about 75% water in chilled and baked tubers, 50% in French fries and formed products; chips and potato pellet based fried snacks contain about 30% vegetable oil.
To produce food of potato tubers, all components (starch, protein, fiber) end up in the finished products. Rather than grinding, tubers upon peeling and cutting initially remain completely or partially intact. Subsequent procedures among others imply baking, boiling, blanching, julienning (and forming), fermentation resulting in (intermediate) products such as flakes, (Cui et al. 2018), French fries and formed products (PotatoPro 2021), made into chips (Van Loon 2005), baked (AHDB 2021), dried (Doymaz 2011), canned baby tubers (PSU 2021), or turned into alcohol (Xu et al. 2016).

*Table 3.3A1. Processes (and operations), intermediate and finished products in starch and food production, finished products in **bold***

Product	Process	Process	Primary product	Processes	Secondary Product	Processes	Pack&store of finished product	Tertiary product
Raw product (Tubers delivered to factory)	Washing[a] grading[b] sorting[c] peeling[d] cutting[e] shredding[f]	Rasping	Pulped tubers	Filtering	Raw fiber	**Feed for ruminants**		
						Cleaning	**Clean fiber, food grade**	
				Concen-tration	Starch	Washing, refining, drying	Bulk for food, ambient	**Native starch**
					Fruit water	Heating	Bulk for feed ambient	**Denaturalized protein (feed)**
						Chromato-graphy	Bulk for food, ambient	**Natural protein (food)**
		Blanching	Blanched Tuber (parts)	Grinding Drying	Flakes	Grinding	Paper bag, ambient	**Potato flour**
				Cooling	Cuts	Gentle mashing	Paper bag, ambient	**Granulate**
				Chilling	**Chilled tuber**		Plastic bag, chilled	
				Par-frying	**French fries**		Plastic bag Frozen, chilled	
				Mashing	Mash	Forming	Loosely packed, frozen	**Formed products**
						Rolling Baking	Stacked in can	**Stackable chips**
				Canning	**Canned tubers**		Pasteurized, ambient	
				Julienning	Shreds	Forming, frying	Loosely packed, frozen	**Hash browns**
		Frying	**Chips**				Loose, CA	
		Baking	**Jacket potato**				In tray, chilled or frozen	
		Drying	**Dried tuber parts**				Loosely packed ambient conditions	
		Hydro-lysing	Sugars	Fermen-tation	Beer	Distillation	Bottled	**Vodka**

a; for all tubers entering factories
b: not for starch production
c: Not for starch production
d: not for skin-on products (baked tubers)
e:: not for whole tuber products (baby tubers, baked tubers)
f: only for raw shreds based products (certain hash brown recipes

Table 3.3A2 presents the five main processes dehydration, conversion, blanching, frying and baking subdivided by the temperature and moisture conditions the process takes place or in case of blanching the subsequent action.

Dehydration is aimed at obtaining raw material as intermediate for further purposes (starch production, forming), to render the tuber storable under ambient conditions tubers or parts dried. Freeze drying (Setiady et al. 2009) in factories is sped up when done in vacuum. Traditionally in the Andes at 4000 m above sea level at 60% of atmospheric pressure compared to that present at sea level is equally advantageous.

The only digestible dehydrated product not needing heating upon reconstitution is flour resulting from drying boiled tubers. Granules (Olson and Harrington 1955) are digestible but not dissolvable in cold water.

Five processes involve conversion of an intermediate potato product: native starch, potato mash, flour, pellets and alcohol. Modification of native starch into substances destined for the food and non-food industry is done by physical means such as heating and chemically among others with the aid of enzymes. Modified starches are raw material for the food and non-food industry. Forming consists of shaping potato dough, mash, of which the result is ready to deep fry as, e.g., croquettes. Pelleting consists of compressing and heating moist flour followed by forcing through a shaped opening and cutting the extruded string at regular intervals resulting in molded pellets with a great variety of shapes.

Blanching and boiling comprise of heating small tubers or tuber parts whereby the starch gelatinizes and becomes digestible but not fully cooked. Blanching is followed by drying to prepare tuber parts for frying, for chilling or for canning. Upon frying pellets expand, the result is seasoned and marketed as snacks. Thin potato slices deep-fried until the sizzling stops also yields snacks and frying larger blanched chunks produces French fries.

Table 3.3A2. Overview of basic processes in transformation of tubers (little detail only for farm, factory preparations and kitchen processes)

Crop	**Raw**	**Process**		**Operations**	**Product**	**In kitchen**
Growing	Potato tubers as raw material washed, peeled, cut	Dehydration	Extraction	Grinding tubers with water, starch settles at the bottom, air dried	Starch	Add Water and heat
			Drying	Tuber cut in slices dried in air (cottage: in sun and wind)	Dried	
			Freezing	Whole tubers traditionally making chuño, industrial tuber parts, cubes, freeze-dried	Dried	
Handling			Heating	Boiling, mashing, hot air drying in heated drums, scraped off and ground	Flour	
			Granulating	Gentle boiling and mashing yields intact potato cells (granules)	Granules	
		Conversion	Modification	Native starch subjected to chemical and physical treatments as ingredient for the food industry	Starch	Industry
			Forming	Tubers are boiled, ground to a mash and formed, subsequently fried	Forms	Fry
storing			Pelleting	Flour is pelletized and dried as intermediate product,	Pellets	Industry
			Fermentation	Fermentation to make beer, if subsequently distilled, vodka	Alcohol	Ready
		Blanching	Drying	Blanched tuber parts are dried at the surface to prepare for frying	Par-boiled	Fry
			Chilling	Blanched parts are supplied with anti-oxidant and chilled, storable for a a week	Chilled	Cook
Transport			Canning	Blanched (baby) tubers are sterilized and canned	Canned	Cook
		Frying	Expanding	Expansion of pellets by deep frying	Snack	Ready
			Crisping	Deep frying thin slices until all water has evaporated	Snack	
			Frying fries	Deep frying of blanched and dried tuber parts	French fries	
		Baking	Of tuber	Unpeeled, skin-on tuber	Jacket	Bake
			Of slices	Chip sized thin slices	Snack	Ready
			Of dough	Of stackable chips size	Snack	

Drying: sun and wind, dewatering starch, freeze dried

In factories, intermediate and final products are transported and further subjected to the mechanical processes washing, peeling, cutting, grinding, grating, forming, extruding and packing. Physical processes are par-boiling to make flour and chilled products, par-frying of French fries and formed products, baking of jacket potato, distillation for vodka, heating and drum drying for flakes, vacuuming and sublimation for freeze drying, cooling for chilling and freezing. Chemical processes are fermentation for beer and some means of modification of starch.

The processes involving dehydration yield dry products such as starch, flour and dry tubers or parts thereof. If it takes place at ambient temperatures in a wet process (grinding and washing) to produce potato starch (Grommers and van der Krogt 2009), or in a dry process whereby potato parts, slices usually placed on a mesh, are subjected to sun and wind and air dried in a cottage industry fashion in developing markets (Haverkort 2018), the product needs to be reconstituted with water and heated for the starch to gelatinize (Wilson et al. 2002). The same holds for the products of freeze drying (Fellows 2017; Wang et al. 2010), lyophilization or cryodesiccation are three concepts of dehydration using sublimation, moving from a solid to a gaseous stage without going through a liquid phase. The procedure is hastened by reduced air pressure (vacuum) and creates dehydrated potato parts that still retain much of the original structure. Flour is produced from blanched or boiled tubers (Cui 2018) and not necessarily needs heating, although in kitchen preparation reconstituted flour or its formed products are baked, boiled or fried before being served.

Conversion of an intermediate potato product is modification in case of starch (Singh et al. 2016), forming of potato-based dough or mash (Kiremko 2021) and pelletizing followed by expansion (Van der Sman and Broeze 2013). Native starch is modified by physical (temperature, pressure) and chemical (enzymatic, hydrolyzation) means into products with a wider range of applications than that of native starch. These include nonfood uses such as in the paper industry and food uses for bakeries e.g. thickeners of sauces and soup. Mashed potato or dough made of potato flour is (trans)formed into shapes (forms) , croquettes and dauphins. Airy, crunchy expanded snacks are manufactured by heating pellets in oil or hot air. Pellets are made by forcing potato dough through a forming opening (extrusion) whereupon the die cut string is interrupted by knife at regular intervals and the result dried, packed and shipped to extruded snack fabricators. The gelatinized starch matrix contains entrapped moisture that upon heating produces steam which makes the pellet to swell into a light snack. Another way of preparing snacks based on extruded moist dough is baking (Onwulata et al. 2001; Avebe 2021).

Blanching or par-boiling for a few minutes at temperatures varying from 75 to 100°C yields tubers or parts (slices, dices, strips, French fries) that are vacuum packed and chilled (Gormly and Walshe 1999), canned and pasteurized (Singh and Rattan 2014) or par-fried upon dewatering and frozen (Pedreschi 2012).

Frying in oil at temperatures between 150 and 180°C until some water has evaporated and the surface has a light crust yields par-fried French fries (Pedreschi 2012) that subsequently are packed, frozen or chilled. Frying thin slices until all water has evaporated yields chips, when prepared from thin slices of dough they form stackable chips (Spoonuniversity 2021).

Baking tubers and parts is in hot air of over 150° only with no water or oil added. Whole tubers upon baking yield (Decker and Ferruzzi 2013) baked or Jacket Potato or, with many incisions, hasselback potato. Baking thin slices at high temperature until al water is evaporated produces low fat chips (Tuta and Palazoğlu 2017). Stackable chips, (cookies, Pringles®) are made of potato dough with some corn starch added, rolled to a thin sheet and from which chips shapes are punched and baked (if not fried), (Spoonuniversity 2021).

Modification of potato starches

Non-food uses of potato starch include adhesives for wall paper and paper bags and for sizing and finishing of textile. For application of derivatives of potato starch in food as an ingredient of an ingredient several methods exist to modify the native starch (Sharma 2012). Physical modification that involves high temperatures, pressures or sounds; chemical modification where the native starch is subjected to reactants and genetic modification whereby the plant's genome is altered to produce a particular type of starch (Table 3.3A3).

Gelatinization of starch (Kadam et al. 2015) by adding water and heating is the same process as cooking raw tubers before extraction of starch. Starch becomes soluble when heated with moisture (gelatinizes) because of loss of its crystalline structure. When consumed before cooling down and given time to retrograde its digestion properties have not altered. With retrogradation (Wang et al. 2016) however, part of the digestible gelatinized starch recrystallizes, resists digestion: resistant starch. The industry uses such starch among others as coating of drugs. Pre-gelatinization consist of a gelatinization step (heating after adding water), whereupon the water is removed again. This process is not unlike preparing flakes from intact tuber parts. The resulting powder is soluble in cold water.

Two processes exist that stabilizes the starch and increases future temperatures at which the starch gelatinizes, and thereby it increases the viscosity of the result. One is withholding adequate moisture at above gelatinizing temperatures (HTM) and the other one (annealing: Hoover et al. 1994) withholding sufficiently high temperatures at above gelatinizing moisture content. Subjecting native starch to gelatinizing temperatures (between 70 and 100°C) at low moisture conditions (25% rather than 80% in raw tubers) is a hydro-thermal modification (HTM: Vermeylen et al, 2006,). Annealing (Muhrbecka 1996) takes place at a moisture content of above 50% sufficient for gelatinating but at around 50°C too low for effective gelatinating to take place. HTM and annealing products find their way in food ingredients such as baking powder (Singh et al. 2016). Preparing food ingredients from native potato starch through mechanical processes, ultra-high pressure (Kim et al. 201) and ultrasound (UHP, US) makes for more convenient gelatinization, faster and at lower temperatures.

Dextrin is produced from starch by heating (pyroconversion) facilitated by first acidifying it (BeMiller and Whistler, 2009). It has many non-food applications and is used as a batter ingredient as it produces crispier products when deep frying. Table 3.3A3. also shows several chemical modification process such as hydrolysis with an acid (Absar et al. 2009) whereby long chains are broken down to smaller ones to make native starch suitable as ingredient in the baking industry. Reducing the size of the starch chains is also achieved through oxidation with an agent that delivers oxygen such as peroxide. The resulting bleached starch is employed as an emulsifier to make batter and coatings. Etherification produces a starch that easily dissolves in cold water to make soup or desserts and esterification changes potato starch such that it is comparable with wheat flour and can partly replace it for breadmaking and other applications. With crosslinking the already long polymer chain of potato starch become heavier still because the cross-binding agent links chains of different starch molecules that resist high temperatures.

Table 3.3A3. Physical, chemical and genetic modification aimed at increasing the suitability of potato starch for multi-purposes After Singh et al. (2016)

Treatment	Treatment (starch subjected to)	Properties of resulting modified starch	Applications in food
Physical modification			
Gelatinization	High moisture, high temperature	Water uptake possible De-crystallization	Rendering starch digestible for humans
Pre-gelatinization	Cooking, drying, grinding	Cold water soluble	Food processing, thickening agent
Retrogradation	Cooling after gelatinization	Partial recrystallization	Resistant starch (e.g. drug coating)
HTM (hydro-thermal-modification)	Low moisture (25%) at above Gelatinization temperature	Increased gelatinization temperature and viscosity	Food processing (e.g. baking powder)
Annealing	High moisture (50%), below gelatinization temperature	More thermostable, gelatinization only at increased temperature	Food industry
UHP. US	Ultra-high pressure , ultrasound	Distortion of crystals, facilitates gelatinization	Food industry
Pyroconversion (acid pyrolysis)	Heating (after hydro-chloric acidification)	Dextrin, shorter chains than starch	Enhances crispiness, used in batter
Chemical modification			
Hydrolysis	Acid or enzymes	Reduced polymer size	Baking industry
Oxidation/ bleaching	For instance peroxide or hypochlorite	Reduced polymer size Bleached starch E1403	Emulsifier (in e.g. batter), coating of products
Etherification	Propylene oxide	Easily soluble starch	Instant starch (soup, dessert)
Esterification	Acetate, phosphate	Esterified potato starch	Partial replacement wheat flour
Cross linking	Phosphoryl chloride or other crossbinding agent links various starch chains	Cross linked starch, resists high and low temperatures better than native starch	Canned food, batter (crispiness)
Genetic modification			
Gene silencing	Antisense downregulation	E.g. amylose free 'waxy' potato (amylopectin potato)	Clear sticky paste use in food industry

Genetic modification does not modify the starch in a factory, but in the potato plant. The production of amylose is downregulated through antisense in such genetically modified plants, yielding amylose free waxy amylopectin tubers (Hameed et al. 2018) that has a specific niche in the food industry because of its stickiness.

Functionality of modified starch, flakes, flour, granulates and protein

Dehydrated potato products and modified potato starch fulfill a range of functions wanted by snack manufacturers, the food industry, bakeries, institutions including among others hospitals and outlets such as restaurants (Table 3.3A4; after Potato USA 2021b,c).

Ground meat in balls and burgers benefits from potato products as they act as a binder to hold the meat particles together and as an extender so more finished product is made with the same amount of meat. Adding potato to wheat flour increases the yield of flour as potato absorbs more water. Flakes and granules alter the preparation properties of fried products. Adding them to batter before frying produces a crispier crust than wheat flour, when adding to liquids such as soups, broths and sauces they are also more effective than wheat flour and are less prone to forming lumps. Role in beautifying is evident when a potato mash decorates a casserole before baking and also the enhanced darker color of baked food is a visual aspect. Dehydrated potato products also influence the taste and mouth feel of food where a potato taste is required, where shelf life of bread is extended and cakes acquire a softer bite. Where a food stuff solely consists of potato ingredients it is formulated as gluten-free fit for coeliac patients. Mash from powder, flakes rather than flour causes less lumps and as such is a nutriment that according to the information on the package also contains an emulsifier (mono- and di-glycerides), an acidulant (natrium citrate) and an anti-oxidant (sulfite).

Table 3.3A4. Functionality of potato derived food ingredients. https://www.potatogoodness.com/wp-content/uploads/2019/08/Brochure-Dehy.pdf

	Use (societal)	**Snack**	**Industry**	**Bakeries**	**Institutions**	**Outlets**
Binding	Free starch and flour hold meat together in balls and burgers		x		x	x
Extending	Flour, flakes increase the volume of minced meat so less is needed					
Yielding	Dehydrates absorb more water than wheat flour so increase yields			x	x	x
Breading	Flakes yield more crispy texture at frying than wheat products		x		x	x
Thickening	Flakes and granules thicken sauces and soups without lumps		x		x	x
Unvarying	Flakes and granules as dough to make uniformly shaped chips	x	x		x	x
Decorating	Mash pressed through pastry tube to decorate casseroles					x
Coloring	Dried potato product enhance darker color at baking		x	x	x	x
Enhancing	Flakes and granules in snacks enhance potato taste in products	x	x	x	x	x
Humidifying	Dehydrated potato in dough moisturize so reduces staling of bread			x		
Texturing	Flakes in cakes provides more moist texture, provide softer bite	x	x	x	x	x
Formulating	Flakes, granules and flour replacing wheat make gluten-free food	x	x	x	x	x

Nielsen (2019) summarizes that modified starches are binders in snack coatings and noodles, they replace fat in sausages, also in French fries sauce where they act as a binder and give it a creamy, smooth texture. They have similar roles in creme fraiche, replacing animal derived products including vegetarian “cheese” and “meat’-balls. Potato starch products derived from waxy potatoes consisting of over 99% amylopectin, according to the producer (Avebe 2021b) achieves the same or better results with a smaller amount of ingredient. In nonfood modified potato starches are present in building material such as in tile adhesive to avoid gliding of the tile, in gypsum as a thickener and for making it more malleable, in yarn spinning to avoid breaking of the thread, in adhesives including paper adhesive tape and glue sticks, card board tubes such as toilet rolls, paper bags and layers of laminate. Potato starch based polymers of anionic and cationic polymers act as a flocculation agent in water purification facilities.

Commercially food grade potato protein is isolated from fruit water (Table 3.3A1) containing native protein and purified through ion exchange bed or membrane adsorption chromatography (Schoenbeck et al. 2013) and dried. Different protein fractions have different functionalities such as no flocculation at low pH in sour sauces and texture requirements of the finished product. It is gluten-free, halal, cosher, vegan and is a replacement of egg and whey protein (Avebe-protein 2021).

Quantification of the processes domain

The processes, products and their use shown in Tables 3.3A1-4 are summarized in the heatmap in Table 3.3B with as superclass the products resulting from the basic principle processes and as classes,

Table 3.3B. Heatmap of 20 classes of processes and their 13 technology related attributes of their products

Much Many High	a	Cumulative energy need for processing	Little Few Low
	b	Temperature of process	
	c	Cumulative water need for processing (after washing)	
	d	Oil use in the factory	
	e	Specificity and price of raw	
	f	Dry matter concentration of product	
	g	Use of product by the non-potato food industry	
	h	Maintenance of original structure and appearance of product	
	i	Recovery from raw (few side flows, wastes)	
	j	Number of operations by user to be able to use	
	k	Advantage large scale factory (low cottage industry potential)	
	l	Size of package of product	
	m	Need of cold chain of product	
	n	Number of factory operations	

Superclass of process	Class of process (product)		a	b	c	d	e	f	g	h	i	j	k	l	m	n	Av.
Dehydration	Cold-wet extraction (starch)	1															3.2
	Cold-drying (discs)	2															2.1
	Freeze drying (cuts)	3															2.9
	Hot drum drying (flour)	4															3.1
Conversion	Modifying (starches)	5															3.7
	Forming (fried shapes)	6															3.1
	Extrusion, baking (snacks)	7															2.8
	Expanding pellets (snacks)	8															2.7
	Fermenting (beer)	9															1.7
	Distilling (vodka)	10															1.9
Blanching	Par-boiling (French fries)	11															2.9
	Chilling (cuts)	12															3.2
	Canning (baby tubers)	13															3.1
Oil deep frying	Dry (Chips)	14															3.2
	Dry (Stackable chips)	15															3.1
	Dry (Pellets expanded)	16															3.0
	Moist (French fries (par fried)	17															3.5
Baking	Whole tuber (Jacket potato)	18															2.9
	Dough (Baked chips)	19															3.0
	Dough (stackable cookies, chips)	20															2.5
		Average	3.8	3.3	2.8	2.4	2.7	3.7	1.7	2.5	2.9	2.7	3.8	2.7	2.1	3.4	2.9

instances thereof. The least energy from fossil sources needed is dehydration by wind and sun in the open, none. The energy need of other processes are closely related to the resulting dry matter concentration as it costs energy to evaporate water from tuber parts, the longer exposed to the higher the temperature. As benchmark par-boiling of French fries was chosen which takes place at boiling temperature for a few minutes after which the tuber parts are dried and fried. Similarly par-boiling and baking is a matter of just heating and subsequent chilling or freezing. Canning increases the energy requirement, as making cans represent energy as well (Drew and Rhee 1980). French fries and formed products still contain a considerable amount of water, around 50% which puts them in the same league as chilled and canned products. Drying and frying to very low water concentrations in powders and snacks involve most energy. When taking the energy embedded in the production of oil present in snacks, it would need another darker red color. The more energy spent in the factory on making a product, usually the less energy it takes to prepare it in the kitchen. Snacks are ready to eat without spending any energy on them, boiled in the factory only need heating in the kitchen (chilled, canned) but reconstitution needs more time at high temperatures, only frying or baking French fries and formed products at over 170°C use more energy. Once washed and cut, only washing starch involves considerable amounts of water, boiling, blanching and canning some, but all other processes hardly or not at all. In the kitchen dehydrated products need most water to rehydrate and cook, chilled products only water that surrounds them for boiling (or nothing when fried, baked or casseroled). Some oil or fat is used in making formed products in a factory but more per unit when producing par-fried French fries or formed products such as hash browns, but none on par-boiled (blanched, canned) products. Baked snacks contain less fat than fried ones. Reconstitution of dehydrated products and cooking does not involve use of oil or fat but unless made into casseroled or deep-fried dishes. When reconstitution with water of dried products and heating them is taken as a standard, consuming snacks is much more convenient, preparing (side) dishes from chilled tuber parts is somewhat more cumbersome and deep frying takes more time and equipment to heating the oil and fry to just the right color.

The raw material used is subjected to a varying array of requirements (Chapter 2), the more (for chips) the more expensive, raw to produce starch is the cheapest. Starch production also has a high proportion of losses, side flows with low value such as feed. In a French fries factory almost all material is recovered and made into flakes when not suitable for the main finished product. A few of the attribute concern the user, such as the size of the package, the opportunities for multiple purposes in the kitchen and the need for a cold chain.

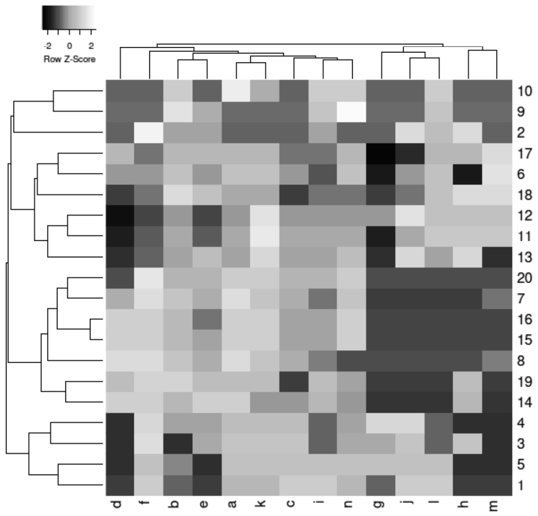
Table 3.3B displays the heatmap of the classes and the degree to which the attributes apply. Of all the products the alcoholic drinks cumulate the fewest scores with beer 1.7 on average only and vodka 1.9, 0.2 more because of the high temperature of the distillation process. Also the cold air dried discs in a cottage industrial setting accumulates a low average score of 2.1, with only a high score for its dry matter concentration. Modified starches reach the highest average with only low scores for oil use, costs of raw, keeping the original structure and the need for refrigeration of the produce. The averages of all other products do not diverge much from 3.0. Across the range of products use of them as an intermediate accumulates fewest scores 1.7 on average only. This because few products (the starches, flour and some dry products find their way to the food industry for sauces, soups, bread, pastry and frozen dishes. A cold chain, freezing and cooling is only needed for the frozen and chilled products so this attribute also accumulates relatively few points

The highest average, 3.8 applies to three attributes, energy need, dry matter concentration and advantage of large scale. Almost all processes, except drying and fermenting in the cottage industry require energy. The required energy is more or less equivalent to the resulting dry matter concentrations as evaporating water at any temperature is at the cost of energy. Most products except the drinks that have a lower concentration then the fresh tuber, canned, blanched and baked whole tubers that have concentrations similar to the raw material about 22 %, the frozen products (French fries and formed have around 50 % dry matter and the dry products (snacks and powders) less than 15%.

Clustering within the processing domain

The dendrogram in Table 3.2C shows four distinct clusters of products. The top three are the cottage industry products dried slices, beer and vodka. The cluster just below mainly contains water holding

Table 3.2C. Dendrogram of classes (1-20, Table 3.2B) and their attributes (a-m, Table 3.2B)



products and the one thereunder dry products, including snacks. The lowest cluster of the four products that did not experience a high temperature and therefore contain ungelatinized starch that needs to be reconstituted and heated before consumption. The closest twins are stackable chips and expanded snacks but also parboiled French fries and chilled cuts have much in common baked extrusion and baked cookies, native and modified starches and beer and vodka.

The clustering of the attributes is less distinct but a few obvious twins appear. Few specs of raw are associated with its low price, the more energy is needed to make a product the greater the advantage of larger scale processing. Products sold in larger packages have more applications: snacks are sold in 50 - 200 g bags but flour and chilled tuber pieces in 500 – 2000 g packages. A twin at some distance is the need for a cold chain for chilled tubers, frozen baked tubers, par fried and par boiled French fries and the still recognizable tuber structure. Chips and canned tubers also retain much of the tuber structure but are stored at ambient temperatures so are at a large distance from the cold products.

The domain of factory operations

Formulation of the operations domain

The domain is delimited by tubers delivered by lorry and tipped into the water at one end and entering the (cold) store of the factory as packed finished product ready to be delivered to the client at the other end of the domain. Except destoning and washing not all finished products undergo all possible operations and processes tubers or parts thereof could be subjected to. Manufacturing native starch involves relatively few different operations at ambient temperatures whereas making frozen French fries requires many steps at ambient, blanching, deep-frying and deep-freezing temperatures. The main means of moving tubers and tuber parts from one operation to the other is by conveyor belts but also Archimedes screws, spiral drums and pipes are vehicles employed. Often streams of material are separated by sieving, centrifuging, gravity or (optical) sorting where material not becoming the main finished product undergoes processes aimed at retaining as much value as possible. Slivers not fit for French fries or chips are blanched and drum dried into flakes for instance.

Condensation of the operations domain

The operations described here are summarized in Table 3.4A1. Removal of unsuitable particles, stones, clay caps, clods, (Potato Business 2021a) stem parts, tubers with too low dry matter is through water treatments (Kiremko 2021) and too small or too large tubers are graded. Unsuitable half products, peeled and fried fries and chips are sorted by eye or camera devices (Hassankhani and Navid 2012) and removed mechanically or by hand. Some products are sorted for various uses such as lengths of cuts and slivers for flakes manufacturing (Novus 2021)

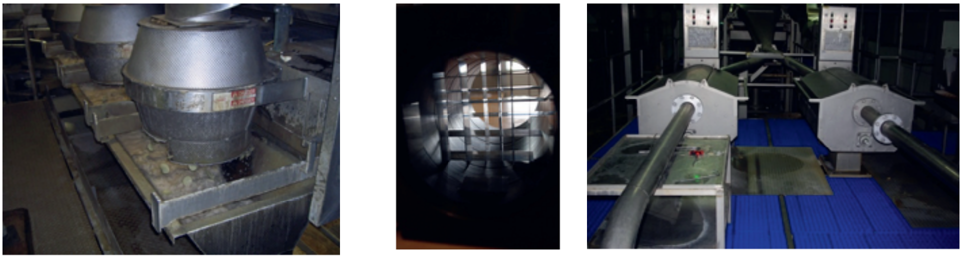
For products that need peeling this is done by knife, steam or abrasion but some products have peeled and skin-on versions (wedges, French fries, chips). In peeling a balance is sought between desired depth to remove all skin including that of the eyes and avoidance of losses (Pelletier et al. 1964).

Starch processing has a sequence of particular processes including grating, sieving of the pulp, washing and refining of the starch, concentrating and flash drying to yield native starch ready for modification (Ratnayake and Jackson 2003).

Disruption of the cell structure before cutting reduces resistance for cutting with water knifes which saves energy and reduces losses through shear and breaking. Pre-heating in hot water is one method (Agblor and Scanlon 2000), subjecting tubers to a pulse electric field is another method widely applied in the processing industry (Fauster et al. 2018; Fauster et al. 2021).

Reducing tubers to smaller parts is through subjecting them to rasps, grates, water jets, knifes in a block or placed in the wall of a drum (slicer): shredding, chopping, dicing, ricing (Potato Business 2021b). These operations result in pulp, halves, quarters, chips, slices and shreds.

Drying is done on a range of tuber parts (whole, slices, cubes, mash) in a range of temperatures (freezing, ambient, hot, superheated) in a matter of days (Chuño, sun and wind dried slices), minutes (drum drying of flakes and removing blanching water from slices and cuts) or seconds (flash drying of starch; Wang et al., 2010; Boutelba et al. 2018).



Cutting tubers for chips and French fries

Table 3.4A1. Description of all operations, depending on finished product, tubers are subjected to a varying number

Operation at ambient temperatures	Operation at elevated temperatures

Operation		Description
Destoning		Delivery of tubers in a washing basin, stones and clods sink to the bottom from where they are removed while tubers move vertically. In cyclone destoners water is pumped upward in vertical screw destoners to siphon water that takes tubers with it and leaves heavier material behind.
Soaking and pre-washing		Removal of adhering soil and clay caps by rinsing the tubers in water moved by a spiral drum or an Archimedes screw
Brine separating		Destoned washed tubers contain light elements such as plant parts and low dry matter tubers. Passing a brine bath of 6% NaCl which is equivalent to a specific gravity (SG) of 1.06 removes the floaters (which have an SG below 1.07 and contain less than 18% dry matter)
Grading		Tubers pass a grid for proper sizing. For chipping 30 – 50 mm and for French fries cuts 45-90 mm size grades are desired.
Peeling	Steam	Perforated container with tubers subjected to steam of 200°C at 18 bar for 8 seconds, upon withdrawing pressure, the skin pops off.
	Brushing	Removal of the remaining steam peels from the tubers with rotating brushes
	Abrasive	Tubers with running water placed in carborundum lined rotating drum or a drum with flint crystals loose their skin which is washed away.
	Cutting	Skin removal with a knife by hand (cottage industry)
	Trimming (cottage)	Removal with a knife by hand of undesired surface spots after mechanical peeling (cottage industry)
	Aggressive	Obsolete polluting techniques employed lye, brine, oil, flames
After-washing		Steam peeled and subsequently brushed tubers are washed to remove all remnants
Sorting		Optical technique to remove blemished peeled potatoes (with defects)
Pre-heating		Disrupting cells of intact tubers for easier cutting and less shear: exposure to warm 55°C water for 40 minutes. Pulse electric field exposure is applied for the same purpose
Grating		Grating tubers into fine particles for starch extraction in (starch factories, ambient temperatures operation)
Washing starch		Washing the starch granules out of the cells in starch factories
Sieving pulp		Separating pulp from starch and juice wit extraction sieves in starch factories
Concentrating starch		With hydro-cyclones starch is concentrated in crude starch milk
Refining starch		Washing of the crude starch milk to remove juice
Shredding		Cutting elongated shreds (julienne) used in e.g. hash browns
Cutting	Halving, quartering	Oversized tubers are cut in halves or quarters to arrive at dimensions suitable for handling by the equipment and for specific end products

	Operation at ambient temperatures	Operation at elevated temperatures
Operation		**Description**
	Knife block	Water and tubers are piped at 40⁺ km/hour through a knife block producing French fries cuts and wedges of various sizes as directed by the maze of the knifes
	Water jet	A water jet cuts tubers in slices
	Mechanical	Varying knife shapes result in three dimensional shapes dices, slices, ribbed, crinkled, waved, waffle shaped
	Slicer	Tubers are spinning in water with a stationary knife to produce slices of varying thickness, 1.5 mm thin for chips, 5 mm thick for chilled products
Sorting	General	Removal of off type tuber (parts) by eye or with camera aided equipment. Off types are removed manually in small operations or mechanically (shoved, pricked, blown) in large ones
	Peeled	Removal of damaged or discolored (black, green) tubers
	Products	(Half) finished products with defects, sugar ends for instance, are removed
	Sliver	Sliver remover takes away slivers and nubbins unfit for blanching and frying
	Length	A tuber produces French fries of different lengths, they are sorted in length classes
Drying	Ambient	Cottage industry in tropical countries: drying slices of raw tuber by exposure to sun and wind. Upon reconstitution with water the slices still need to be cooked
	Belt	Blanched tuber parts are dried by hot air (flow of 70°C) over a belt before par-frying the parts in oil
	Hot air	Super-heated steam (well above 100°C) on raw potato slices, cooks and dries them
	Flash	Spread julienned tuber parts subjected to a stream of hot air cooks and dries them and avoid conglomeration.
	Drum	Potato mash applied to a drum with a screw conveyer dried with steam is scraped off yielding flakes, flour when ground
	Retro-gradation	First boiling or blanching followed by cooling slowly at 10°C retrogrades gelatinized starch that takes up water leading to stronger fritters in hash browns
	Freeze	Chuño is made by spreading tubers at over 4000 m above sea level where they freeze at night and become hot during the day thereby desiccating
	Vacuum, Microwave	Freeze drying under vacuum and/or with microwave application speeds up the sublimation process
	Dewatering	In a starch plant, the starch suspension is dewatered, first by vacuum filtering followed by spreading the result in hot air of 160°C for 2 seconds, just short enough to avoid gelatinization
Grinding		Ground flakes become flour
Blanching	General	Heating tuber (parts) for a limited period (2 minutes) at a limited temperature (90°C) and subsequently cooled to stop enzyme activity or for 5 minutes at 75° to cook(gelatinate). The process also removes excess reducing sugars and starch after cutting and the intermediate product is chilled and shelved and/or immediately finished in next stages: frying baking, grinding and drum drying, cooking
	Belt	Conveyor belt with chips slices sprinkled with hot water
	Steam	Steam injected in screw driven tubers, readying them for mashing
	Screw	Hot water filled screw packed with French fries
Dipping	SAPP	After blanching the product is dipped in a 1.5% SAPP (disodium acid pyrophospate) solution to prevent after cooking darkening (ACD)
	Dextrose	The SAPP solution can be provided with a 1% dextrose (a reducing sugar, oleoresin of turmeric) to give fries a golden color at frying
	Batter coating	Batter is a watery slurry of starches of potato, cassava, corn, rice and dextrins. When fried for the second time in the kitchen the coating enhances crispiness and flavor
Shredding		Cutting cooked tubers into thin several cm long strips of 2 mm^2
Chopping		Cutting cooked tubers before freezing arbitrarily into parts less than 20 mm
Dicing		Cutting cooked tubers before freezing into 1 cm cubes
Ricing		Pressing cooked tubers before forming through a ricer (sheet with small holes)

Operation at ambient temperatures	Operation at elevated temperatures

Operation		Description
Forming		Shaping potato dough, mash, shreds and riced blanched tuber into forms (croquettes, balls) before coating and frying
Par-frying		Frying tuber parts at near cooking temperatures for less time than required for completing cooking (deep frying). The latter takes place when preparing the meal ingredient in the kitchen by adding frozen or chilled to heated oil
Frying	French fries	Mostly continuous over belt with steam cover over oil to prevent oxidation
	Battered fries	Battered fries first pass a hot oil bath to settle the batter than a second cooler oil bath to cook the product to the desired degree
	Specialties	Formed products are delicate and cannot be tossed like French fries so require special care to assure an even color when led through the hot oil
	Chips	The chips are paddled when moving through the frying oil to avoid clumping and assure contact of the whole surface with the hot oil
	Pellets	Pellets expand manifold within some 10 seconds so need to be kept in the oil by a submerged conveyer belt
	Kettle	Frying unwashed, uncooked and thicker chips than in the continuous process, in batches in an oil bath (kettle)
Oil removal		After (par) frying excess oil is removed by vibrating the belt on which they leave the oil bath
Cooling		After frying or blanching before freezing or chilling the product is cooled in a tunnel with an outside air stream
Freezing		Upon cooling with ambient air the chilled or par-fried product is frozen to -18°C. To avoid clumping together of individual parts, they are 'individually quick frozen' (IQF) by cold air blown under the conveyor where they are
Chilling		Upon cooling with ambient air the chilled or par fried product is chilled to 4°C
Extrusion (pelleting)		Slightly moisturized flour is pressed through a mold and the string cut at regular intervals. The process yields pellets of exactly the same shape and size, ready to be fried and expand.
Expansion		Exposing pellets to temperatures well above boiling, so deep frying or air frying expands them as the inside water forms steam which takes more space
Flavoring		Adding flavor, seasoning , to chips and expanded products through a dispenser and tossing the product gently in a drum
Packaging		Wrapping products, dry ones in paper and carton packs, moisture containing ones chilled or frozen in plastic enrobed bags, boxes and trays.
Pasteurizing/sterilization		Heating the vacuum packed product to (near) boiling temperatures so it can be stored at 4°C for a few months. When steam heated at above 100°C, the shelf life is longer still
Controlled atmosphere		Loosely stacked products where ambient air is replaced with air devoid of oxygen (nitrogen usually)
Anti-oxidant		Par fried or blanched products not frozen but chilled are supplied with an anti-oxidant to prolong their shelf life. Ascorbic acid is an example

Heating of tubers occurs without water in the oven (baking), with water to near boiling temperature for a near fully cooking duration (blanching), in boiling water or steam (cooking) or in hot oil (frying). All these processes suffice to gelatinize the starch and renders it digestible for humans (van Loon 2005).

Depending on the specification of the finished product, a range of additives applied in different operations is available. For fried products consisting of tuber parts (not formed), the parts are dipped in a solution of SAPP (sodium acid pyrophosphate) to avoid after cooking darkening (Calder et al. 2012); added dextrose in the SAPP solution enhances the golden color (Van Loon 2012) and a batter of various

Frying chips, croquettes and patties

starches makes the fries crispier and keeps them warmer for a longer period which is an advantage in quick service restaurants. An NDTV-Food (2021) website mentions as ingredients in McDonalds French fries: *"Potatoes, vegetable oil (canola oil, soybean oil, hydrogenated soybean oil with tertiary butylhydroquinone (anti-oxidant) and dimethylpolysiloxane (anti foaming)), natural beef flavor (wheat and milk derivatives), citric acid (preservative), dextrose, sodium acid pyrophosphate, salt"* Formed products are seasoned and hash browns often contain onion. Snacks, chips and expanded snacks have a wide range of flavors beside the original sweet bell pepper (paprika) and salt&vinegar added.

Temperature, other than ambient related processes to make the finished products, in increasing order are freezing in freeze drying (-50-80°C), cool air in retrograding (10°C), hot water in blanching (75°C), boiling water in cooking (100°C), superheated steam (Sotome and Takenaka 2009) in cooking (130°C), hot oil for par-frying (155°C), hot oil for deep frying (175°C) and hot air in oven baking (190°C). Temperature related interventions regarding the finished product are aimed at storage prolongation (De Kock et al. 1994) in order of increasing temperature: freezing (-18°C), chilling (3°C), pasteurizing (90°C) and sterilizing (125°C, steam temperature).

Finished consumer products need packing that suits their protection from the environment, stackability and longevity. Powder (flour, granules) and flakes are packed in paper bags and cartons in ambient air, without cooling but protected from moisture. Formed frozen products are loosely packed in plastic (polyethene) bags without risk of deforming (Emmerson 2021)., when displayed chilled, so at risk of compacting, they are placed in stackable aluminum or plastic trays (casseroles). Blanched or par-fried and chilled French fries and slices are not at risk of deformation and are either loosely stacked in controlled atmosphere or vacuum packed and pasteurized or sterilized.

The various groups of manufactured dried intact tuber pieces, dehydrated powders and pellets, fried, blanched and baked, totaling 22 products and the 66 processes yield 1452 grid cells in Table 3.3A2. Of all processes 24 require water such washing, peeling, blanching and dipping, the other 42 process are 'dry' treatments. Operations where tubers, cuts or dough are heated number eighteen and include steam peeling, pre-heating, par-boiling and frying, drum drying and expansion of pellets by frying or baking. The other ones take place at ambient temperature or below such as chilling, freezing and freeze-drying. The physical operations such as heating, cooling and drying number twenty six, the other 40 concern mechanical operations such as grading, cutting and flavoring. Some generic operations, conveying, monitoring, weighing to mention a few are not included in the list as they apply to all products. Packaging does not apply to all products, native starch for instance, is not packed usually, but transported in bulk to its users, manufacturers in the food and non-food industry.

Drying tubers or pieces without grinding involves the fewest number of operations, six on average followed by dehydration whereby the original tuber structure is lost with about nine

Blanching, dipping, packing, freezing

operations. Heating through baking and blanching leads to more opportunities to create intricate products with about thirteen operations. The greatest opportunities to create complex products are linked to frying with on average over twenty-two operations.

The fewest processes tubers go through is making chuño, washing and freeze drying although a third one, not listed in Table 3.2A2 is part of making chuño, namely crushing the tubers by foot to remove the skin and squeeze out the juice. Modern freeze drying requires seven steps including washing peeling and draw a vacuum. The highest number of processes, thirty one, is needed to make mash based fried and frozen products such as croquettes. To make battered frozen French fries, tubers undergo thirty processes. As is shown in Table 3.4A2, the more operations products are subjected to the higher the added value with the exception of chips with 21 operations derives its high value from the degree of dehydration (fully at the cost of much energy) and, the costly ingredient (oil) and precious way of packing (loosely packed with ample controlled atmosphere in aluminum coated polyethene wrapping). The same holds for expanded snacks that have the same number of operations that apply to pellets (ten) but added frying, oil removal, flavoring and packing under controlled atmosphere.

Table 3.4A2. Operations per product (Italics Skin-on products are not peeled x)

		Category																					
		Dried tuber					**Dehydrate**				**Fried**					**Blanched**				**Baked**			
Process		Chuño	Freeze dried uncooked	Freeze dried cooked	Cold air dried	Hot air dried	Starch (cold extraction)	Flakes	Flour/granulate	Pellets	French fries	Chips	Extruded and expanded	Mashed and formed	Shredded and formed	Pre-cooked tuber/parts	Casseroled	IQF dices and shreds	Canned	Jacket potato/ halve	Casseroled	Gratinated	Rissoled
Destoning			x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Soaking and pre-washing		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Brine separating										x	x		x										
Grading			x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Peeling	Steam			x				x	x	x	*x*	x	x	x	x	x	x	x	x		x	x	x
	Brushing			x																			
	Abrasive											*x*											
	Cutting				x																		
	Trimming				x																		
After washing				x				x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
Sorting				x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Process		Category																					
		Dried tuber					Dehydrate				Fried					Blanched				Baked			
		Chuño	Freeze dried uncooked	Freeze dried cooked	Cold air dried	Hot air dried	Starch (cold extraction)	Flakes	Flour/granulate	Pellets	French fries	Chips	Extruded and expanded	Mashed and formed	Shredded and formed	Pre-cooked tuber/parts	Casseroled	IQF dices and shreds	Canned	Jacket potato/ halve	Casseroled	Gratinated	Rissoled
Pre-heating											x	x											
Grating, rasping							x																
Washing starch							x																
Sieving pulp							x																
Concentrating starch							x																
Refining starch							x																
Shredding															x			x					
Cutting	Knife block										x												
	Halving										x												x
	Water jet										x												
	Mechanical											x					x				x	x	
	Slicer											x					x				x	x	
Sorting	Peeled															x	x	x	x				
	Products										x	x											
	Sliver										x	x											
	Length										x												
Drying	Ambient										x	x											
	Belt										x	x											
	Hot air					x		x	x														
	Flash						x																
	Drum							x	x														
	Retrograde														x								
	Freeze	x	x	x																			
	Vacuum		x																				
	Dewatering						x																
Grinding									x														
Blanch-ing	Belt											x											
	Steam														x	x	x	x					
	Screw										x					x	x						
	SAPP										x												
Dipping	Dextrose										x												
	Battering										x												
Shredding															x			x					
Chopping																		x					
Dicing																		x					
Ricing														x									
Forming										x	x		x	x	x								
Par-frying														x									
Frying	Battered																						
	Specialties													x	x								
	Chips										x												
	Pellets												x										
	Kettle										x	x											

	Category																					
	Dried tuber					Dehydrate				Fried					Blanched				Baked			
Process	Chuño	Freeze dried uncooked	Freeze dried cooked	Cold air dried	Hot air dried	Starch (cold extraction)	Flakes	Flour/granulate	Pellets	French fries	Chips	Extruded and expanded	Mashed and formed	Shredded and formed	Pre-cooked tuber/parts	Casseroled	IQF dices and shreds	Canned	Jacket potato/ halve	Casseroled	Gratinated	Rissoled
Oil removal										x	x	x	x	x								
Cooling					x		x			x	x				x	x	x		x	x	x	x
Freezing										x			x	x					x	x	x	x
Chilling										x					x	x	x		x	x	x	
Extrusion (pelleting)									x													
Expansion												x										
Flavoring											x	x										
Packaging		x	x		x		x	x		x	x	x	x	x	x	x	x		x	x	x	x
Anti-oxidant										x					x							
Pasteurizing/sterilization									x						x	x	x	x	x	x	x	x
Controlled atmosphere										x	x						x		x	x	x	x
Sum	2	7	9	5	7	9	8	10	10	30	21	14	31	15	14	15	17	8	9	14	14	12
Average	6.0					9.3				22.2					13.5				12.3			

Quantification of the attributes of the classes of operations

Assigning scores between 1 and 5 according to the degree attributes apply to an operation creates the heatmap as shown in Table 3.4B. The temperature at which the operations take place vary from -80°C for freeze drying to 190°C for baking. Some take place at intermediate products close to the raw material such as peeling, whereas packing is the last one products are subjected to. Some operations among them grinding, completely destroy the structure of the tuber whereas making jacket potato hardly alters it. Operations of varying duration, destoning is immediate upon immersion and air drying slices in the open takes a few days and operations to a varying degree influence the quality, flavoring very much so, and recovery, sorting does, cooling does not. Of the distinction between physical (green), drying is an example and mechanical (red), grading, only two color codes were used. An operation contributes to a specialty such as retrograding upon blanching and shredding, both for making hash browns or not at all, oil removal for example.

Conveyance in factories

The use of energy is negligible in case of separating tubers in a brine bath or high in case of baking, similarly for the use of water is zero in case of drying but relatively high in washing. The heatmap, color scheme from dark green to dark red shown in Table 3.4B, equivalent to values from 1 to 5 produces the dendrogram presented in Table 3.4C.

The highest average value of the attributes (4.1) is assigned to frying specialties such as patties, hash browns and croquettes followed by frying battered French fries (4.0). Relatively simple mechanical operation such as destoning, grading and packing cumulate few points (2 or less).

Table 3.4B. Heatmap of 66 classes of operations and 10 attributes, degree to which they apply

High value			Low value
	a	Temperature of the process	
	b	Stage between raw and finished (high)	
	c	Alters structure of the tuber	
	d	Improves quality	
	e	Affects recovery	
	f	Duration of the process	
	g	Physical (high) Mechanical	
	h	Special or regular product(low)	
	i	Energy use	
	j	Water use	

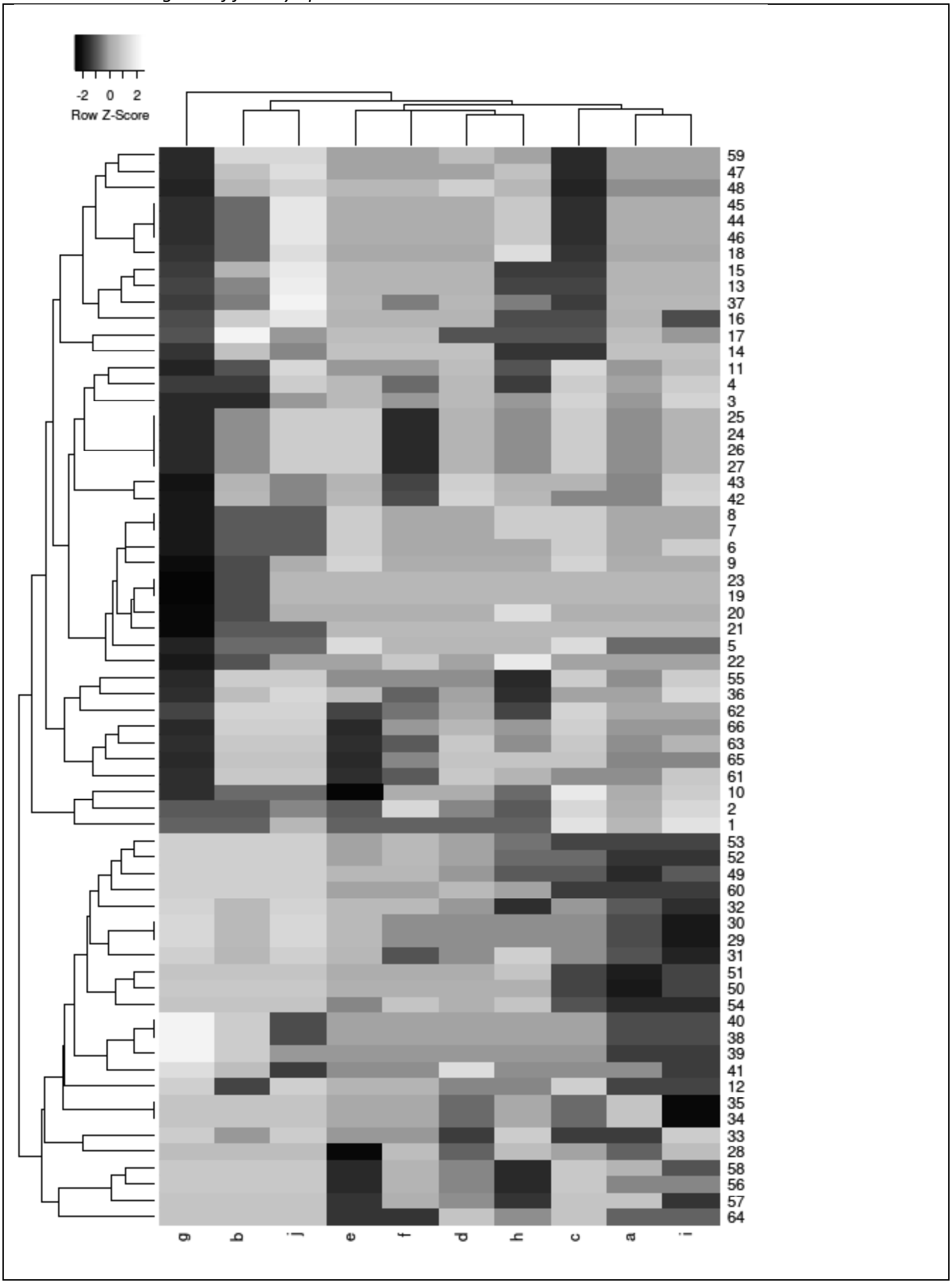
			a	b	c	d	e	f	g	h	i	j	Av.
Destoning		1											1.4
Washing		2											2.0
Brine separating		3											2.4
Grading		4											2.0
Peeling	Steam	5											3.2
	Brushing	6											3.1
	Abrasive	7											3.1
	Cutting	8											3.1
	Trimming	9											2.9
After washing		10											2.4
Sorting		11											2.4
Pre-heating		12											3.1
Grating, rasping		13											2.5
Washing starch		14											2.9
Sieving pulp		15											2.6
Concentrating		16											2.9
Refining starch		17											3.0
Shredding		18											2.9
Cutting	Knife block	19											2.9
	Halving	20											2.8
	Water jet	21											2.8
	Mechanical	22											3.0
	Slicer	23											2.7
Sorting	Peeled	24											2.4
	Products	25											2.4
	Sliver	26											2.4
	Length	27											2.4
Drying	Ambient	28											3.1
	Belt	29											3.5
	Hot air	30											3.5
	Flash	31											3.6
	Drum	32											3.6
	Retrograde	33											3.3

High value		Low value
a	Temperature of the process	
b	Stage between raw and finished (high)	
c	Alters structure of the tuber	
d	Improves quality	
e	Affects recovery	
f	Duration of the process	
g	Physical (high) Mechanical	
h	Special or regular product(low)	
i	Energy use	
j	Water use	

			a	b	c	d	e	f	g	h	i	j	Av.
	Freeze	34											3.5
	Vacuum	35											3.5
	Dewatering	36											2.3
Grinding		37											2.5
Blanc hing	Belt	38											3.6
	Steam	39											3.5
	Screw	40											3.6
	SAPP	41											3.8
Dip-ping	Dextrose	42											3.0
	Batter	43											3.1
Shredding		44											2.8
Chopping		45											2.8
Dicing		46											2.8
Ricing		47											3.0
Forming		48											3.4
Par-frying		49											3.7
Frying	Battered	50											4.0
	Specialties	51											4.1
	Chips	52											3.7
	Pellets	53											3.8
	Kettle	54											4.2
Oil removal		55											2.2
Cooling		56											2.7
Freezing		57											2.6
Chilling		58											2.9
Extrusion		59											3.1
Expansion		60											3.9
Flavoring		61											2.6
Packaging		62											2.1
Anti-oxidant		63											2.4
Pasteurization		64											3.0
Controlled atmosphere		65											2.8
Vacuum packing		66											2.5
		Average	3.3	3.5	3.1	3.4	3.1	3.0	2.5	3.0	3.1	1.8	3.0

The highest average value of an attribute over all the operations is the stage between raw and finished (3,5); apparently most operations take place when the products are (almost) finished such as blanching and frying whereas the numbers of basic operations at the beginning of entering the factory (washing, grading) are fewer. The temperature of the process also has a high average score because many processes involve a higher than ambient temperature. Of all the 66 operations tabled, only few have water involved, hence the low score (1.8) for water use.

Table 3.4C. Dendrogram of factory operations and their attributes



Clustering of factory operations

The dendrogram of the factory operations and their attributes is presented in Table 3.4C and clearly shows two main clusters. One, at the bottom, contains all operations that involve the physical processes heating, cooling and drying, the other one all the mechanical operations. The cluster with physical processes has a few sub-clusters holding identical attributes, those are drum and hot air drying, belt and steam blanching and, freeze and vacuum drying. Processes that resemble each other closely are frying regular and battered French fries, frying chips and pellets and the trio cooling, chilling and freezing and in the same sub-cluster at some distance , pasteurization. Pre-heating to soften tubers to facilitate cutting is closely affiliated with all blanching methods (belt, steam, screw, SAPP dipping).

The 'mechanical' cluster also contains twins such as cutting in French fries size and halving, a triplets shredding, chopping, dicing and a quadruplets sorting of peeled tubers, sorting of slivers not fit as French fries but destined for flakes, sorting of different sizes of cuts and of finished products to be rejected or not. Related are removals of excess oil after frying and water after blanching in one sub-cluster but rather distinct, so are the two squeezing methods ricing and extrusion, the two conservation methods controlled atmosphere and the application of an anti-oxidant and dipping in a solution of dextrose or batter. Similarly peeling and cutting or slicing of tubers are related and, so are the operations where separation of tubers takes place by grading, sorting or brine which are in the same sub-cluster but at a large distance from the optical sorting of intermediate and finished products. The three mechanical peeling methods (abrasive, cutting and trimming) are near identical but at a large distance from the physical method of steam peeling.

The attributes consist of a single one 'physical or mechanical' and of three clusters. They reveal that the closer an operation is to the raw material, the more water is required (washing for instance), shorter operations (grading for example) have a greater impact on recovery than operations that take more time (in case of blanching). Impact on quality largely concerns specialties and higher temperatures evidently are accompanied by a greater use of energy and, at some distance in the same cluster by processes that alter the tuber structure. This results from frying and drying at high temperatures that is often preceded by mashing, shredding and chopping.

Deliberations and conclusions

Potato differs much from the other global major staple foods. This tuber crop is ready to heat and eat, whereas wheat, rice and corn being cereals require milling and in case of wheat and corn additional manufacturing of the flour into food stuffs. Processing of a moist tuber as raw material, that in many cases needs to be dehydrated, is different from starting with flour of wheat as the raw material that needs to be hydrated to become a product. In many potato products, chilled tubers, French fries and chips, the tuber or its parts are still recognizable as such, this, with the exception of rice, is not the case with cereals. These two observations justify the disproportionate interest, especially of the industry, beside the versatility of the crop into many consumer food and snack products available in supermarkets. And its starch after modification and its flakes, flour and granulates as ingredients for the food industry are further grounds. The main properties of these substances are their thickening, binding, texture and taste enhancing abilities.

Research question about products

The about 170 classes of potato products present in a supermarket are divided in subclasses by attributes on heating procedures (frying, boiling, baking), appearance (intact, cut, shredded, mashed, formed), dehydrated (snacks, flakes, flour) and storage temperature (ambient, chilled, frozen). Tables 3.2A1 and 3.2A2 illustrate this condensation process. In the heatmap further condensed to fresh, chilled, fries, formed, dishes, dry products, snacks and baked with attributes that in some cases permit a different appreciation of consumers than of processors. This theoretical transformation illustrated an appreciation of a product from the manufacturer's point of view and of the consumer where both agree regarding desired shelf temperature, fanciness and convenience but where consumers prefer a wide range of products concerning, weights, flavors, shapes at low prices, while processors prefer the opposite with the results found on the shelves as a compromise. Fresh tubers have the lowest price but compared with products offer the least convenience to cooks. Products that provide more convenience involve more processes to manufacture them.

Clustering 'consumer products' groups has convenience as a central theme, 'processor products' are grouped according to costs associated with making them, the more factory operations the higher to costs. These happen to be the products that consumers are willing to buy as they offer most convenience. Further explorations in this domain are possible by refining the kind of user of products , cooks at home, in restaurants, caterings or institutions (theoretical) or to set the supply in a developing market with less products supplied and other demands applying.

Research question about processes

Upon entering a processing plant and having gone through the basic operations including washing, tubers destined for a specific product undergo different operations. These are related to dehydration, conversion, blanching, frying and baking as demonstrated in Tables 3.3A1 and 3.3A2. Manufacturing of starch differs much from that of food stuffs. The former takes place at ambient temperatures upon rasping and involves filtering yielding fiber and, concentration yielding starch to be washed, refined and dried and, fruit water from which denaturalized protein emerges after heating or natural food grade protein upon chromatographical separation. The bulk of the native starch is modified to make it suitable for the non-food and food industry that makes use of the functionality thus created. These condensation efforts are revealed in Tables 3.3A3 and 3.3A4. Unless gelatinized the modified starches still need to be reconstituted and heated to render them suitable for human consumption. Except for drying and fermenting, heating is a process all finished food products have in common. The processes dehydration, conversion, blanching, frying and baking are subdivided by sub-processes that determine the finished products. Dehydration through extraction turns out starch, by freezing dried products, and flakes by drum drying. Examples of conversion are starch modification, forming of mash or dough into shapes to be fried with pellets as a specific group subject to expansion by heating by the snack industry, usually not the potato pellet manufacturer. Heatmapping the products emanating from the processes were supplied technical (temperatures, scale), not social (convenience, preferences) attributes as the latter received attention in Chapter 2. The average score of attributes is high for products that undergo more processes such as dehydration + modification and low for home made and cottage industry fermented potato juice. Clustering distinguishes the gelatinized starch containing from the ones that still need reconstitution and heating. The products heated already, are grouped according to increasing temperatures (blanched, fried, baked) or, another discriminator based on reconstituted powder (starch or flakes) and products with recognizable potato or parts. Extending the heatmapping and clustering by adding social attributes is doable in a reiteration if so desired. These are feasibility in cottage industry, relative importance in developing markets, convenience, number opt operations in kitchens needed upon purchase of the product, to name a few.

Research question about operations

Tubers are subjected to many operations to expose them to the processes they have to go through: dehydration, transformation, and the several means of heating, drying and cooling. Condensation of the classes of operations and allocating them to products that undergo them (Table 3.4A1 and 3.4A2) reveals 66 classes of operations of which the classes of fried products on average undergo 22 against 6 for the classes of dehydrated products. In the heatmap and its dendrogram the operations and their 10 attributes a dichotomy is recognized. One cluster comprises the physical processes and its three sub-clusters on elevating the temperature, lowering it and on dehydration, and one on mechanical operations with sub-clusters on size reduction (grinding, cutting et cetera) and separation (grading, sorting, brine separation). The former ones are associated with high energy use, as the pieces are subjected to par-boiling, drum drying, to frying and the latter ones, aimed at rejection have the greatest impact on recovery of finished products. The approach shown here is limited to a few attributes only and could be extended by the cost of an operation, the cost of machinery, the intricacy, the need to monitor closely, the feasibility in a cottage setting for instance. Of interest too how easily, or not, the processes can be altered such that they make more efficient use of resources, or can be automated or replaced.

packing

Chapter 4.

PRODUCTIVITY
Domains of chains, performances and efficiencies

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Abstract

Potato has strong links between the actors as varieties bred by breeders, crop management of growers and location of processors strongly influence the yield and quality of the finished products. Here the actors (breeders, growers, processors, retailers and users) in the value chain are recognized, and their information and material flows identified. The influence of genotype, environment and crop management and the efficient use of resources during the production of raw material, tubers harvested for processing purposes are delineated. It is shown that climate change affects performance and that consumers, looking for quality and new products are hardly interested in the primary processes. Nor are breeders and processors involved in consumer concerns. Crop performance is dependent on yield and quality (dry matter, sugars, tuber size and desired and undesired constituents). Factory performance relies on recovery, reuse of rejects and avoidance of wastes. Heat maps drawn of classes of productivity and losses and their attributes reveal where gains are to be made on fields, farms and factories to improve efficiencies, reduce the impact on the environment and opportunities for decarbonization.

Inception and research questions

Compared with the cereal staple foods, links between the breeder, seed grower, ware grower, processor and outlets are much stronger with processing potatoes. This because the clonally multiplied crop has a special basic and certified seed program, and variety specific characteristics play a central role in making starch, flour, French fries, baked and chilled products. Information is conveyed from the consumer, through shops, processors, growers and breeders and its magnitude increases with each link passed. Material flows in the opposite direction, breeders seed, basic seed, certified seed, raw material, finished product, packed according to own or shop's brand, pantry, pan or oven. To supply the market raw material needs to be produced and processed with minimal losses. The following domains are distinguished: the supply chain, the performance of farms and factories, and losses at farms and in factories. Defining classes and their attributes in these domains and assessing the degree to which the attributes apply to the different classes is an innovative approach not found in scientific literature.

Research question about imaging the supply chain

Where consumers are mainly interested in convenience, taste and environment friendly production, shops add attractiveness and shelf life, processors add value to raw material, growers add yield through new techniques and breeders add quality traits, resistance, tolerance and recovery promoting traits. The information and material flows in the potato products supply chain need to be identified and their links described: preparation in kitchens, processing in factories and production of tubers on farms. Performance of production such as yield, dry matter, sugar concentration and other quality aspects depend on the variety planted, on the prevailing environment and that as affected by climate change, where grown and the cultivation techniques employed resulting in use efficiencies of resources, among them land, water and energy. Performance of processing, recovery of dry matter but also of its constituents as proportion of finished product of tubers grown depend on losses at harvest, handling, storage and processing. But to what degree?

Research question about performance of farms and factories

The performance of the crop, harvest and pre-harvest, its yield and quality, and the efficiencies to a large extent, are a function of the variety and seed quality planted, the environment where grown and of the management practices of the farmer (Chapter 2). Post-harvest performance, i e. the recovery of finished product are a function of on-farm handling, storage between harvest and delivery to the factory, and on the kind of operations in the processing plant from washing to packing (Chapter 3). To be able to judge the efficiency of field and factory production an analysis of yield is needed: what are the classes of yield components (quality), what are their attributes, among them the effect of climate change, and how much do they vary in exerting an influence on quality?

Research question about resource use in processing

Efficient use of resources not only depends on the quantity of tubers produced and products made but also on losses and wastes on farms, in factories, shops and kitchens. How efficiently are energy and water used in manufacturing? Which classes of losses exist in each link of the supply chain? How are they affected by the environment and management? The subject needs to be discussed in the light of sustainability issues: resource availability (fresh water), emissions (CO_2) and climate change (elevated CO_2, increase in temperature and erratic precipitation patterns). Avoidance of losses are the attributes of the classes of losses and there is a need to identify them and to which degree they apply to the classes.

Research question about impacting the habitat

Beside field production of tubers destined for processing, transport and processing too are associated with withdrawal of resources such as water and habitat for fauna and emissions of deleterious substances, carbon dioxide and nitrogenous compounds. Which operations on farms and in factories are associated with undesired and harmful withdrawal and emissions, to what degree and which measures keep it within bounds?

Research question about losses and wastes.

Not all tubers grown in the field are delivered to the factory and not all tubers received end up as high-value finished products. Losses (not recovered tuber material) and wastes (unused inputs and resources) are incurred on farms and in processing plants. It has not been thoroughly assessed what these losses are and how are they to be avoided with varying degrees of chances of success.

Supply chain domain

Formulation of the chain domain

In a narrow sense the potato sector or potato industry, encompasses all activities carried out by potato breeders, seed potato growers, growers of tubers meant to be used as raw material and by processors buying and processing the tubers. Potato breeders exist in a wide variety. There are individual, single persons breeding companies, and larger ones that annually produce millions of seedlings, as it takes some hundred thousand seedlings of two parent clones to create a variety. The company has shareholders or is owned by a farmers' cooperative (Van Loon 2019) and both types may have farmer breeders, farmers receiving a few thousand seeds or seedlings to assist in selecting a new variety. Here and there potato processing companies have their own breeding division such as the largest starch industry in the Netherlands and the largest potato chips maker in the US. Seed potato production in developed markets in general takes place in three stages by one company but often involving three different firms, 1) the creation of in-vitro plantlets and mini-tubers thereof, 2) production of basic seed in about three field stages and 3) producing certified seed in another three to four field cycles. In developing markets usually the multinational breeding company, in order to assure a regular supply of the favorite variety owns all steps. Local companies in such markets, especially when making chips, depend on what the growers have on offer or pay a higher price for specs meeting lots. Growers of the raw material may have a small area of less than an hectare in developing markets or over a thousand in Idaho. They sell their crop, generally on contract base to the processing company. The processors' procurers (with agronomists in the team who carry out research and development for the company and also give consult to growers) are in close contact with the growers to assist them and monitor yield and quality for factory intelligence. In developing markets processors also, initially, grow their crops on rented land. This corporate farming assures the regular supply but as soon as the grower base has been trained growing own tubers is abandoned. Processors make the products for the outlets retail, institutions and food industry. In this section retail, cooks and consumers are included in the supply chain. Providers of equipment, materials and services for breeders, (seed)growers, and for outlets are not included in the chain as formulated here.

Condensation of the supply chain domain

The value chain of potato-based products is aimed at reinforcing current, and establishing new consumer-product combinations and at an efficient means of communication from consumers to sales and down-chain links, and among links (Kiil et al. 2019). It also serves as a rapid upstream of materials (Olsen and Aschan 2010), i. e. tubers and products (Table 4.1A1.). The cook's desire is ease and time

Table 4.1A1. Flows of information and material among classes of actors in the potato product value chain

Classes of actors	Desire	Flow of information upstream	Flow of information downstream	Flow of material upstream
Eater	Taste, origin	Share with friends	Tell the cook	Left over to waste
Cook	Convenience, ease, safety, health	Performance for peers	Performance	From pantry to stove
Customer	Optimize price quality	Product preference	Consumption pattern	From shop to pantry
Trader	Rapid turn-over of shelf space	Product information Product range	Requirement of products	Product from factory to shelf
Processor	Optimized recovery	Availability of finished products	Need of tubers according to specs	Deliver products to trade
Procurer	Continuous flow of raw to factory	Quantity and quality of lots of raw material	Quantity and specs of raw	Raw material (tubers to be processed) from farm to factory
Agronomist	Assuring growers meet quantity and quality	Provide information on quantity and quality to be expected	Consulting growers on optimal management practices	
Grower	Meeting specifications	Availability and management practices	Demand of seed tubers	
Seed producer	Meeting demand of growers	Seed quality characteristics	Wants new varieties better meeting specs	Seed tubers
Breeder	Resistant, adapted, processing quality	Variety characteristics: resistances, tolerances	Interacting with knowledge institutions	Basic seed tubers

saving and is not necessarily the person buying the products nor consuming the dishes prepared from them, in restaurants for instance. Upstream the cook communicates the quality of the dish with the eaters, the pros and cons with other cooks and downstream the preferences for future products. Trade, shops and supermarkets, are interested in rapidly overturning shelf space informing customers of products' advantages and producers of their requirements. Factories usually make several products such as frozen French fries, formed products and flakes or chips and flakes, so the specs of the raw material vary, and there is a constant need to adapt varieties to changing conditions such as black listed chemicals, growers moving to more marginal lands and governments restricting irrigation water or biocide use. Buyers of tubers from growers, procurers, are the only actors that do not actually own any material, they go between, and convey specs to growers. They work closely with the company's agronomists who act as consultants for the growers with ultimate aim to assure that the raw material meets the specs and inform procurement of the quantity and quality of the current crop in the field, at harvest or in the farmers' stores.

Aligning seed of new and current varieties among breeders, seed producers and growers of tubers to be processed is aimed at assuring the fulfilment of the processors' needs. Where information trickles down from the cook to the breeder, a stream of material goes the opposite direction: breeders deliver basic seed tubers to seed growers who provide growers with seed from which they grow the raw material. Products are handed over from producers to shops, customers and cooks ending up as ingredients or dishes for eaters.

With variety (ADHB 2021) being an important factor (beside environment and crop management) that determines the recovery of finished product from raw, a most intensive finetuning takes place between breeders and processors. This especially so when the processing company is interested in assuring the exclusive right to deploy a new variety, to be in control of it rather than the competition. These activities, aims and deliberations, iterative processes, are shown in Table 4.1A2. The first two rejection rounds of seedling clones include low yielding off-types and as of the third year kitchen/lab type assessments of dry matter concentration (under water weight), fry color (reflecting

Table 4.1A2. Crucial steps in creating a processing variety

Activity	Aim	Rejection reasons for a manufacturing company
Selection and crossing of parents	Establishing processing potential	Parents lacking 1 of 3 (suitability, adaptability, resistance)
Selection of processable clones, lab approach	Detecting suitable dry matter, fry color, shape	Not meeting all three criteria, besides yield, adaptation and tolerance
Bulking tubers of selected clones in the field	Obtention of sufficient tubers for factory runs	Factory trial runs shows different data than lab/kitchen conditions: peeling, cutting (shear), blanching (discoloration) conditions differ, rejection follows disappointment
Factory runs with several tons of tubers	Assess performance of advanced clones under factory conditions	
Bulking seed	Assuring enough seed to rapidly launch a new variety	Seed and crop health and tolerance of insects and drought play a role in the assessment
Variety naming and licensing	Protecting intellectual property	If exclusive rights cannot be guaranteed (non UPOV)

concentrations of reducing sugars) and shape (length:width ratio). Breeding and selection result in factory trial runs after some six years of selection. Seed tubers of an outstanding clone that met the criteria in previous seasons are rapidly bulked as to provide the factory with several tons of raw material to be subjected to factory processes. Recovery whereof is compared to that of currently employed varieties. When advantageous from the processing (high recovery) and production (efficient cropping) points of view, a company assures exclusive rights provided a fixed annual amount is mutually guaranteed upon.

Quantification of the supply chain domain

Nine actors of the ten (agronomy and procurement are one team) of Table 4.1A are given fourteen wishes and needs (attributes) listed in Table 4.1B, each of them to a greater or lesser degree important peers where competition is not at stake) is important for all actors, so is meeting the specs. Breeders

Table 4.1B.Heatmap of the 9 classes of actors and 14 attributes the degree they are important for an actor

Very important	a	Necessity to meet specs[t]	Not important
	b	Price of raw material	
	c	Quality and quantity of seed potatoes	
	d	Environmentally friendly production of raw	
	e	Information on the supply of raw[u]	
	f	Information on need of amount of finished	
	g	Information on the product characteristics[v]	
	h	Taking needs of end user into account	
	i	Interest in having new products[w]	
	j	Storability of material actor deals with	
	k	Access to performance of peers	
	l	Desire to supply info upstream and to peers	
	m	Desire to supply info downstream and to peers	
	n	Consumer satisfaction of product, dish	

#	Actor	a	b	c	d	e	f	g	h	i	j	k	l	m	n	Av.
1	Consumer															2.8
2	Cook															3.6
3	Customer															3.4
4	Trader(shop)															3.5
5	Processor															4.4
6	Procurer[x]															4.0
7	Grower															3.5
8	Seed grower															2.7
9	Breeder															3.0
	Average	4.0	2.9	2.8	3.8	2.9	2.9	3.1	3.2	3.2	4.1	3.7	4.1	4.0	3.4	3.4

t Specifications of raw, finished and dish

u Quantity and quality of the raw material tubers going to factory

v Description and food value of the product

w New products on offer, wider range of products

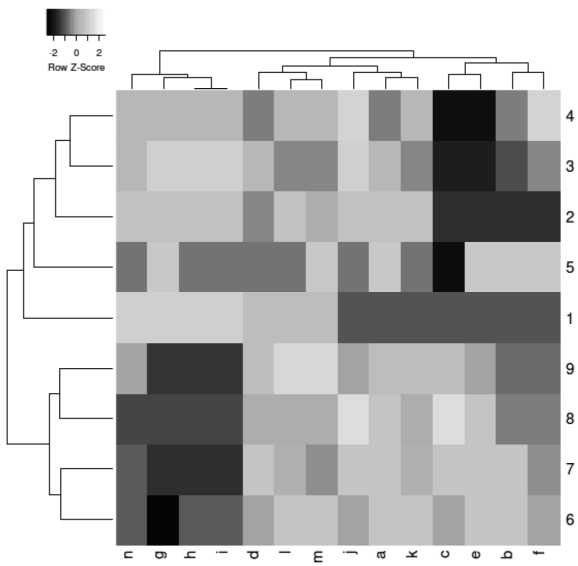
x Procurement consists of agronomists assisting growers and informing factory, and also of agents contracting growers for a particular actor. The heatmap shows that supplying information up- and downstream (and to are at the bottom of the supply chain, and have no actors below to give information to and in general for fear of competition, they are not interested in sharing information with peers. So the score awarded for the attribute “Desire to supply info downstream and to peers” is low (1). For consumers (eaters) there is no actor above them but they like to share experiences with pears and possibly with a dietician.

The map shows a dichotomy here and there with attributes b, c and e of special interest of producers and g, h and i for trade and users. Here all actors keep the average of attributes well below 3.3 whereas meetings specs, sharing information and environmentally friendly production is important for most actors yielding averages of over 3.8. The average value of all attributes is lowest for the seed growers and the eaters, 2.8 and less. Seed growers are not concerned about what the eaters think nor how (new) products look like. Consumers have no interest in all attributes regarding the raw material price, quality and availability. The processors have the highest average value of the scores of the attributes underpinning their central role in the chain.

Clustering within the chain domain

The dendrogram reveals that actors are divided in two distinct clusters (Table 4.1C). The cluster at the bottom with four members represent the four actors from breeder to procurer and has two twins: breeder with seed grower, and grower of raw material with procurers. The remaining five actors handle the product with the trader and consumer, connecting best with the cook at some distance and the processor farther still. The eater is not closest associated with the cook but takes a rather independent position as the consumer has no specs to meet, does not store the products nor the dish made thereof and has less need to learn from peers than cooks do.

Table 4.1C. Dendrogram of the importance of the attributes (a-n) for the actors (1-9), see Table 4.1B.



The fourteen fields of interests, attributes, of the players show four distinct clusters. The first one treats the eater's interest in end-uses' needs and information, satisfaction and desire for new products. The second cluster groups upstream and downstream information with environmentally friendly production explained as the latter needs to be passed on. Meeting specs (of raw, product and dish) needs access to information of peers and somehow is in the same cluster, albeit as some distance, as storability, likely because raw and products share interest in storage. Quantity of seed is linked to the quantity of raw because of the interdependence and the price of raw and need of amount finished are grouped because these are the main concerns of the processors.

The performances domain

Formulation of the domains

In the previous section about the supply chain, the role of the actors growers and processors was described and their information requirements made explicit. Here the domain of performance is defined for growers as yield and quality of the raw material they produce (value per unit area) and that of the processors defined as recovery of the finished products made from the raw material with minimal losses by having to produce lower value products or waste (value per ton raw).

The task of cooks is to use products for the Composition (C) of a dish or side dish as a meal component through Preparation (P) , Heating (H), Arranging (A) taking into account Societal (S) aspects such as affordability : C = P + H + A + S. Product depending preparation includes unwrapping, thawing, reconstitution, selection type of meal ingredient ranging from plain boiled tuber to complicated gratins. Heating, also product dependent, is through boiling (microwaving), frying or baking. This review in this chapter does not go into detail about the tasks of cooks but will discuss losses in kitchens and on the plate.

Condensation of the field performance sub-domain

All harvested tubers and their recovery determining quality, the production of a field, is its yield (Y). It results from the Genotype and seed tuber quality planted (G) in a particular Environment with its climate and soil (E). Performance equally follows from farmer's Management (M) practices supplying the soil with water and nutrients and protecting the crop. The ensemble is represented as Y = G + E + M + S (Kropff et al. 1995; Haverkort 2018), summarized in Table 4.2A1 and subsequently elaborated.

Moving earth: planting, hilling, harvesting

Devaux et al. (2021) used the same expression and discussed how breeding (earlier, resistant), by using new techniques (hybrid seed, genetic modification and gene editing), better seed quality, crop management (precision farming, decision support systems) and supply chain management (turn waste into value, reduce post-harvest losses) all lead to improved performance.

Table 4.2A1. Aspects, examples and societal issues not exhaustive. Yield = Genotype + Environment + Management + Society (Y = G + E + M + S)

Aspects		**Examples**	**Societal relevance**
Y	Yield Quality	Tubers t/ha fresh Tuber size Dry matter content	More efficient attainment of high yields and quality increases the recovery of finished products in the factory and assures a greater return on investment with minimal use of resources
G	Species *Solanum*	*S. andigena* (Peru) *S. phureja* (Colombia) *S. tuberosum* (global)	Different species evolved in different environments where people domesticated them by continuously selecting larger tubers with less undesired compounds (acrylamides)
	Variety	Vrieslander (NL) Criolla (Colombia) Russet Burbank (USA)	Varieties within species are clones selected traditionally or in a breeding program adapted to local biotic and abiotic growing conditions, taste and processing needs
	Propagation material	Seed tubers Cuttings, TPS Mini-tubers	The clonally multiplied tuber crop needs renewed stocks of healthy seed tubers derived from multiplication programs increasingly using mini-tubers from in- and ex-vitro cuttings
E	Altitude, latitude, soil	Highlands (Kenya) Summer (Europe) Winter (India) Spring and autumn (Tunisia)	Potato thrives not well at low nor high temperatures so farmers can grow year round at tropical highlands and at lowlands in winter in the subtropics, in autumn and spring in dry summer climates and in temperate summers (soil conditions permitting)
M	Watering Fertilization Protection	Rain and irrigation Manure, fertilizers Crop protection chemicals	The level of technology and availability of water, nutrients and chemicals to a great extent determine how farmers can optimize crop yield and quality so their subsistence and/or profitability
S	Environment Food Safety	Resource use, emissions, residues	Producers and consumers want food to be produced in a sustainable way

Yield

The expression of the performance of a crop is its yield (Haverkort and Struik, 2015), expressed as t/ha fresh matter or dry matter and in case of starch crops, their starch yield as t/ha. High dry matter yield means a high amount of finished processed products and as such is of socio-economic importance.

More irrigation, nitrogen and potassium fertilization and earlier harvesting before crop maturity reduce dry matter (Haverkort et al. 2015). In general the range is from 16 to 27% dry matter of tuber fresh matter. The protein concentration of about 2% of fresh matter is not much influenced by variety, growing conditions and farming methods. Variety hardly affects the mineral (Fe, Zn, K, Mn) concentrations but soils rich in certain minerals yield tubers with high contents of them, so does supply of minerals through fertilizers strongly increase their concentrations in the tubers. Tubers of different varieties differ in vitamin concentrations from 15-45 mg/100 g (Jea-sook Han et al. 2004) but hardly from altered growing conditions. The flesh color of varieties is indicative of the quantity of flavonoids (red) or yellow terpenoids (Brown 2005), more expressed at lower temperatures and at more intense solar radiation. Glycoalkaloids concentrations (TGA) are strongly variety dependent and tubers exposed to sunlight have higher concentrations than those buried deeper in the soil, and higher levels of nitrogen fertilization are associated with higher levels of TGA. In the USA the legal maximum level of TGA in fresh potato is 20 mg per 100 g (USFDA 2021). Nitrate concentration in tubers is variety

Table 4.2A2. Yield determining efficiencies (conversion factors) in raw material production (after Haverkort et al. 2015)

Resource	Use Efficiency	Dimension	Optimal value	Main efficiency determining factors
Land	LUE	g/m^2	4500	Length of growing season, radiation, water
Marketable	MUE	g/g	90	Meeting market specifications
Radiation	RUE	g/MJ	1.25	Water availability
Water	WUE	g/L	6	Nitrogen availability
Nitrogen	NUE	g/g	200	Water availability
Biocides	BUE	g/g	2500[1]	Rainfall
Labor	LaUE	s/kg	1.68[1]	Yield (Land Use Efficiency)
Costs	CUE	€ /kg	0.18[2]	Yield, rainfall, manure
Seed tubers	SUE	g/g	20	Yield
CO_2[3]	CUE	g/g	0.1	Yield, rainfall, storage conditions

[1]Haverkort 2018 (s = seconds) ; [2]FAO 2021; [3]Haverkort and Hillier 2011

dependent and decreases in the tubers during the growing season so prematurely harvested tubers have the highest concentration. Tubers grown at high levels of soil nitrate levels also have higher nitrate levels in tubers. The maximum concentration allowed in the USA is 250 mg/kg (EFSA, 2022).

Not all tubers are marketable as it depends on the specifications of their destiny, 90% is assumed but is 100% for starch and around 80% for crisping tubers (Halseth 2015) due to the elimination of odd sizes tubers, defects and ones with too low specific gravity. Yields depend on the efficient use of resources of which approximations of optimal values are listed in Table 4.2A2.

Genotype

The family of Solanaceae (nightshades) has many species (Machida-Hirano 2015) among them *Solanum tuberosum* adapted to long days and grown worldwide but also many less widespread species still occurring in South America such as the late maturing *S. andigena* in Bolivia, Peru and Ecuador and the yellow fleshed *S. phureja* still popular in Colombia and recently introduced into the variety packages in North America and Europe. The edible tuber bearing species are just a few among the hundreds of wild species that were domesticated by the peoples that lived in the Andean highlands of S. America. They selected tubers that were not too small and contained not too much bitter substances, glycoalkaloids (Johns and Alonso 1990) with lengths of growing and tuber dormancy periods that suited the dominant environment. From human aided natural selection in the Andes and through breeding programs there and globally varieties were produced that are liked by the consumers for taste, perform well in the given temperature window and resist the most common viral, fungal and bacterial diseases and the most common pests. Closely linked to the genotype planted is its propagation material, usually whole or cut seed tubers. Cuttings and minitubers play a role in the production of commercial seed tubers but in a few places farmers plant rooted sprout or stem cuttings as propagation material (Uyen and Vander Zaag 2008) . Recently several hybrid seed breeding program

Chemical control

aim at the use of botanical seed (hybrid true potato seed, HTPS) to produce tubers from its seedlings for seed and/or consumer purposes.

Environment

The four main processing potato cropping environments are dry or rainy, summer or winter seasons (Table 4.2A3). Mediterranean climates also have spring and autumn crops but these have no processing quality. Winter seasons typically have a duration of 3 months and summer seasons of 6 months. With a projected (IPCC 2021) increase of atmospheric carbon dioxide from current 400 to future 600 ppm and a 2°C temperature increase by 2060, crops have a higher growth rate due to the 'fertilizing' effect of CO_2 (Jaggard et al. 2010) but heat-free winter seasons are shorter by a week and frost-free summer seasons longer by three weeks (Haverkort et al. (2013) and Franke et al. (2013), based on the LINTUL crop growing model. With average day-night temperatures above 8 and below 28°C the potato crop grows (Haverkort et al. 2015). Beside above-ground factors (the weather), below-ground factors are equally important (rooting depth, water holding capacity).

Table 4.2A3. Current and future average climate data over the growing season crop yields and evapotranspiration (ETP) in four contrasting growing environments

Property	**Unit**	**Rainy winter**		**Dry winter**		**Rainy summer**		**Dry summer**	
		South Africa		**India**		**North Europe**		**West America**	
		2020	2060	2020	2060	2020	2060	2020	2060
Radiation	MJ/m²/day	15	15	20	20	25	20	30	30
Minimum T	°C	10	11	12	13	10	12	10	12
Maximum T	°C	24	25	24	25	21	23	28	30
Season length	Days	100	95	95	88	180	205	170	195
ETP	mm/season	200	220	500	550	600	660	1100	1200
Yield	t/ha	45	49	65	72	79	101	88	109
Radiation use	MJ/t x 1000	33.3	29.0	29.2	24.4	57.0	40.6	58.0	56.4
Water use	mm/t	4.4	4.5	7.7	7.6	7.6	6.5	12.5	11.0
NASA data		Cape Town		Ahmedabad		Lelystad		Pocatello	

Besides provision of nutrients, the potential depth of the rooting zone and the water holding capacity of this zone to assure an adequate supply of water from rain and/or irrigation (Haverkort 1990).

POTATO model (Kooman and Haverkort 1994) calculated yield and water need with daily weather of 1960 and 2050 in four contrasting South African environments. Table 4.2A3 shows a similar exercise with monthly weather data from NASA (2021) and Gaisma (2021) of four sites representing such environments. Too warm days for potato number about six both at the start and the end of the winter season. The remainder of the season is about one °C warmer than current. The yield effect of the lengthening of the summer growing season is more or less nullified by the increase of heatwaves during which crop growth halts. As a result of increased CO_2 yields of winter crops increase by about 10% and of summer crops by about 20%. Yields of spring and autumn crops hardly increase as both move closer to winter with shorter and more cloudy days with reduced solar radiation. The water use efficiency of winter crops stays more or less the same but for summer crops it moves up for Europe for instance from 131 kg/mm to 153 kg/mm. The amount of solar radiation to produce 1 t of fresh tubers decreases in all four situations. Van der Waals et al. (2013) calculated that with an increase in total temperature sum in summers pest pressure increases as more generations will fit in one season but that of late blight caused by the oomycete *Phytophthora infestans* decreases because of an increase in frequency supra-optimal for its development. The projected yield levels do not take into account major occurrences of deleterious heat-waves, droughts, floods and introduction of pests and diseases that reduce average levels. Nor do they make allowances for crop management practices aimed at increasing yields such as site selection, cooling the crops, evacuating water and adequate crop protection measures.

Management

Potato crops need to be planted in loose friable soils, earthed up (hilled), supplied with water and nutrients and protected against prevailing pests, diseases and weeds. All these aspects of crop management involve intensive organization and planning, use of labor, compost and manure in subsistence and low input farming. In high input farming tractor driven equipment and the use of chemicals (fertilizers and biocides) are deployed (Haverkort 2018). Further decisions taken by the grower regard selection of site, season, variety, seed quality, timing of operations, handling (grading and sorting), storage and marketing.

Condensation of the factory recovery sub-domain

The interface of the domains field and factory performance is made explicit in Table 4.2A4 which shows the product requirement and how G, E and M steer the processing qualities into the desired direction. Tubers destined for the production of starch need the highest dry matter concentration of which the major proportion consists of starch. Other variety requirements, besides disease resistance, are few as the tubers after washing in the factory are ground. Starch factories are found at sites where tuber production is at the lowest costs: rainfed summer crops yields with low input needs. Raw material for

Storage

crisping needs the lowest concentration of reducing sugars as cooking in oil at relatively high temperatures for a prolonged period offers an optimal scope for the formation of acrylamide. Fluctuating temperatures and water supply during crop growth lead to high concentrations of reducing sugars that decrease towards crop maturity and increases during storage at low temperatures, less than 5°C (Seal et al. 2008). The protein concentration, in general close to 2% of the tuber fresh matter, is not an issue with most destinations but starch factories, except those producing food-grade protein, prefer a low protein: starch ratio.

Table 4.2A4. Quality of raw material dependence on crop variety, surrounding conditions and cultivation practices

Quality classes	Product classes	Desired attribute	Issue	Geno-type	Environ-ment	Manage-ment
Dry matter concen-tration	Starch Chips Flour Frozen Chilled	Highest High High Moderate Lowest	Starch varieties have the highest concentration (27%) followed by crisping varieties (23%). French fries raw material 21.5% and boiled chilled tubers around 20%	Apt variety	High DMC in temperate summer crops	Low nitrogen, potassium, irrigation late harvest
Reducing sugars	Starch Chips Flour Frozen Chilled	No issue lowest No issue low No issue	Glucose and fructose cause product browning at frying, more so at higher temperatures and for a longer time so the issue is most prominent in crisping tubers but also causes sugar ends in French fries	Apt variety	Problem fluctuating moisture, tempera-ture	Regular irrigation, cool crop, late harvest, warm storage
Protein	Starch Chips Flour Frozen Chilled	Lowest No issue No issue No issue No issue	To date starch varieties were selected for low protein as they had low value as feed. Recently some factories extract food value protein and then prefer high concentrations	Starch varieties are low in protein	Temperate climate has the highest starch:pro-tein ratio	High nitrogen
Minerals	All	No issue in starch	Potassium and Phosphorus are assumed to be present in all products and to deliver food value	Hardly any influence	Influences K, Fe, Zn, Cu content	Influences K content mainly
Vitamins anti-oxidants	All	No issue in starch	Vitamin C, B, flavonoids, terpenoids and phenolics matter in chilled and frozen products	Strong variety influence	Hardly matters	Hardly matters

The mineral concentrations are mainly determined by their soil concentrations, and health affecting compounds by variety. The major loss of weight of the raw material entering a processing facility is a consequence of the loss of water. Tubers or parts that are only boiled, packed and chilled loose no water. Fried and frozen products, French fries and formed, retain a considerable proportion of the water present in the fresh tuber, about 78%, resulting in a recovery after peeling, blanching and frying of about 50% (Somsen 2004).

Dry products (chips, starch, flour) have the lowest recovery of about 25%. The market value is inversely proportional to the degree of recovery. Some mineral concentrations are reduced through leaching when boiling tubers in water especially when cut into pieces such as magnesium, zinc, manganese and particularly potassium over 50% reduction. (Bethke and Jansky 2008). Other minerals, such as calcium are close to 10 mg/100 g fresh weight boiled and unboiled but the concentrations increase with dehydration resulting in chips having concentrations close to 40 mg Ca/100 g fresh tubers (Bethke and Jansky 2008). The vitamin C concentration is about halved by boiling but the levels in dry products are about the same as in fresh uncooked tubers, considering that potato consist for over 75% water it implies that in dry products about 75% of the ascorbic acid disappeared (Camire et al. 2009. The anti-oxidant chlorogenic acid – iron complex when in touch with oxygen oxidizes and give processed potatoes a grey hue, so-called after cooking darkening, which in the factory is counteracted by soaking the slices or sticks in a solution of SAPP sodium acid pyrophosphate (Wang and Novak, 2004) that inactivates iron by chelating. The compounds nitrate (dissolves in boiling water) and glycoalkaloids considered unhealthy disappear mostly when peeling and heating at processing.

Each product destiny x environment combination has its own range of cultivars. Starch needs late varieties making the best use of the available length of the growing season which also have a number of rustic characteristics such as some frost and late blight resistance, tolerance of intermittent dry spells and of nematode. Starch factories in general do not run year-round so storability is less of an issue. Factories producing fried products do run year-round so the varieties need an adequate dormancy period and should not accumulate reducing sugars.

Recovery and its components are considered in the following paragraphs.

Recovery

Recovery in potato processing is the weight of the finished product produced per ton of fresh tubers delivered to the factory as raw material, expressed as a fraction. For chips this is about 25%, for starch 20 % and for French fries 50%. When more tubers meet size specifications and when the raw material has a higher dry matter concentration, recovery is higher than from crops with a lower dry matter content, many tubers with an odd size and presenting defects. The recovery of a freshly harvested crop is less than that of the crop delivered to the factory because losses occur in post-harvest crop handling (H) and storage (S). Manufacturing products from the harvested tubers as raw material aims at a high

Table 4.2A5. Non-exhaustive aspects of "Recovery = Handling + Storage + Processing (R = H + St + P)"

	Classes of factory performance aspects	**Examples (instances)**	**Societal relevance**
R	Finished product	French fries	Farmers grow specific crops and processors make desired end products in a cascade e.g. Chips (end product), flakes (from slivers), feed (from peels) and waste water to the purification unit
	By-product	Flakes	
	Waste	Water treatment	
H	Tare removal	Sieving, washing	Consumers and processors need clean tubers without defects and of the right size as to reduce transport and losses in kitchen or factory.
	Sorting	Removal of defects	
	Grading	Sizing to use	
S	Ambient	Temperature	Controlling the ambient conditions of tubers after harvest makes them available to users for a prolonged period after harvest and reduces losses
	Ventilated	Relative humidity	
	Refrigerated	Carbon dioxide	
P	Dehydration	Starch extraction	

	Classes of factory performance aspects	Examples (instances)	Societal relevance
	Boiling	Flour production	Potato derived products fulfil the needs of the industry as an excipient (filler starch), intermediate (pellets before expansion) or final consumer use as snack (chips), ingredient (flakes) or convenient replacement for home or restaurant preparation (French fries)
	Frying	Frozen French fries	
	Cooling	Hilling, freezing	

recovery: kg finished product per ton tubers harvested (R). This is realized through product-specific Handling (H), Storage (S), Processing (P) of the tubers and also considering matters of social interest such as attention given to spare the environment (Table 4.2A1). Together they are represented as R = H + St + P, elaborated below and outlined in Table 4.2A5.

Handling

Sorting of tubers by eye on a (revolving) sorting table or computer vision aided technology (Pedreschi et al. 2016; Bahadirov et al. 2020) involves the removal of unmarketable tubers (rotten, odd-shaped and tubers showing defects such as cuts). Incidence of diseases (bacteria and fungi) cause rot when insufficiently controlled, fluctuation of temperatures and soil moisture during the growing season cause tuber regrowth, knobbiness, growth cracks, translucent ends, hollow hearts and other defects. Harvesting by how or machine causes cuts but also gnawing animals are a reason for defects. Grading through passing the tubers over grids with appropriate dimensions leads to sizing into desired classes according to specifications of the customer. Very small tubers below 30 mm are disposed of or used as feed, the remainder sized according to what the customer specifies. Crisping factories require small round tubers, French fries factories need large oblong-shaped tubers and starch factories take all, including very small and defective ones. Handling does not influence the other tuber qualities such as the concentrations of dry matter, protein and other tuber constituents. On-farm post-harvest tuber treatments are aimed at delivering tubers fit to store and fit to deliver to customers, among them processing factories. Therefore firstly adhering soil is removed as it hampers the flow of air in ventilated stores (Rastovski and van Es 1981) and as little tare as possible is transported to the factory. On-farm washing of tubers is less common practice but is substantial for the growers that deliver tubers to the crisping industry.

Storage

Only part of the tubers goes to the customer ex-field without being stored for a pre-determined period, ranging from a few days for an early delivery to the factory, up to five months in regions with two growing seasons per year and up to some 10 months where there is only a single growing season. Tubers stored in bags, boxes or bulk produce heat, moisture, ethylene and CO_2 which need to be evacuated through ventilation (Eltawil et al. 2006), excess heat requires refrigeration at lower temperatures when storing for an extended period. Adequate storage management reduces losses through respiration, evaporation and rotting and assures a regular year-round supply of raw material. At ambient conditions, the temperature is the main limiting factor and in heap storage usually does not exceed one or two months. With ventilation to evacuate built-up heat and moisture this period is extended especially when combined with refrigeration to reduce respiration and the formation of carbon dioxide. If a sprout suppressant is applied (Paul et al. 2016), the total storage period is up to 10-11 months allowing a factory (with some leeway in harvesting) to run year-round. Storing tubers takes place temporary on a heap in the field protected from rain and sunshine or for a longer period in purpose-built buildings in bags, boxes or bulk with forced ventilation and where need be forged refrigeration. Losses in storage are due to three factors, the main one being the evaporation of water through the skin of the tuber (Emragi et al. 2021). Evaporation is higher when the temperature of the tubers is higher and the relative humidity surrounding them is lower. Frequency and intensity of ventilation and the inlet air temperature regulate the two key aspects to reduce losses. The dry matter concentration of the tubers during storage increases when evaporation surpasses respiration (at low temperatures) and decreases when respiration is considerable at high temperatures and high relative humidity. Losses also occur due to rotting because of diseases such as late blight and bacterial wilt physical damage and freezing. Storing at very low temperatures for a destination and too high CO_2 concentrations cause an increase in reducing sugars (Mazza and Siemens 1990) leading to dark colored products at frying, reason why seed tubers are stored at 3°C, tubers for frozen French fries at 6°C and for chips at 9°C, this because at higher temperatures reducing sugars formed from starch increasingly disappear through respiration. Prolonged storage for several months leads to a decrease in the concentrations of beneficial Vitamin C and detrimental nitrate and chlorogenic acid. When tubers are exposed to light, greening occurs and with it an increase of glycoalkaloids content (Haruko Okamoto 2020), similarly contents increase when tubers sprout (Sengul et al. 2004).

Processing

Processing is aimed at products that add value to the raw material. Cold processes yield native starch that, when used for human consumption, whether or not after chemical of physical transformation, needs to be heated in water. Heat treatments consist of blanching, steaming, microwaving, boiling and frying. Fried moist products reach consumers chilled or frozen. Boiled tuber parts are sold chilled or dried and ground (powder), and all processes underlying operations in factories are treated in Chapter 3. Somsen (2004) modeled proportion recovery he called ‘yield index' of French fries as a function of average tuber weight expressed as tuber number per kg, dry matter concentration and tuber shape (length , width, height) and losses resulting from peeling, slivers (to thin strips) and nubbins (too short strips). Larger tubers with a higher dry matter concentration have a higher yield index due to reduced losses, also of water evaporated.

Quantification of the performances domain

The 19 performance indicators, including the suitability of raw material for the production of starch, chips, flour, frozen French fries and chilled products and 11 attributes are listed as a heatmap in Table 4.2B. The heatmap shows a predominance of red color, indicative of a minor influence of attributes on constituents such as minerals, vitamins and antioxidants, a moderate influence on the products made of tubers and a relatively strong influence on crop characteristics with green dominating. The columns show that variety and processing influences virtually all crop performance indicators but seed and crop protection only target a few. The vitamin content is least affected by the attributes with an average score of 1.7. There is only a slight difference between varieties but processing does influence the concentration of vitamins (Chapter 5). Many attributes exert an influence on deliverable yield to the factory, hence its highest average score of 4.3. Products requiring many specs, chips and French fries for the same reasons also receive average scores of above 4.

The lowest average of an attribute is the influence of seed on the classes, a value of 1.9. Seed quality (size, age, health) only wields influence on crop duration and yield, this also holds for crop protection for the same reasons and the weather and fertilization to a somewhat lesser degree. Variety and processing affect many classes both scoring close to 4 on average.

Table 4.2B Heatmap of the 19 classes of performance and the degree the 11 attributes influence them

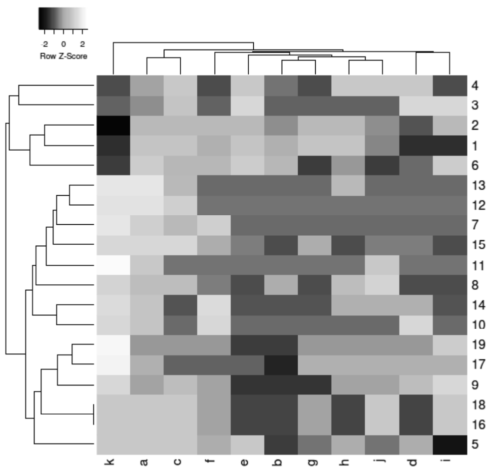
Strong influence			Minor influence
	a	Variety	
	b	Seed	
	c	Climate	
	d	Soil	
	e	Rain/irrigation	
	f	Fertilization	
	g	Crop protection	
	h	Defoliation of the crop before lifting	
	i	Handling (grading, sorting)	
	j	Storage	
	k	Processing affecting contents and yields	

#	Classes of performance of field and factory production	Geno-type		Environment			Manage-ment			Recovery			
		a	b	c	d	e	f	g	h	i	j	k	Av.
1	Crop duration												3.5
2	Yield delivered to factory												4.3
3	Tare												2.5
4	Harvestable period												3.1
5	Dry matter concentration												3.7
6	Tuber size												3.2
7	Protein content												2.1
8	Reducing sugars content												2.8
9	Proportion of defects												3.0
10	Minerals content												2.4
11	Vitamins content												1.7
12	Antioxidants content												2.0
13	Glycoalkaloids content												2.1
14	Nitrate content												2.5
15	Starch yield												2.7
16	Chips yield												4.1
17	Flour yield												2.7
18	Frozen French fries yield												4.1
19	Chilled products yield												3.5
	Average	4.1	1.9	3.6	2.7	2.6	3.0	2.2	2.8	2.5	2.8	3.9	2.9

Clustering within the performances domain

The classes (Table 4.2C) show three distinct clusters. The top one with five crop related members

Table 4.2C. Dendrogram of the rank of the attributes (a-k) for the performance indicators (1-19) in Table 4.3A.



contains the very remote twin tare and harvestable period and the less remote crop duration and yield. Tuber size also belongs to this cluster. The lowest cluster with six products contains the identical twins chips and French fries yields, and the closely related twins flour and chilled products. The cluster in the middle with eight members concerns the contents of components with twins mineral and nitrate content and another one that of antioxidants and glycoalkaloids.

Clustering of the attributes reveals that processing stands alone and that climate and variety are close twins more or less similarly affecting the classes. Other twins are seed and crop protection both affecting crop health, duration and yield, defoliation and storage for less obvious reasons and a remote twin soil and handling.

Resource use domain

Formulation of the resource use domain

Efficiency is defined as the amount of resource input per weight unit finished product and is optimized by avoidance of losses and unwanted emissions. For processing potato this domain is delimited by the production of the tubers as raw material on farms and the manufacturing of finished products. Resources in tuber production as illustrations are land, water and fertilizers and in processing energy and water mainly. Productivity then is t/ha tuber (or g/m^2), t/m^3 water on farms (examples in Table 4.2A3) and t/GJ French fries in factories. Losses reduce these figures and avoidance of losses increases them. Examples of (partly) avoidable losses on farms are tubers left in the soil at harvest and weight loss in stores. At processing sorting of washed, peeled and processed tubers with defects creates losses. These are partly avoidable by altering operations (trimming) and/or criteria (accepting shorter French fries) and using rejects as raw material for alternative high-value products such as flakes. Activities impacting the habitat, affecting air, water and soil are included in this domain.

Condensation of the resource use domain

Resource use in processing tubers

At the turn of this century interest in the use of land, water and energy in growing, processing and

Table 4.3A1. Early reports on energy use in potato production, processing and preparation. Based on Williams et al. (2006)[1], Mattson and Wallen, (2003)[2], Foster et al. (2006)[3]

Per 1 kg raw potato stored[1] (Williams et al, 2006)	**Data**		**Per 1 kg peeled and prepared**	**MJ**	**% of 4.5 MJ**
Energy MJ	1.3		Cultivation	0.6	13
CO_2 equivalent g	97		Storage and cooling	0.5	11
Pesticides dose g	4.4		Transport to packer	0.2	4
Land use ha	0.000022		Packing	0.6	14
Energy breakdown[2]	**% of total**		Transport to retail	0.55	12
Field diesel	28		Retail	0.2	4
Machine manufacturing	8		Transport to home	0.65	14
Crop storage and cooling	36		Household use	1.2	28
Fertilizer manufacturing	24		TOTAL	4.5	100
Pesticide manufacturing	3.9				
			Finished product[3]		
			Kg French fries	**5****	
			Kg flakes	**36****	
**Authors inferred this from gas use and production data of a Pollution Prevention and Control factory founding permit					

preparing tubers grew, resulting in the data of three groups of researchers with focus on the situation in the United Kingdom represented in Table 4.3A1. The amount of energy to grow one kg of tubers was calculated at 1.3 MJ, equivalent to 97 g CO_2 grown on 0.22 m^2 so 45 t/ha with fuel for traction, electricity for cooling and energy embedded in fertilizer production as the three main components. Haverkort and Hillier (2011) and Baltussen et al. (2016) calculated respectively 77 and 65 g CO_2 per kg tubers as yield levels (somewhat lower in the UK than in the Netherlands), definitions, systematics and systems boundaries differ. More precise life cycle analyses by, amongst others, Swiss researchers (e.g., Walker et al. 2018) yield more consistent data, also more in line with those of Haverkort and Hiller (2011) and Baltussen et al. (2016). Mattson and Wallen (2003) and Haverkort and Hillier (2011) calculated a somewhat higher figure for organic production where no chemicals are involved but more energy is spent on transport of manure, machinery and cooling than for conventional growing of tubers. Boiled potatoes for household consumption represent 4.5 MJ/kg with cultivation and storage taking 24%, transport and trade 34% and bringing tubers home and cooking them 42%. Factory production of flakes was calculated at 5 MJ/kg and for flakes at 36 MJ/kg (Table 4.3A1).

Walker et al. (2018) calculated the energy and water use for the production of 1 kg of frozen French fries: 3.3 MJ thermal energy for steam peeling, blanching and frying and electricity for transport, sorting, grading and freezing. West et al. (2020) calculated decarbonization options

Table 4.3A2. Energy and water use and material loss to produce 1 t of frozen French fries and flakes E=Electricity, F = Fuel, S = Steam (West et al. 2020)

Classes of processes	**Frozen French fries (2 t raw)**			**Flakes (5.1 t raw)**		
	Energy (GJ)	**Water use (L)**	**Weight loss (t)**	**Energy GJ**	**Water use (L)**	**Weight loss (t)**
Grading and sorting Washing	0.0023 E	13000	0.11	0.018 E	33035	
Peeling, trimming	0,47 S	265	0.24	1.5 S	762	0.2
Cutting or slicing	0.0004 E		0.03	0.068 E		
Sorting	0.0004 E		0.02			
Blanching	0.001 E 0.29S	333	0.01	0.034 E 5.1 S		
Drum drying				0.085 E 13.0 S		3.9
Frying	0.02 E 2.13 F	0	0.59			
Cooling				0.02 E		
Freezing	0.35 E	0	0			
Packaging	0.01 E	0	0	0.01 E		
Refrigeration	0.01 E					
Total/t finished	3.2837	1895	1.0	19.835	35710	4.1
Notes: Mass of potato products excludes packaging. It is assumed that chilled potato products processing consumes the same amount of energy, minus the freezing energy use, and that chips production excludes both freezing and refrigeration.						
Source West et al. 2020 ("Adapted from Walker et al. 2018; Masanet et al. 2008; and Rijksdienst voor Ondernemend Nederland, 2016")						

for the Netherlands potato processing industry enumerated the processes involved in producing frozen French fries and flakes, their aims, methods and kind of material loss that maximally reach 10% per process (peeling, sorting, blanching). The energy in processing French fries was from electricity for transport, washing, grading, sorting, cooling and packaging, from steam (natural gas heated) for peeling and blanching and fuel (natural gas) for frying. These data are shown in Table 4.3A2.

The figure of 3.3 MJ/kg (GJ/t) is less than the 4.84 from Walker et al. (2018) because West et al. (2020) took reuse of energy and decarbonized energy into account (Table 4.3A3). The data in Table 4.3A2 also show water use and material losses: 1 kg loss of two kg of raw material started with in grading, peeling, blanching and frying French fries. The flakes data are also shown: it takes 6 times more energy to produce flakes than French fries. Here some remarks apply: the French fries data do not include the energy embedded in the oil present in the finished product and for French fries production much less water is evaporated (at the cost of energy) from the product (weight loss in blanching and frying is 0.33 t of the 2 t of raw material (16.5%) against 3.9 t weight loss of 5.1 t raw from the start (76.5%). Looking at it from the perspective of raw to make finished products, 1.65 GJ/t for French fries and 3.88 for making flakes which reflects the reality that to make flakes twice as much water needs to be evaporated from a kg of raw material.

Table 4.3A3. Options for decarbonization : energy efficiency, material efficiency and energy source (West et al. 2020)

Energy	**Options**
Steam peeling	More efficient design saves energy and reduces peel losses. Heat recovery
Pre-heating	Through Pulse Electric Field (PEF) rather than thermal
Blanching	Microwaves costs less energy and less water, infrared combined with heating and closed loop blanching saving water and energy
Frying	Inserting hot oil at various stages of frying (multi-flow injection), heat recovery for drying and pre-heating
Chilling and freezing	More efficient (compressors, condensors) mechanical freezing, changed refrigerants, (ammonia), re-use heat from pumps
Material	
Peeling	Abrasive peeling, involves skin loss and requires more capital and water
Sorting	Intelligent optical sorters prior to peeling reduce losses from over-peeling
Blanching	Steam blanching causes less leaching of nutrients from slices but requires more energy
Source	
Biogas (own)	Produced by the factory from waste water and solid tuber parts (skin)
Biogas (bought)	Purchased from companies deploying anaerobic digestion of plants or gasification of wood
Electrification	Use electricity (lower CO_2 emission than gas) to produce heat for steam, water and frying
Hydrogen	Hydrogen used to fuel boilers, provided it is produced with renewable electricity
Geothermal	Injecting cold water to 4 km depth and extracting hot (130°C) water

Chips production does not need cooling nor freezing thereby saving MJ 0.373 /kg but evaporating water is at higher costs, comparable to dehydrating to produce flakes at 19.8 MJ/kg. A further reduction to CO_2 emission from electricity and gas use in the Netherlands as proposed by the TNO report (West et al. 2020) is shown in Table 4.3A3, reduction of fossil fuel and reduction of loss of potato mass through optimized procedures for peeling, sorting and blanching. Energy saving options include improved equipment in steam peeling and cooling, heat recovery and deploying microwaves and pulse electric fields. Other sources of energy also lead to less CO_2 emission such as biogas, hydrogen and geothermal energy and use of more electricity from part renewable sources where hitherto fossil fuel is used.

Losses and wastes

Not all material that grows in the field, that is lifted, traded, processed and prepared is consumed as some is lost, wasted or given another destination in side flows. Table 4.3A4 shows these, among others



Transport

based on Baltussen et al. (2016) and Mouron et al. (2016). Losses in the field concern small unharvested tubers dropped between bars of sieves, tubers too deep for the digger, cut tubers and bruised tubers when harvested under too dry conditions. Pre-storage sorting eliminates defects and rots and post storage pre-delivery eliminated sizes and shapes not meeting specs of trade or processors. Losses during storage are due to water loss, shrinkage mainly. Left over seed tubers if not treated with fungicides are used as feed for cattle, same as tuber lots that show many rotten tubers or completely sprouted. This is exceptional when lots are intended for processing and shows some calamity took place in the store. When arriving at packing stations ex-field tare is collected there. Left over fresh tubers in retail because of green coloration or sprouting become feed. Rejected truckloads because of

Table 4.3A4. Losses, wastes and side flows in subsequent stages of tubers and products and their destination. Partly after Baltussen et al. (2011) and Mouron et al. (2016), more exhaustive personal observations added

Stage	Material	Definition	Destination
Farm	Foliage	Stems, leaves 3 t/ha	Stays in the field
	Seed tubers	Surplus not planted	If untreated, feed
	Tubers	Not harvested or damaged at harvest	Remain in soil or are partly lifted
	Tare	Adhering soil, stones and plant parts	Remain on farm return to field
	Sorting, grading	Tubers with defects or of size not meeting market demands	Feed
	Rejected tuber lots	Rotted or sprouted lots	Exceptional situation, feed or starch
	Unsold	End of season surplus	Feed, or to factory for flakes
Trade and packing	Washing water	Remains after washing tubers	Sanitation, cleaning recycling
	Tare	Adhering soil, stones	Returns to farms
	Rejects	Sorted tubers	Feed
	Past date	Not sold in time in retail outlets	Feed
	Transport	Tubers to factory, products to shop	Some damage
Processing	Rejected tuber lots	Truckload rejected, floaters	Feed, flakes
	Washing water	Remains after washing tubers	Sanitation
	Tare	Adhering soil stones	
	Starch	In processing water (from cutting)	Reclaimed, purified, modified
	Slivers	Too small cuts to make product	Flakes, feed
	Rejected par-fried	Products not meeting specs	Feed
	Oil	Residual oil after replacement	Biofuel
	Fat crumbs and batter	Retrieved at sieving frying oil	Feed and pet-food
	Peels (steam, raw)	Peels released at steam and abrasive peeling	Feed (steam for non-ruminants, raw for ruminants)
	Processing water	Used in cutting and blanching	Treated (biogas, struvite)
Kitchen	Oil	After frying	Waste
	Unused fresh produce	Unsuitable (green, sprouted)	Organic waste, substantial
	Unused frozen produce	(Small) portions left over	Organic waste, not substantial
	Not consumed	After preparation	Organic waste
	Packing material	Cartons, polyethene	Plastic/paper waste
	Past date	Waited too long in pantry	Organic waste

excess defects or too low dry matter (floaters in brine) become feed, same as with peels, slivers (if not turned into flakes) and rejected par-fried products among others because of sugar ends. Left over oil after use for frying for some time is turned into biofuel. Reported losses per stage vary widely among the eight literature sources consulted, partly due to inaccurate boundaries (for instance sorting by farmers or by traders, not all sources include processing) and their definitions but also where (Europe, Germany, EU, Switzerland UK, USA, worldwide) and how (interviews, surveys, measurements, mass flow analysis) the data were collected. The mean value of the eight sources shown in Table 4.3A5 therefore, is only taken from at least 4 sources with unambiguous data. Traders remove rejects (sorting) and unwanted sizes (grading) with destination feed or flakes. The losses at processing are elaborated in Tables 4.3A2 (West et al. 2020) and Table 4.3A4 (Baltussen et al. 2016). Definitions and boundaries here are not clearly defined by the authors. When the proportion of lost weight is reported with definition recovery 'losses' are 50% with 500 kg French fries recovered from 1 t of fresh tubers but less than 20% on dry matter basis. More often than not, processors do not procure raw material through wholesale trade, so losses due to sorting and grading are then not allocated to 'Processing' but to 'Trade'. Losses in kitchens of fresh tubers WRAP (2012) are due to rejection of tubers following greening, rot, skin blemishes and sprouting. Products do not suffer from such rejections but have in common that not all prepared are consumed with left overs in the pot and on the plate.

By far the greatest proportion of losses are reported for the kitchen, be it at homes or in outlets such as restaurants and institutions. According to Betz et al. (2015) and Willersin et al. (2015) losses at retail and home are similar to those out-of-home. Losses in kitchens are due to tubers never prepared because of rejection (green, rot, sprouted, skin blemishes due, to among other, silver scurf (WRAP, 2012), losses during preparation and wasted after cooking (unemptied pots and plates). Most material wasted in kitchens is organic waste and becomes compost or biogas such as fresh tubers and products not prepared and meal components not consumed after preparation. Cooking oil, as far as not collected by super market chains, is wasted and burnt.

Mouron et al. (2016) analyzed the Swiss potato supply chain assuming that 1 kg of French fries use 1.84 kg of fresh tubers and identified for each stage a few hotspots where the industry could make strides to reduce losses to the environment in terms of non-renewable energy at the cost of CO_2 emissions, and loss of biodiversity contributing to global warming and terrestrial and aquatic ecotoxicity (Table 4.3A5). Production of tubers and oil for frying require fertilizers that negatively impacts terrestrial ecotoxicity. Machinery, to make and to use, requires fuel and fumes, also of transport, affect human health. Waste water from washing tubers is withdrawn from and affects surface waters. Lighting in stores causes greening of tubers accompanied by the formation of glycoalkaloids. The origin of the frying oil matters as canola and sunflower have high scores on ecotoxicity because of the use of biocides. Palm trees to produce palm oil are low on renewable energy while high on CO_2 emissions. Improvement of the efficiency of fertilizers, machinery, transport electricity for cooling tubers and products and frying in the kitchen, use, origin and production of frying oil and gas for steam peeling would have the greatest reducing effect on the negative environmental impacts. Mouron et al. (2016) reported that including frying French fries by the cook, 41 MJ of energy was spent on 1 kg, 25 MJ in the household, most of it represented in the canola oil used for frying, 10

Table 4.3A5. Losses in the supply chain and kitchen (Mouron et al 2016) following a particular case. The mean value of percentage losses in the various stages in industry and kitchen are based on the average value provided by 8 authors in different countries.

Stage	Kg loss	Losses due to	Hotspots	Impacting	Mean% loss
Farm, storage, grading	0.47	Rejects, water	Fertilization	Aquatic and terrestrial ecotoxicity	19
			Machinery use	Energy, human toxicity	
Wholesale (Trade)	0.11	Grading sorting	Transportation	Energy, human toxicity	7
			Electricity for cooling	Energy	
Processing	0.22	Water, rejects	Waste water washing tubers	Aquatic toxicity	17 'process often ill defined'
			Natural gas steam peeling	Energy, non-renewable, CO_2	
			Heating frying oil	Energy, non-renewable, CO_2	
			Frying oil	Terrestrial ecotoxicity	
Retail	0	None	Electricity for cooling, lighting	Energy, human toxicity	1
Kitchen Home, resto	0.04	Frying	Frying oil	Terrestrial ecotoxicity	32
			Electricity for frying	Energy, CO_2	
*Betz et al. 2014; Caldeira et al. 2019; Gustavsson et al. 2011; Kantor et al. 1997; Kranert et al. 2012; Mouron et al. 2016; Willersinn et al. 2015; WRAP 2012					

MJ in the factory and 6 MJ on the farm and transport; five times more than boiled tubers on the plate and at the cost of more than 4 times the amount of CO_2 emission. Water use in the factory was 18 liter per kg French fries. Assuming that 50 t/ha potato yield requires 500 mm of water and 2 kg of tubers are needed to produce 1 kg of French fries, field production requires another 20 liter of water from rain and irrigation (Haverkort et al. 2015). Loss of tuber and product mass at the various stages has received attention of the sources mentioned in Table 4.3A5. On-farm average losses reported were 19% due to harvesting in too dry conditions leading to bruised tubers, shrinkage during storage and removal of odd-sized tubers. Losses in trade following grading and sorting were 17% and in processing (often not well defined) were 17% due to rejected intermediate of finished products but the bulk of losses was reported in kitchens of restaurants, caterers and households of products never prepared or not consumed. Hotspots identified concerned operations, processes and substances at the stages of production and their impact on ecotoxicity, energy use and CO_2 emissions. Fertilizers and waste water affect water quality, machines and transport produce fumes, electricity for cooling (and

Irrigation

frying in kitchens) requires energy, nonrenewable fuels emit CO_2 and frying oil (canola, sunflower) production is associated with terrestrial ecotoxicity from biocides and fertilizers. Reducing the environmental impact of the production and preparation of frozen French fries, according to the authors needs to focus on these hotspots.

The hotspots indicated in Table 4.3A5 are divided into six themes, 1) soil health, fertility, water holding capacity and conservation, 2) water use, availability and quality, 3) energy use as electricity and fuel and embedded in chemicals, 4) mineral balance, availability and reducing leaching through green manure, 5) biodiversity and environment with effects of land use, emissions and 6) human health with emphasis on residues of biocides and diets. Table 4.3A6 recaps the decarbonization options (from Table 4.3A3), losses (Table 4.3A4) and among others shows leads of solutions to the issues raised in the hotspots of Table 4.3A5, but accentuates matters regarding production of raw material. Solutions regarding soil include control of soil borne pests and diseases though crop rotation (affecting soil availability) and variety resistance management and maintaining or improving soil quality by enhancing soil organic matter content and avoiding salinity, erosion and stoniness. Crop growth requires water from rain and/or from irrigation from surface water, dams or deep wells. Its impact is reduced by adjusting demand and supply, assuring water is replenished from local rainfall or at the source. Avoidance of salinity at fields near coasts and improving soil water holding capacity through soil depth and organic matter affect water availability as well. Energy savings in raw material production (also Haverkort and Hillier 2011) are realizable through regulating fertilizers especially nitrogen, fuel in machinery and electricity for water pumping and cooling. Handling minerals is through avoidance of leaching practicing nutrient balances, assuring availability of potassium as potato especially needs this element and avoidance of leaching of nitrate by employing green manure. The habitat is spared by avoiding cropping and biocides in vulnerable areas and reduction of emissions to

Table 4.3A6. Leads to reduce the impact of processing potatoes on soil, water, energy, minerals use and health. (Baltussen et al. 2016 as starting point) and elements of previous tables and chapters

Stage	Soil	Water	Energy	Minerals	Biodiversity/ environment	Health
Production raw (This Chapter)	Health, nematodes, bacteria	Availability, origin surface, deep wells	Fuel (field operations)	P nutrient balance	Land use	Biocides
	Fertility, Organic Matter	Restrictions, DSS irrigation	Electricity (Storage, pumping)	N nutrient balance	Biocides	Sprouting inhibitors
	Availability	Quality (health, salinity)	In fertilizers	K availability	Emissions	
	Erosion, salinity stoniness	Water holding capacity soil	In biocides	Green manure		
Processing (Chapter 3)	Tare Waste water	Closed cycle Use and sanitation	Fuel for frying Electricity for cooling	In waste water, recovery of P	Gaseous emissions	Residues, MRL
Kitchen (Chapter 2)		Washing	Cooking	Organic waste	Waste separation	Diet, unhealthy calories, baby food, gluten-free

Chapter 4

soil, water and air of gases, biocides and minerals. Biocides affect growers and nearby residents of applied fields less when deployment follows regulations aimed at safety and users of finished products are protected by maximum residue levels (MRLs). Canali et al. (2014) in their extensive study reported in “Drivers of current food waste generation, threats of future increase and opportunities for reduction in their extensive” distinguish three context categories, technological, institutional (divided into economic and legal aspects) and social (consumer behavior and lifestyles). In the supply chain they distinguished the links primary production, processing of agricultural staples, food processing and packaging, wholesale and logistics retail and markets, food services and households. For drivers of food waste current, future worsening and future improving scenarios were selected. This matrix is shown in Table 4.3A7. The potato processing industry from farm to fork 120ncludes some on-farm operations such as storage, grading and sorting and in Table 4.3A7 these activities are assumed to pertain to primary production. The processing industry most often deals directly with farmers and with retail so the wholesale and logistics link coincides with food processing. The two links Food Services (restaurants, institutions and caterers) and Households are lumped assuming that total losses are similar for both ‘Kitchens’ but the contexts of both are considered in Table 4.3A7. There are a few recurring issues as common denominator across chains, drivers and context. These are poor communication about supply and demand, with current flaws, but also hints at better communication that contributes to solutions. Governments policies on subsidies and taxing of growers and actors in the supply chain segment disposing of waste and on enhancing awareness and R&D are considered essential contributors to drivers of food waste. Consumer preference for how food is produced and the potential to reduce waste is brought up a few times by Canali et al. (2014) and Aramyan and Valeva (2016) as well as the low cost of production, processing and distribution.

Losses occurring from primary production to kitchens of outlets and household are driven at the current level and get worse or improve in future in technological, economic, legal and social contexts (Table 4.3A7). Across links and contexts current flaws in communication lead to losses but future developments contribute to solutions, awareness of losses being a main aspect with government interventions through taxation, subsidies and research and development key as to make food more expensive by including externalities and so inviting consumers to waste less as it will be increasingly costly. Losses are greater in fresh produces due to their perishability compared to chilled and especially frozen products that have a longer life on the shelf and in cold compartments of pantries.

At higher cost of production and sales, increased prices would reduce food losses as consumers would consider it a financial waste. Including externalities (costs of avoidance of emissions and of the use of non-renewable resources) makes products substantially more costly and so contributes to future reduction of food losses. An increased awareness of the issues regarding food waste as a waste of resources land, water and clean air, besides financial aspects, as ethical dilemmas, are considered an important contributor to diminished food waste. The report was not specifically aimed at fresh nor processed (packed, dried, chilled, canned, frozen) products, but as generic to include all foods. So many of the issues raised do not pertain to chilled, frozen and dry potato products where perishability is less of an issue than is the case with fresh vegetables exposed on shelves. For processed products planning is not a major issue, it is more imminent for fresh vegetables than for frozen French fries which can be stored for up to 24 months.

Table 4.3A7. Current and future contributors (+) and opponents (-) of waste of potato products in the various segments of the supply chain in different context categories (after Canali et al. 2014)

Segments	**Drivers***	**Context categories**			
		Technological	**Institution**		**Social (consumer behavior and lifestyles**
			Business and economy	**Legislation and policies**	
Primary production	Current	Storage	Supply/demand not well tuned	Taks /subsidies for growers	Consumer preference
	Future+	Climate change with storage challenges	customer demand less well known	Contracts supplier-retailer	-
	Future-	Genetics delivery of robust varieties	Shorter supply chain, better info exchange	Subsidy anti-food waste, more expensive primary production	Consumer awareness, information
Processing of agricultural staples (lumped with primary production)					
Food processing, Packaging	Current	Planning supply raw	Contracts agreements	Low cost food, externalities not charged	Consumer preference
	Future+	Not meeting specs (climate)	Customer demand	Low disposal costs	Increased demand processed food
	Future-	Use all parts, automation	Awareness food waste, information	Subsidy R&D	
Wholesale and logistics (lumped with food processing)					
Retail and markets	Current	Customer knowledge	Information sharing	Marketing standards	Behavior, tools
	Future+	Reduced shelf life (not frozen)	Marketing strategies	Low costs waste disposal	Consumer preference and attitude
	Future-	Inventory management	Awareness food waste	Sanctioning waste inductions	Consumer awareness and attitude
Food services Losses in retail and household are similar to those in other outlets (restaurants, caterers so this link also becomes redundant					
Kitchen (of food services and households)	Current	Cooling	Low prices = waste easier	Waste collection policy	Attitude, behavior
	Future+	Health drivers (perishability)	More left over, increased variety	Food laws not taking waste into account	Affluence, small portions/households
	Future-	Appliances	Doggy bag, awareness,	Waste collection, dietary guidance	Initiatives on awareness and innovations
*Drivers of food waste are the 'Current' ones, the ones increasing 'Future+' and decreasing them 'Future-'					

Quantification of the resource use domain

Quantification of impact on habitat

Yield production of raw and subsequent manufacturing, so growing, handling storage and processing lead to environmental concerns. Soil health is not affected by most operations but biocides have residual effects. Irrigation affects soil fertility through leaching of minerals but field operations compacting soils have a stronger effect. Fresh water as a resource is mainly withdrawn from the environment for irrigation and washing. Fuel leading to CO_2 emission and particulate matter (eco-toxic) is deployed in many operations and so is electricity. Decarbonization opportunities are few for irrigation but for transport use of renewable electricity sources is opportune. Eco-toxic substances are nutrients from fertilizers, biocides for crop protection and fine particles from diesel fuel (tractors and lorries). Biodiversity is affected by most field operations and humans' health by crop protection and anti-sprouting chemicals, particulate matter and some side effects of frying in kitchens such as the formation of acrylamide.

The operations on farms traction and supplying resources, storage and mechanical operations such as conveying, grading and sorting that are shared with manufacturing, transport and temperature related operations in factories, as expressed in Tables 4.3A1,2,3 are grouped in 10 rows in Table 4.3B1 with nine columns with attributes embodying their direct or indirect effect on the habitat. Many operations affect energy from fuel and electricity, and only a few exert an influence on soil health, fertility and water need.

Table 4.3B1 Heatmap of 10 classes of operations and 9 attributes about negative impact on environment and society (habitat)

Much	a	Soil fertility affected	Little
	b	Soil health affected	
	c	Quantity of water needed	
	d	Energy from fuel needed	
	e	Energy from electricity needed	
	f	Lacking decarbonization opportunities	
	g	Eco-toxicity at risk	
	h	Biodiversity at risk	
	i	Human health at risk	

Classes of operations			a	b	c	d	e	f	g	h	i	Av
1	Growing	Irrigating										3.3
2		Fertilization[m], organic matter										2.8
3		Crop protection[m]										3.2
4		Energy use in operations[n]										2.4
5	Storage (cooling, sprout control)											2.6
6	Transport[o]											2.8
7	Washing[p]											1.9
8	Heating[q]											1.9
9	Cooling, freezing											1.6
10	Mechanical operations[r]											1.6
Average			1.3	1.4	1.9	3.3	4.1	2.0	3.0	2.7	1.9	2.4

m Includes energy embedded in its production
n Traction only, irrigation apart in the first row
o Transport of tubers to factory, of products from factory to shops and from shops to users
p Washing of tubers, of peeled tubers (after washing) and of starch
q Steam peeling, pre-heating, blanching, frying, drying (drum, flash), baking
r Abrasive peeling, sorting, grading, cutting, grinding, conveying

Irrigation receives the highest average value of all attributes (3.3) as almost all, human health exempted, habitat affecting attributes apply to a large (energy and water need) or to a lesser degree

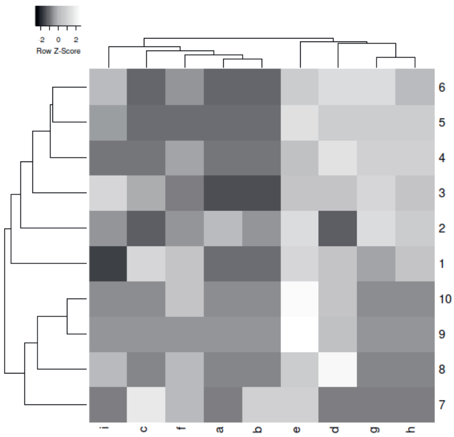
Flour based products

(soil health and fertility). Crop protection also has a high average score with only low values for soil. The relatively confined and contained factory operations all receive low scores of 1.9 on average to 1.6 as they pose few threats to the habitat. Average values of attributes over all classes of operations are lowest for soil fertility and health (1.3 and 1.4) as they affect few classes, and highest for the use of electricity as in all operations, to a greater or lesser degree, electricity is involved. The attributes are not weighed so possibly the fuel score of 3.3 for diesel for traction on farms and transport and frying in factories is impacting habitat through CO_2 and particulate matter more that electricity, especially when partly derived from renewable resources. This is open for debate.

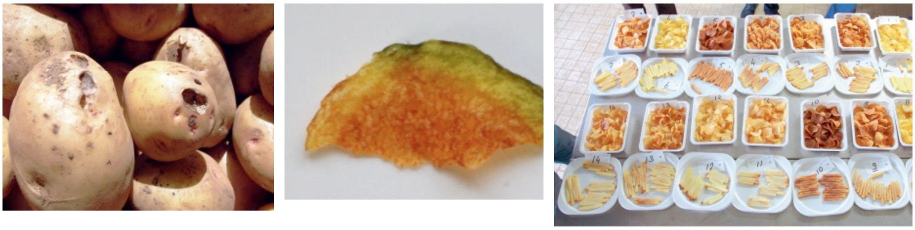
Clustering of impact on habitat

The factory operations are in in one cluster and transport and farm operations in another (Table 4.3C1). Cooling and mechanical operations in factories have much in common as they both use electricity and fertilization and driving machines as both are much energy consuming. Storage and transport, albeit at a large distance, have several attributes in common concerning toxic effects for the environment and humans.

Table 4.3C1. Dendrogram of operations (see Table 4.3B1) and their effects on soil, water, energy and environment



The attributes show two distinct clusters with on the right the close twins ecotoxicity and biodiversity with energy needs at quite some distance. This is indicative that CO_2 associated with energy production



Rejects: tubers, product, criteria

is linked to the ecosystem. The larger cluster on the right holds the doubles soil fertility and health with decarbonization opportunities, water need and risks for human health at increasing distances.

Quantification of losses and wastes

Several opportunities exist (Table 4.3B2) to diminish losses in production of tubers, products and dishes. Buying and selling the appropriate quantity of seed tubers, ware tubers and products by growers, processors, shops and cooks reduces losses as mismatches here lead to depreciation and

Table 4.3B2. Heatmap of 28 classes of losses with 9 attributes: the opportunities to reduce wastes and losses of material

Very important	a	Avoidance of mismatch procured/sold and used	Unimportant
	b	Proper management of operation	
	c	Timing of the interference	
	d	Aligning of the equipment	
	e	Selection of the location production raw	
	f	Altering specifications/quality of finished product	
	g	Altering the specifications of the raw material	
	h	Recovery and re-use of waste	
	i	Calamity (glass, other foreign bodies, toxic substance)	

Stage	#	Classes of losses	a	b	c	d	e	f	g	h	i	Av
Farm	1	Seed tubers										2.6
	2	Tubers lost, bad weather										2.4
	3	Tubers left deep in soil										2.4
	4	Tubers damaged at harvest										3.3
	5	Tare at store loading										1.7
	6	Defects, sorted										3.1
	7	Odd sized, graded										3.1
	8	Shrink, storage										2.2
	9	Sprouted in store										3.4
	10	Surplus tubers not sold										2.9
Processing	11	Surplus total raw procured										2.9
	12	Washing water										2.2
	13	Solids, brine/clay separation										3.6
	14	Peels										2.6
	15	Sorting, tubers optical										2.3
	16	Slivers, sorted optical										2.3
	17	Lengths, sorted optical										2.3
	18	Color, sorted optical										2.3
	19	Processing water										2.4

Very important	a	Avoidance of mismatch procured/sold and used	Unimportant
	b	Proper management of operation	
	c	Timing of the interference	
	d	Aligning of the equipment	
	e	Selection of the location production raw	
	f	Altering specifications/quality of finished product	
	g	Altering the specifications of the raw material	
	h	Recovery and re-use of waste	
	i	Calamity (glass, other foreign bodies, toxic substance)	

Stage	#	Classes of losses	a	b	c	d	e	f	g	h	i	Av
	20	Vegetable oil, crumbs										2.1
	21	Dry matter conc. Product										2.3
	22	Surplus product not sold										3.0
Shop	23	Expired										2.3
	24	Recalled										1.9
	25	Cooling/freezing failure										2.0
Kitchen	26	Left in storage in pantry										2.6
	27	Failed cooking (burnt…)										2.9
	28	Left in pot, on plate										1.6
		Average	1.9	3.6	2.6	3.1	1.7	2.6	2.0	3.4	2.0	2.5

use as a lower value side stream. Managing operations such as dose and amounts influence wastes as well as their proper timing. Adequate aligning of machinery such as the scissors of diggers and optical sorters avoids losses. Where there is a threat of losses occurring due to the environment or specs strategic decision assist such as looking for sites with fewer risks of losing crops due to adverse weather. Alternatively, altering the specs of raw as to meet the demand and/or alter the specs of the finished products. In years with low yields smaller tubers and shorter French fries have to be accepted to reduce losses and meet demands. Recovery of otherwise wasted material to be used as a side flow is valid for surpluses and sorted and graded material as feed or raw material of flakes. Some calamities such as floods, glass in stores or noxious chemicals lead to losses or recalls but adequate prevention offers opportunities to reduce these.

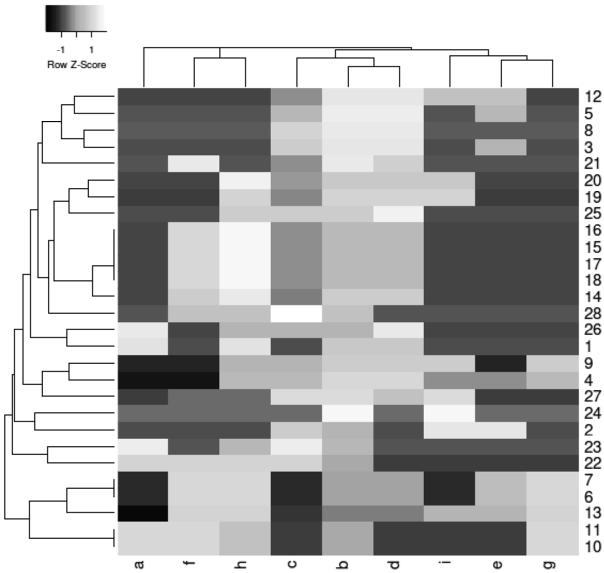
The average values of the scores of the attributes per class are shown in the rows of the heatmap in Table 4.3B2. Losses at the table seem hardest to avoid by the opportunities enumerated in Table 4.3B2 with an average of 1.6 only. This is similar to tare such as adhering soil and stones where only aligning the harvester has some influence. Harvest damage, sprouting, low solids as becomes apparent in separation of tubers in a brine solution offer most chances through interferences.

The average values of the scores per attribute over all classes are shown at the bottom of the columns. Better management in general and re-use are best means of interference with an average of 3.6 and 3.4, with site selection offering the slightest chance (1.7).

Clustering within the sub-domain impact on habitat

The dendrogram in Table 4.3C2 shows several groups of losses with exactly the same opportunities to reduce them. These are x) the surplus tubers of growers and surplus products of processors, y) sorting and grading and, z) all optical techniques sorting defected peeled tubers, sliver and divergent lengths and colors of French fries. Losses of peels are closely linked to these. Closely related regarding interventions to reduce them are tare and washing water of harvested tubers, losses due to unharvested tubers and shrinkage in the store with losses of water during processing reflected in the dry matter concentration products. Reducing losses of processing water and processing oil has many options in common and so have growers buying too many seed tubers and cooks buying too much product and further surpluses of factories and of shops. Other groupings of losses are less open to explanation.

Table 4.3C2. Dendrogram of losses and wastes 1-28 and opportunities to reduce them (Table 4.3B2)



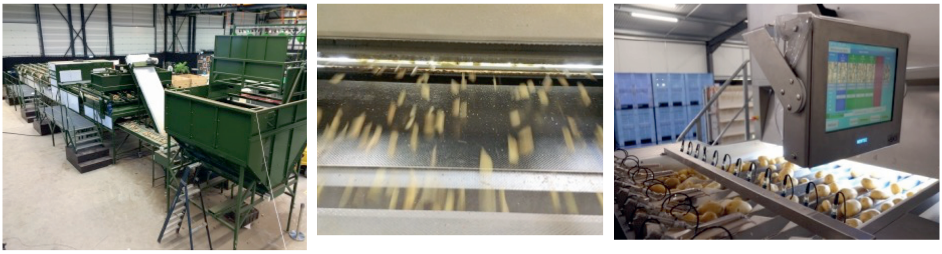
The nine opportunities show three clusters and a single one, avoidance of the buying and selling mismatch. Changing the specifications of the finished product shares many opportunities with re-use of lost material. Management, timing and alignment are in one cluster and so are specs and location selection of production of raw.

Deliberations and conclusions

This chapter with focus on production aspects of the domain "On Processing Potato" applied the Four-Tier Analysis starting with formulating and delimiting each of the domains: supply chain, performance of farms and factories and Resource use (including impact on the environment, losses and wastes. In each domain classes were identified descriptors assigned in the process of domain condensation. The four heatmaps were quantified and classes and attributes clustered. The research questions proved to be relevant to structure this chapter and were adequately addressed by the analysis. Here follow some conclusions per question.

Research question about imaging supply

Breeders interact strongly with processors because variety and environment exert the strongest influence on tuber yield and processing quality. In some instances large processors have their own breeding department or own a breeding company. At an early stage, well before a variety is named factories do proof runs with advanced material to assess the processing quality for the production of chips, flour, French fries and more. Although the quality of the product is visible in the finished products, flesh color for instance, the breeder does not have the strongest say so. Of all the actors the breeder only exchanges material with the seed growers and exchanges information with them and



Rejection: grading and sorting

with the processors. The latter are most central in the supply chain and send information upstream and downstream and almost all attributes of the classes of actors. Customers of processors and shops are not always cooks, as outlets such as restaurants, institutions and caterers have buyers of provisions they need. Eaters, cooks and buyers at the upper end of the chain have great interest in quality and use of old and new products whereas breeders and growers at the opposite end hardly show interest as they cannot influence this. The clustering shows this dichotomy with actors dealing with raw material and those processing and moving it upstream.

Research question about efficiencies on farms and in factories

Tuber yield and quality depend on four major factors (G, E, M, S): the planted seed material (variety, seed age, size and health), where and when it is planted and managed by the grower. Society preferences and legislation impose further requirements on products and how they are brought about. These factors also largely determine the efficiency of resource use expressed as land use efficiency (yield) in t/ha, water use in g/liter and seed use expressed a g of tuber yield per g seed tuber planted to name a few. Typical values given - 45, 6 and 20 - vary much reliant on the four factors and naturally fluctuate from 10 to 80, from 3 to 10 and from 10 to 30 respectively. Higher temperatures and an increase in the CO_2 concentration of the ambient air also impact yield specially potentially positive in temperate climates. G, E and M also influence the concentration of tuber components and the aptness for processing into classes of starch, chips, fried and chilled products expressed as Recovery, the proportion of finished product extracted from the harvested tubers. Recovery follows from Handling, Storing and Processing (H, S, P). The G, E, M, H, S and P aspects are made attributes of the classes of farm and factory performance indicators that very much apply to yields of tubers, chips and French fries and hardly to concentrations of constituents. Especially variety, environment (twins at short distance in the cluster hierarchy) and processing impact classes most.

Research question on resource use in processing

Energy in factories is from electricity and fuel (gas, diesel, coal), the latter partly used for frying and partly transferred to steam and applied in other processes such as peeling, blanching and drum drying. Electricity is for PEF, conveying, drying and cooling. Water is mainly used for washing fresh and peeled products, as conveying agent through pipes and some for steam production. Different scientific literature sources produced diverse data on energy and water costs of production. Early sources compared factory product output with its energy and water input over a fixed period, other went into more detail per process and whether or not take re-use of hot air from cooling or blanching to preheat tubers or intermediate products. Decarbonization, mainly by electrification which gives opportunities to apply electricity from renewable resources, draws special attention with some companies declaring to become fully independent of fossil fuels in the future. Losses on farms follow from defects, grading, shrinkage in stores to name a few and from peels, slivers and starch at processing and thrown away in kitchens. Operations on farms (fertilizer use), in transport (diesel), cooling (electricity), factories (waste water) and oil and energy use in kitchens involve not only losses but also negatively impact the environment and human health. Losses and wastes are partly avoidable through technology (genetics, adapting to climate change planning supply, through organization (contracts, subsidies, legislation) and social behavior. Quantification of the attributes avoidance of 28 classes of losses from planting to plate yielded a heatmap showing that mismatch between supply and demand applied to few losses only and aligning equipment and aiming at high recovery touches many losses. Shops have the fewest possibilities to avoid losses because losses there are scarce, expired dates mainly. Sorting and grading on farms and in factories are major operations where material is discarded and where only altering criteria, leniency, offers solace.

Losses on fields, in factories and habitat

Yields of fields are expressed as tonnes of tubers per hectare and in factories as kilograms finished product per tonne of raw material. Yields are achieved at the expense of resources and inputs with an efficiency determined by unavoidable losses in fields and factories, by intended losses, by avoidable (to a certain degree) losses and wastes of resources and inputs. Intended losses are skin at peeling and water in the tubers at drying and frying. Avoidable losses, albeit not fully, are tubers left in the soil, rejection due to low solids and not emptying the plate. Partly avoidable wastes are water and nitrogen fertilizer in growing tubers, water and heat in processing and fruitless efforts in the kitchen. The most significant losses occur with sorting by eye, optics and brine of tubers and/or (semi) finished products. The cause is not sorting but lies in prior avoidable losses. Habitat is affected by sourcing of water and emission of polluting agents to soil, water and atmosphere.

Chapter 5.

NUTRITION
Domains of dishes, senses and nutrients

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Abstract
Worldwide, hundreds of potato dishes exist, originally composed by cooks in traditional kitchens. Gradually cooks more and more applied processed products as ingredients to save time and to widen their range of dishes. The products are classified according to their features, ranging from thickener in soups to ready to eat snacks. Besides cooks, also the food industry makes ample use of (modified) potato starches, flakes, flour and granulates. Before users prepare meals from purchased ingredients, they only have had visual perceptions of the products as displayed on shelves and in freezers of shops and presentations at the internet. The organoleptic properties, taste smell and structure of tubers and products are perceived in the kitchen only. Sensory appreciation, likewise, is a function of the types of ingredients in dipping and batter during processing, and their role to improve products and flavoring. The nutritional value of tubers, other staples and potato products and dishes is analyzed and their enhancement and losses in the production of the raw material and processing are discussed. The nutritive value of tubers and their products was explored. Often, not in all cases, the density of nutritive components of the products is correlated with their water content that decreases from blanched or baked, to fried French fries, chips and flour. Starch, minerals, some vitamins and antioxidants become less diluted and appear in higher concentrations in products than in the raw material they were derived from. The energy content increases more than proportional in fried products because of adhering oil that per unit weight almost has more than double the energy content of starch. Additives such as sodium acid pyrophosphate (SAPP), batter and dextrin improve the color of French fries, their crispiness, and staying hot time, and give the golden hue. Flavoring creates a wide range of tastes of French fries and chips. Blanched and chilled products whether or not mixed with vegetables are often supplied with sachets of seasoning to be spread on the product while preparing a dish in the kitchen as the seasoning effect would partly disappear when mixed with the chilled product. Different consumer desires from, among others, health and environment perspectives are articulated and it is assessed how easy or difficult it is for processors to manufacture suitable innovative products.

Inception and research questions
The objectives of this paper are to review existing potato dishes in national cuisines and how the processing industry derived thereof products that represent these dishes and/or their ingredients and distributes these through retail, the food industry and consumer outlets. Exploring the nutritive value of tubers and products is aimed at determining the influence of processing on the contents of carbohydrates, protein, fiber, minerals and vitamins and some of the factors that are related to human health. More specifically the following questions are addressed.

Research question about potato dishes
Potato dishes vary from country to country and among regions, families and generations. In general, worldwide, what is the variety of potato dishes and can they be classified and characterized according to groups with similar attributes? Which manufactured products are ingredients of such dishes prepared in kitchens and which manufactured products are used by the food industry?

Research question about sensory perceptions
In shops, customers can just see the packages of products and only when wrapped in transparent polyethene chilled or frozen tuber parts are visible. Package materials differ such as cartons, polyethene bags or aluminum trays and within the package units differ in shape and size, individual

chips for instance. Some products appear in a wider variety of sizes and shapes than others, which ones? How they taste and smell and what the structure of tubers and of their products, is perceived upon consumption, how is it described? It all depends on which additives and flavorings were applied and which processing steps they went through. Is it feasible to classify products and attribute sensory perception, visually and olfactorily?

Research question about the nutritive value of potato products

What is the nutritive value of tubers and of their products and how is it altered by processing? How do potato and its products compare to other major staples? Which health claims are there for tubers and their products and which are adverse constituents and how are their concentrations modified through processing? Classifying products according to concentrations of constituents as attributes, will it clarify questions about their health-supporting properties?

Research question about consumer perspectives

Different groups of consumers need and acquire products from their personal perspectives. That may be for reasons of health (supplements), or concerns (community, environment) or other ones. It has not been mapped which perspectives exist for potato products and how the industry, with what kind of deliberations, is going to deliver the aspired products.

Dishes domain

Formulation of the dishes domain

A potato dish is a meal component in which potato dominates, including side dishes such as French fries accompanying a meal. Before products came to the market dishes were prepared from fresh tubers that were washed and subjected to operations as discussed in Chapter 3. The variety of dishes is boundless and is composed in different manners in diverse communities that may be countries, regions or neighboring groups. Families and generations have their own (succession of) dishes. They all have heating in common as potato starch needs to gelatinize to become digestible, this contrary to cereals that can be consumed raw, for breakfast for instance. Potato dishes differ mainly by how heating takes place and which non-potato ingredients are added. Potato products are ingredients of dishes (flour and canned as illustration), or just heat and eat (gratin) or just open the package and eat (chips).

Condensation of the dishes domain

Wikipedia lists over 150 potato dishes originating from over 40 countries, which shows the widespread presence and use of this tuber. It is considered a vegetable in German and Russian potato salads and samosa, a staple as boiled potato but also fried or mashed or added as cubes in a curry, as a dessert in a sweet doughnut and as a snack such as chips. The description of the dishes reveals how the tuber ends up, such as whole, cut into pieces, cubes, slices, chips, wedges and fritters, into smaller particles following grating up to mashing where no original potato structure is recognized anymore. Another feature that distinguishes dishes is the way of heating, potatoes are blanched, boiled, microwaved, poached, deep-fried, pan-fried, salted and cooked or gratinated. Tubers are consumed as peeled or skin-on, boiled whole or in pieces, French fries, chips, hash browns, baked, in the liquids soups and curries, mashed in stews or formed mash or dough in pancakes, gnocchi, balls, bread and croquettes.

Where in the past all such dishes were made in kitchens of homes, restaurants and institutions, now a very large proportion of the dishes and their ingredients are produced in factories and finished after reconstitution where necessary and heated before being served. Table 5.1A1. shows a somewhat condensed version of the list with potato boiled, mashed, fried or baked as an ingredient.

Table 5.1A1. List of potato dishes after https://en.wikipedia.org/wiki/List_of_potato_dishes with dishes that are very similar removed (P.= potato, pomme, papa)

Ajiaco	Chipsi mayai	Home fries	Pichelsteiner	Salt potatoes
Aligot	Chocolate-chips	Hoppel poppel	Pickert	Savoury pattie
All-dressed	Cholera (food)	Hutspot	Pitepalt	Scotch pie
Aloo gobi	Chorrillana	Imelletty	P. Anna	Shepherd's pie
Aloo gosht	Chuño	perunalaatikko	P. dauphine	Shlishkes
Aloo pie	Clapshot	Irish stew	P. soufflées	Siles. dumplings
Aloo tikki	Coddle	Jansson tempt.	Pone (food)	Spanish omelette
Aloo posto	Colcannon	Jeera aloo	Potato babk	Stamppot
Aloor Chop	Corned beef pie	Kartoffelkäse	Potato bread	Stargazy pie
Bacalhau à Gomes	Crisp sandwich	Knödel	Potato cake	Steak frites
de Sá	Crocchè	Knedle	Potato doughnut	Stegt flæsk
Batates bechamel	Croquette	Knish	Potato filling	Stoemp
B à Zé Pipo	Curly fries	Kouign patatez	Potato kugel	Stovies
B. com natas	Dabeli	Kroppkaka	Potato pancake	Szałot
Baeckeoffe	Dhoper chop	Kugel	Potato salad	Tartiflette
Baked potato	Dì sān xiān	Kugelis	Potato scone	Tater tots
Bangers & mash	Duchess potatoes	Lancashire hotpot	Potato skins	Tiella
Batata harra	Dum Aloo	Lefse	Potato waffle	Tombet
Batata vada	Far far	Llapingacho	Potato wedges	Toobs
Bauernfrühstück	Farali potatoes	Lyonnaise p.	Potatoes O'Brien	Tornado potato
Bedf clanger	Fish & chips	Mashed p.	Potatonik	Trinxat
Bombay potato	Fish pie	Meat and p. pie	Poutine râpée	Triple-cooked
Bonda	Fondant potatoes	Milcao	Forest gateau	chips
Bosnian pot	Frico	Munini-imo	Raclette	Truffade
Boxty	Fried potatoes	Nikujaga	Ragda pattice	Tuna pot
Brænd. kærlighed	Funeral potatoes	Olivier salad	Rakott krumpli	Vichyssoise
Brynd. halušky	Game chips	Panackelty	Rappie pie	Woolton pie
Bubble & squeak	Gamja-jeon	Panskurar Chop	Raspeball	Xogoi Momo
Caldo verde	Gamja-ongsimi	P. a la huancaína	Reibekuchen	Zippuli
Papas arrugadas	German fries	Papa rellena	Rēwena bread	
Carne asada fries	Gratin	Papas chorreadas	Rioja style p.	
Causa limeña	Gratin dauphinois	Pasty	Rössypottu	
Cepelinai	Halal snack pack	Patatas a lo pobre	Roasted potato	
Chairo (stew)	Hash browns	Patatas bravas	Rösti	
Champ (food)	Hasselback p.	Patatnik	Rumbledethumps	
Chapalele	Hodge-Podge	Pâté p. de terre	Salade cauchoise	
Chip butty	Hoggan	Péla (dish)	Salchipapa	

Of this alphabetical list with about 200 potato dishes, the Wiki site also gives the origin and a brief description showing how the dish is prepared or what it consists of. Starting with the first dish and going down, 13 intrinsically different dishes are distinguished, with features that reappear in the other 160 ones in one form or another. These 13 dishes are shown in Table 5.1A2. It shows how in cuisines potato is used: as thickener and substance in soups, boiled and eaten warm as such and in stews or cold and sliced in salads. Boiled tubers are whether or not mashed and when formed and fried appear as croquettes or Duchesse potatoes. Baking is done with skin-on whole tubers or as a gratin with slices or scallops in a sauce. Frying is done in a pan with some oil or deep frying as tuber pieces submerged in hot oil but still containing moisture as opposed to chips. Dumplings are cooked stuffed potato doughs. If deep-frying is done with very thin slices it results in chips. Chuño is prepared by reconstituting freeze-dried tubers and has browns are shreds formed as patties, seasoned, with onion added and pan- or deep-fried. Roasted potatoes are cut tuber chunks, blanched and pre-fried or sprinkled with oil and baked in the oven at high temperatures.

Table 5.1A2. Examples of dishes from Table 5.1A1 with typical features that distinguish them as a class

Nr	Dish instance of class	Attribute origin	Few features as attributes	Class of product manufactured
1	Ajiaco	Colombia	Thickener	Soup
2	Aloo gobi	India	Served as such or cuts in stew, curry	Boiled
3	Aligot	France	Boiled, mashed	Mash
4	Aloo tikkie	India	Fried mash	Formed
5	Baked potato	International	Whole baked, slit	Jacket potato
6	Batates bechamel	Egypt	Sliced or scalloped, baked in sauce	Gratin
7	Batata harra	Lebanon	Blanched, cut sprinkled with oil	Pan-fried, sauteed
8	Bengal potato	India	Deep-fried moist	French fries
9	Bryndzove halušky	Slovakia	Dried mash envelope	Dumpling
10	Chips & Dips	International	Deep dry-fried dry	Chips
11	Chuño	South America	Freeze-dried	Dry products
12	Hash browns	International	Formed fried shreds	Hash brown
13	Roast potato	United Kingdom	Oiled, baked chunks	Roast potato

Potato products in dishes and their users

From homemade dishes starting with fresh tubers, the potato processing industry gradually Survey 1 (Haverkort et al. 2022a) produced more and more ingredients and complete dishes. Also new products previously not prepared in kitchens were developed and commercialized. Table 5.1A3 lists in

alphabetical order such dishes, the food ingredient from the shop or the market, the process it went through, how it is sold and what kitchens in restaurants, institutions and homes need to do after opening the package. Most favorite replacements of kitchen preparations are French fries and hash browns (still needing deep or pan-frying) and peeled blanched tuber(s) (parts) still needing boiling or (pan) frying in the kitchen. Very frequently purchased but rarely prepared by cooks are chips, croquettes and dumplings. Fiber, protein and expanded or stackable chips are not made in kitchens but are on offer on the market.


Potato salads

The purchased food components, potato products, are listed in Table 5.1A3. cover the whole range of basic products made by the processing industry (starch, fiber and protein) as well as prepared ones (cooked, dried, formed and fried). The processes underlying the products were addressed in Chapter 3.

Table 5.1A3. Homemade dishes of Table 5.1A1. from (partly) manufactured ingredients/components. Darkest color: baking and frying, heating above 100°C, intermediate color: cooking, boiling blanching at 100°C, light color, ready to eat

Dish (main example)	Purchased food component	Basic processed ingredient	Usual status at purchase	Kitchens preparation
Andean stew	Chuño	Freeze dried pieces	Dried tuber (pieces)	Reconstitute, cook
Baked potato	Jacket potato	Pre-baked tuber	Frozen, Chilled	Bake, grill, microwave
Cooked	(Baby) tubers, slices	Pre-cooked, chilled	Chilled vacuum packed, canned	Heat/fry
Sauteed	Tuber parts	Pre-cooked, roasted	Chilled vacuum packed	Pan fry
Croquette	Filled/dough	Flakes	Frozen	Thaw, deep or air fry
French fries	Fries	Par-fried chips	Frozen, chilled	Deep or air frying
Gnocchi,	Dumpling	Formed flour dough	Chilled/frozen/dry	Steam, boil
Gratin, scalloped	Whole dish	Gratinated slices	Whole, frozen	Thaw, bake in oven
Hash brown	From shreds	Pre-cooked shreds	Frozen	Deep fry
Ketogenic diet	Potato fiber	Skin mainly	Dry grainy substance	Reconstitute, boil or add wheat flour (bread)
Kugel	Casserole	Flakes, flour	Frozen	Thawing, baking
Pan cake	Formed dough	Flakes or flour	Frozen	Pan-fry
Scalloped	Raw dry slice	Air-dried raw slice,	Loosely packed	Reconstitute, heated
Roasted	Heated cuts	Pre-fried cuts	Frozen, loosely packed	Hot oven 200°C
Snack	Popped chips	Swollen hot pressed slice	Dry, loosely packed	Ready
Snack	Airy chips	Expanded heated pellet	Dry, loosely packed	Ready
Snack	Coated nuts	Starch coating	Dry, loosely packed	Ready
Snack	Stacked chips	Deep-fried dough slices	Dry, stacked in a box	Ready
Snack	Oven chips	Oven-baked dough slices	Dry, loosely packed	Ready
Snack (tuber)	Chips	Deep-fried tuber slices	Dry, loosely packed	Ready
Soup (dry)	Soup powder	Flakes, modified starch	Powder	Add water, heat
Soup (liquid)	Liquid soup	Flakes, modified starch	Liquid	Heating
Sport drink	Supplement	Protein	Powder	Add liquid

Products for the industry

In Chapter 3 it is shown how potato starches are modified to be used by the food and nonfood industry. Several potato products from the processing industry, besides being employed by the end-user, cooks in kitchens, also find their way to the food companies such as bakeries for bread and biscuits, general food industry as thickeners and extenders and as ingredients for patties, soups and gratins (Table 5.1A4). The majority of such intermediate products are the standard flakes, as such producing a mash for food services. When finely ground they serve as binder and thickener for the general food producers. When mixed with granulate they better mimic freshly cooked and dried tubers so suit making salads and side dishes. When ground very finely it produces a potato flour not fit for making a mash but used as thickener and extender. Low peel, low leach flakes are made of very lightly peeled and blanched tubers that only rehydrate when part of a dough (Mu et al. 2007) for e.g. pizzas and for

Table 5.1A4. Use of potato (intermediate) dehydrated products by food industry and services, after PotatoesUSA (https://www.potatogoodness.com/ingredient/resources/dehydrated-potato-varieties/)

Product	Characteristics	Reconstitution	Main use
Modified starches (Chapter 3)	White starchy powders	Substantially improved over native starch	Food industry (baking, batter, clear thickener)
Standard flakes	Bright white, coarsely ground. Finely ground: thickener, breading, binder	Water + milk at 77 °C (not 100 ºC to avoid stickiness (cold water possible)	Potato taste mash for food service, bakeries, general food manufacturers
Mashed potato mixes	Flakes and granulate mixes, add taste highly convenient	Water + milk at 77 °C (not 100 ºC to avoid stickiness	Mash for salads, main and side dish (found in supermarket, restaurant, institution)
Low peel, low leach flakes LP/LL	Less white, finely ground, starchy structure	Only rehydrated in cohesive dough mixture, convenient handling	Food industry pelleted snacks, cookies' ingredients, adds flavor to pizza dough
Standard granules	Toughened cell walls cause granular structure. Taste and feel as mash of fresh tubers	Added to boiling water and whipped (not cold water soluble)	Institutions as potato mash, also for hash browns, extruded products (pellets) , thickening agent
Flour (granular <420 µm and fine <177 µm)	Produces sticky substance with water, not for mash	Not rehydrated by itself always is an ingredient for softer mouth feel	Thickener, extends other flours, ingredient in biscuits
Slices, dices, shreds	Dehydrated blanched tuber parts	Hot water added, then used as ingredient	Canned soups, stews, hash brown, casserole, gratin

the production of pellets. Standard granules are not soluble in cold water. With their mouth feel of boiled and ground tubers, they are at the base of among others hash browns. Cut (as slices, cubes and shreds), blanched and dried but not ground tuber parts, upon rehydration reappear as cooked potato parts and as such find their way to the food industry for processing into soups, hash browns and gratins. Table 5.1A4. gives an overview, of these products, some typical characteristics, how they are rehydrated and their main use by the potato processing and other food industries.

Quantification of the dishes domain

The previous tables successively displayed the variety of traditional potato dishes, classes of products made by the processing industry based on these dishes and how products are used as ingredients to prepare dishes to complete the cycle. The heatmap in Table 5.1B demonstrates the 13 classes of dishes listed in Table 5.1A2, extracted from Table 5.1A1. The chosen attributes concern three frequencies, the first one is how often such a dish is made by cooks in kitchens, most frequently boiled and rarely prepared as chips. Basic ingredients bought are flour or chilled blanched tuber parts that cooks deploy to make more intricate dishes, salads and soups for instance. Frequently found in supermarkets are French fries and chips that also have the least local image, least frequently found are roast potatoes. The other attributes speak for themselves.

Table 5.1B. Heatmap of 13 classes of dishes with 10 relevant attributes

High			Low
	a	Frequency of preparation in kitchens	
	b	Frequency of using a basic processed products as ingredient	
	c	Frequency as finished products on sale in supermarket	
	d	Image as a local , not global, dish	
	e	Proportion of potato in the dish	
	f	Preparation time based on fresh tuber	
	g	Dry matter concentration	
	h	Cooking temperature	
	i	Serving temperature	
	j	Visibility of original potato structure	

Nr	Classes of dishes	a	b	c	d	e	f	g	h	i	j	Average
1	Soup											3.0
2	Stew											3.3
3	Boiled											3.3
4	Salad											3.4
5	Mash											3.3
6	Formed											3.2
7	Hash brown											3.5
8	Baked											3.7
9	Gratin											3.5
10	Pan fried											3.7
11	French fries											4.0
12	Roast											3.7
13	Chips											3.3
Average		2.6	2.8	3.8	2.8	4.4	3.9	3.1	3.9	4.0	3.2	3.5

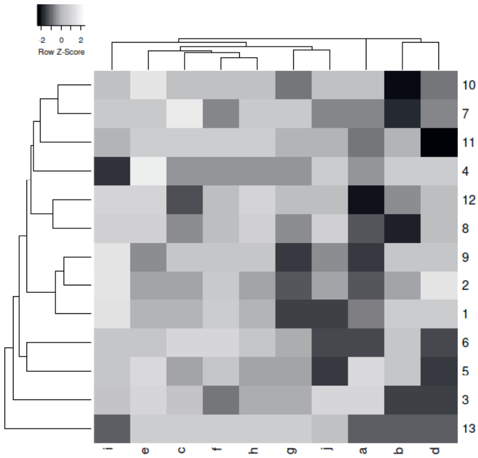
The heatmap (Table 5.1B) shows that the highest average score of 4.0 is for French fries that only have a low score for not being a local dish. Potato soup has the lowest average of 3.0 because it is relatively rarely cooked, has a low dry matter concentration and when there are no potato chunks present but potato merely used as a thickener the original potato structure is gone. In general, the red and the green colors cancel each other out, resulting in average scores between 3.0 and 3.5. The mean value of the attributes across all dishes is low, for often they are cooked and are being considered local food. High scores are for the potato content and for serving temperatures of the dishes, all hot except salad and chips.

Clustering within the dishes domain

Clustering the products as seen in the dendrogram of Table 5.1C reveals a few meaningful twins, the closest being stews and gratins, with soups nearby. Pan-fried potato and hash browns (rösti) are quite similar and so are baked and roasted tubers. Mash and formed mash based products are also twins but at a considerable distance. Chips do not belong to any cluster and stand alone.

The attributes also have twins: preparation time and cooking temperature (the higher the temperature the more time it takes), dry matter and potato structure are twins (the drier the more the products shows tuber features). Albeit at a larger distance, the rightmost twin indicates that deploying basic products still needing several preparation steps by the cook have more local appeal.

Table 5.1C. Dendrogram of the classes of products 1-13 (Table 5.1B) and the attributes a - i (Table 5.1B)



Dishes: Fish 'n Chips, gratin, burger

Senses domain

Formulation of the senses domain

Humans have five basic senses that potato and its products all appeal to: sight, touch, smell, taste and hearing. Products are seen in supermarkets and on the plate and appreciated, they are touched by hand when eating chips and have a mouth feel. They have a taste and can be smelled. Depending on the crunchiness of the product, they can be heard as well. All five senses belong to this domain and are addressed in the following sections.

Condensation of the senses domain

Taste and structure of tubers and products

When eating potatoes and their products, besides how they look, three senses matter, their taste, their smell and their texture or mouth feel (Taylor et al. 2007). These are summarized in Table 5.2A1. Potato cells contain soluble substances - non-volatile compounds responsible for the five basic tastes, bitter, salty, sour, sweet and umami (Solms 1971). Solms and Wyler (1979) attributed the taste of boiled tubers mainly to umami from an array of glutamate compounds and hardly to acids, sugars and salty molecules. During frying, at the Maillard reaction the release of such substances increases (Beksan et al. 2003). Maga (1994) reported pyrazines and degraded fatty acids to deliver

Table 5.2A1. Description of flavor and texture of cooked potato tubers and a selection of their products

Taste, feel	Elements	Range	Remarks	Salted only, compared to boiled tuber		
				Mash from flour	French fries	Chips
Flavor	Non-volatile compounds	sweet, sour, salty, bitter and umami	Umami taste (glutamates) dominates. Enhanced in Maillard reaction	Diminished umami	Increased	Still more increased
	Volatile compounds	Pyrazines, degraded lipids	Maillard reaction creates many volatiles	Diminished smell	Increased smell	Somewhat increased smell
	Glycoalkaloids	Toxic over 20 mg/100 g	Off flavor (bitter) at high concentrations in boiled tubers	Not an issue	Not an issue	Not an issue
Texture	Disintegration	None to completely disintegrated		Moderate	Slight	Complete
	Consistency	Firm to soft		Softer	Firmer	Firmest
	Mealiness	Not mealy to dry (also flouriness, waxiness)		Less mealy	Mealier	Hardest
	Dryness	Humid to dry		Moister	Drier	Driest
	Structure	Fine to coarse		Finer	Coarser	Coarsest

typical potato smell and taste in raw and cooked tubers and that the Maillard reaction produces many volatiles. Mash produced from potato flour has less taste and smell related compounds than cooked tubers but French fries and chips have a stronger smell than boiled tubers. Glycoalkaloids at relatively high concentrations lead to off-flavor (Ross et al. 1978) but at higher concentrations, above 20 mg per 100 g, they become toxic.

De geur van het aardappelonderzoek	The smell of potato research
Een aardappelfilm in kleuren is maar kinderspel - maar in geuren!! *Dat zou pas de kijkers gaan boeien* *En belangstelling ziende groeien* *Eerst ruikt men dan Post met zijn wagen* *Waar hij is, hoef je niet naar te vragen* *Dan wordt er gemalen en gesneden* *Het lab geurt van 't dak tot beneden* *Ook wand'laars langs lieflijke dreven* *Moeten met de neus wat beleven* *En nu komen keurige heren* *De smurrie met gist inoculeren* *Wat zijn er toch moedige mensen!* *Men blijft nog de geurfilm verwensen.* *De eerste gasbel stijgt er naar boven* *Men kan er zijn neus haast niet geloven!* *Men meent nu zeker te dromen...* *Alcoholische geur schijnt te komen* *En dan wordt de geurfilm bekoorlijk!*	A potato film in colors is just child's play - but in smells!! That would surely captivate the viewers. And see their interest grow First one smells Mail with his wain. Where he is, you don't have to ask. Then one grinds and cuts The lab smells from the roof down. Also walkers along lovely avenues Must experience something with the nose And now neat gentlemen come To inoculate the gunk with yeast What brave people there are! One still wants to curse the odor film The first gas bubble rises upwards One can hardly believe ones nose! People now think they are definitely dreaming... Alcoholic smell seems to arise And then the fragrance film becomes enchants
Dr Maria Löhnis (1888-1964) wrote this verse when working at Wageningen Microbiology, 1940's	

The mouth feel of cooked tubers and their products is as important as their smell and taste. Lugt (1961) proposed a description of the potato texture consisting of five properties (Table 5.2A1) and four degrees of expression such as for structure for instance: fine, fairly fine, slightly coarse and coarse where Table 5.2A1. only shows the two extremes of each characteristic. Disintegration of potato tissue in reconstituted mash is moderate, in chips it is complete. Obviously, mash is softer, more humid and has a finer structure than boiled tubers and chips are extremely firm, dry and coarse.

Visual aspects

Besides the taste and mouth feel of tubers and their products, their color, size and shape are of importance for trade and consumption. Consumer preferences for size (baby tubers < 20 mm diameter, small tubers about 35 mm, middle-sized tubers ≈ 45 mm and large tubers > 55 mm) differ per consumer and depend on the meal ingredient. Pan-frying is done with baby tubers or chunks of larger ones and for jacket potato, baked, large tubers are needed. French fries are made of long large tubers and chips of small round ones. For starch and flour, size hardly matters, although losses of peels are reduced when tubers are larger.

French fries come in many sizes and shapes with MacFry, specs for MacDonalds, thin and long at one end of the spectrum and Flemish cut at the other. Formed products are also made in different sizes and shapes. Peeled or skin-on is another visual aspect but is also coupled with taste and mouth feel. The first column in Table 5.2A2. represents the range of shapes of French fries. Chips appear in different sizes and shapes, flat or undulated with varying depths of the furrows. Of the natural chips made of thin slices of tuber each all individuals differ both in shape and size but stackable and expanded chips all have the same size and shape. Chilled tuber parts also come in many shapes to prepare boiled, pan-fried and fried dishes or ingredients. The color of the product matters too. For example, consumers in the UK and USA prefer white-fleshed products whereas in most other countries creamy colored tubers have preference. French fries and chips are not dark colored and dextrose is added to the batter to enhance the ‘ golden’ color. Some flavorings of chips act as a dye and alter their hue such as the orangish bell pepper (paprika) powder. Beside visual observations in shops, the internet increasingly offers presentations that allow users to form an opinion about the product as a basis top purchase.

Additives and flavorings

Depending on the specification of the finished product, a range of additives is available for different operations. For fried products consisting of tuber parts (not formed), the parts are dipped in a solution of SAPP (sodium acid pyrophosphate) to avoid after cooking darkening, (Calder et al. 2012) added dextrose in the SAPP solution enhances the golden color (Van Loon, 2012) and a batter of various starches make the fries crispier and keeps them warmer for a longer period which is an advantage in quick-service restaurants. An NDTV-Food (2021) website mentions as ingredients in McDonald's French fries: *“Potatoes, vegetable oil (canola oil, soybean oil, hydrogenated soybean oil with tertiary butylhydroquinone (anti-oxidant) and dimethylpolysiloxane (anti-foaming), natural beef flavor (wheat and milk derivatives), citric acid (preservative), dextrose, sodium acid pyrophosphate, salt”* Formed products are seasoned and hash browns often contain onion.

Table 5.2A2 enumerates the additives in dipping (e.g. SAPP) and batter of French fries (second column in Table 5.2A2) and of chips (oxygen in the package replaced by nitrogen) and blanched and chilled products are usually accompanied by an anti-oxidant. The bulk of frozen French fries battered or not, is not flavored. A substantial proportion, however, especially in the UK market, contains batter with a range of tastes as shown in the third column of Table 5.2A2. Snacks, chips and expanded snacks have a wide range of flavors beside the original sweet pepper (paprika) and salt&vinegar additions. Market leader Frito-Lay according to their website produces over 150 flavors ranging from simple kiwi to intricate Spanish chicken paella.

Chips

Table 5.2A2. Not exhaustive list of shapes, additives and flavorings of French fries, chips and blanched and chilled products

Frozen French fries			Chips		Blanched chilled[d]	
Cuts[a]	**Additives**	**Flavors[b]**	**Shapes**	**Flavors[c]**	**Shapes**	**Flavors**
Strait cut	Oil[1]	Cheese	Flat, original	Lays chips	(Baby)tuber	Waxy
Curly cut	Anti-oxidants	Bacon	Undulated	worldwide offers	Sections	Floury
Crinkle cut	Preservatives	BBQ smoke	Furrowed	over 150 flavors.	Round slice	Bell pepper
MacFry	Dextrose[2]	Chimichurri	Ribbed,	Here follow a few:	Oval slice	Gratin
Flemish	SAPP	Garlic	ridged		Crinkled	Ham
Wedges	Salt	Beef	Popchips[5]	- Salt and pepper	slice	Onion
Taterdrums	Wheat, rice	dripping	Kettle chips[6]	- Sour cream and onion	Small discs	Vegetable
Lattice cut	flour[2]	Beer (IPA)	Stackable[7]	- Honey, mustard	Cubes	mixes
Twister	Milk	Paprika	Sticks	- Spanish chicken paella	Wedges	Burgundian
Skin-on	derivates	Cayenne	Wafer, lattice		Hasselback	Texan BBQ
Wedges	Dextrin[2]	pepper	Extruded,	- German sausage	Skin-on	Bistro
Chunks	Bleached	Turmeric	expanded.	- Scottish haggis	French fries	
	starch[2]	(curcumin)	Many two	- Fried green tomato	in various	
	Gluten-free[3]	Lemon oil	and three	- Hot and sour fish soup	cuts, see	
	Pea fiber	Citric acid	dimensions		first column	
	Xanthan	Onion,		- Kiwi		
	gum[4]	parsley	Additive: nitrogen (CA)		Additive: anti-oxidant	

a: From chapter 3, Table 3.2A2
b: Examples taken from : https://www.mccain.co.uk/products/
c: Examples taken from https://www.listchallenges.com/lays-chips-flavors-worldwide-list
d: Mainly based on the inventory presented in Chapter 3 Table 3.2A1

1: Examples Palm, canola, soybean, sunflower, groundnut
2: Component of batter
3: Additives devoid of gluten
4: Stabilizer
5: Popped, not fried, dough based, regular shape
6: Thicker than original flat
7. Saddle shaped, all identical

Quantification of the senses domain

The thirteen basic products addressed in Table 5.1A2 are present in Table 5.2B with senses related attributes. Potato mash has the lowest average score of all products and only has some potato flavor and mouth feel. Also, soups and simply boiled tubers have low scores with soups having many ingredients and small and boiled visible tubers. The highest average is for chips with high scores for all sensory appreciations except for the original tuber texture that has gone completely with deep-frying till all water is gone. Another high score for many of the same attributes but with a lighter weight are for French fries that outperform chips with the assortment of shapes.

Table 5.2B. Classes of 13 potato product based dishes and their 12 sensory related attributes

High Much Many Dark	a b c d e f g h i j k l	Variability in shapes per product unit within package Variety in weight/size among packages of the same products Crunchiness Additives beside potato Flavor intensity Variety in flavors Smell intensity Color intensity Skin on visibility Variety in shape of products Original tuber shape visible Original tuber texture sensible	Low Little Few Light

Nr	Classes of dishes	a	b	c	d	e	f	g	h	i	j	k	l	Average
1	Soup													2.6
2	Stew													3.2
3	Boiled													2.8
4	Salad													3.1
5	Mash													1.9
6	Formed													3.1
7	Hash brown													3.5
8	Baked													3.5
9	Gratin													3.2
10	Pan fried													3.7
11	French fries													3.9
12	Roast													3.8
13	Chips													4.2
	Average	2.9	3.2	3.1	3.4	4.0	3.2	3.7	3.3	2.6	3.1	2.9	3.6	3.3

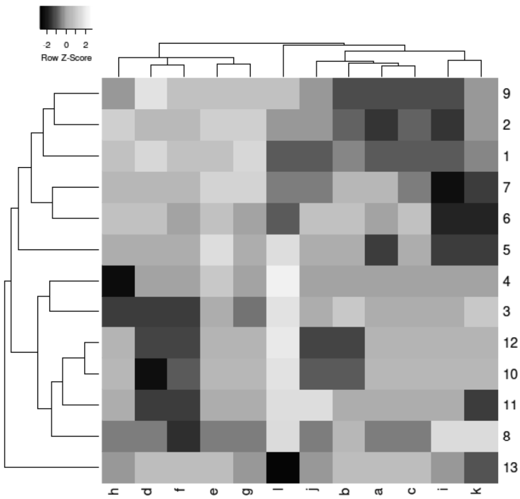
The highest score over all products is for flavor intensity (4.0), which is high for all products except for boiled and mashed tubers. Low scores (2.9) are for the variability of product units within a package which is only very high for chips with each unit having a different shape, size and color and also for the original tuber still visible (2.9) with only a very high value for baked skin-on tubers.

Chips information tables: ingredients, footprint , nutriscore

Clustering of the senses domain

Chips stand alone and are not grouped with any other dish. The three moist dishes soup, stew and gratin are in one cluster beside the group mash, formed mash and shreds (hash browns). This clustering is not unlike that of Table 5.1C with a different set of attributes that were not related to senses. The attributes reveal 4 twins: more additives are associated with more variety in flavors, smell and flavor coincide, crunchy chips also vary much in shape and skin-on reveals most original tuber features.

Table 5.2C. Dendrogram of classes of potato-based dishes product (1-13, table 5.2B) and their sensory related attributes (a-k, Table 5.2B)



Nutrients domain

Formulation of the nutrients domain

Nutrients are substances living organisms need to sustain themselves. The most important ones to deliver energy to animals are, carbohydrates mainly and fat and for building material for tissues, protein is especially vital. In the following ten tables nutrients are presented, the first one with conversion factors of nutrients to energy and the results for potato tubers. Next, four tables are dedicated to the comparison of nutrient concentrations in potato to some other root and tuber crops and potato flour with wheat flour. The following table shows the range of nutrient concentrations in tubers of different varieties and origins; variety, environment and crop management influence tuber composition strongly, especially for low concentration constituents such as vitamins, antioxidants and minerals. Three tables are dedicated to the nutrient composition of potato dishes with different varieties of dishes and origins of data. The last table in the section "Condensation of the nutrients domain" discusses some health claims specifically of potato nutrients.

Condensation of the nutrition domain

Comparison with other foods

The value of staple crops for feeding humans and animals is mainly expressed by the two main components: the energy content in its carbohydrates (sugars, fiber and starch) and its protein content as an essential element of body tissue but also a deliverer of energy, both 17 kJ/g beside lipids that deliver 37 kJ/g. The European Union food industry labels its food according to its contents of fat, ethanol, proteins carbohydrates and a few other substances and derives from it the energy content of the product according to European conversion legislation shown in Table 5.3A1. There are more

Table 5.3A1. European Union conversion table of food constituents to its energy content (EU, 1990)

Food component	Energy Density		Component in 100 g unpeeled potato	Energy density in 100 g tuber (kJ)
	kJ/g	Kcal/g		
Fat	37	9	0.2	7.4
Ethanol	29	7	0	0.0
Proteins	17	4	1.9	32.3
Carbohydrates	17	4	18.5	314.5
Organic acids	13	3	0.02	0.3
Polyols (sugar alcohols , sweeteners)	10	2.4	0	0.0
Fiber	8	2	1.7	13.6
Total				368.1

nutrients such as minerals in food but these are considered noncaloric so their value is zero. The potato values in Table 5.3A2. are taken from Table 5.3A3. an average of a few sources. The actual value of dry matter concentration (22.1% in Table 5.3A3) differs according to variety, degree of maturity of the crop at harvest, soil type and management practices all discussed in Chapter 4. When a freshly harvested table potato after boiling contains 18% dry matter only, its energy density will be about 300 kJ per 100g.

Besides these components, other constituents are important such as minerals among them calcium in bones and teeth and vitamin C (ascorbic acid) essential for an array of bodily functions. The tuber crop potato compares well with other tropical root and tuber crops such as sweet potato, yam, taro, and cassava (Table 5.3A2). Potato has the lowest proportion of dry matter, carbohydrates mainly, about half that of cassava. In other words: potato has the highest proportion of water of these crops. The two crops with the highest proportion of carbohydrates, sweet potato and cassava have the lowest protein concentration. Potato is low in energy but frying makes it a high energy food. Resistant starch is present and increases upon retrogradation, reducing sugars contribute to acrylamide formation and chlorogenic acid to after cooking darkening. Part of its protein, patatin a storage protein comprises about 40% of all protein (Alting et al. 2011), is high in lysine but low in methionine and cysteine so complements cereals. Its antioxidants concentrations vary considerably with flesh color, carotenoids high in yellow and anthocyanins high in red-fleshed tubers. The calcium concentration varies widely among crops with potato lowest and so do those of Vitamin C with taro and yam being relatively low but the other crops are effective sources for the ascorbic acid needs of humans.

Table 5.3A2. Contents of energy, carbohydrates, protein, calcium and vitamin C per 100 g edible part in the five major root and tuber crops (Woolfe 1987)

Crop	kJ/100 g	g Carbohydrates	g protein	mg Ca	mg Vitamin C
Potato *Solanum tuberosum*	335	18.5	2.1	9	20
Sweet potato *Ipomoea batatas*	485	27.4	1.4	33	26
Yam *Dioscorea* spp.	444	24.2	2.2	25	9
Taro *Colocasia* spp.	423	23.5	1.9	38	6
Cassava *Manihot esculenta*	607	35.2	1.1	38	36

The following not exhaustive list of root and tuber crop globally or regionally play a role as staple (Chandrasekara and Kumar, 2016): Potatoes (*Solanum tuberosum)*, country potato (*Solenostemon rotundifolius)*, cannas (*Canna edulis)*, arrow root (*Maranta arundinacea)*, taro (*Xanthosoma sagittifolium)*, yam (*Dioscorea alata)*, sweet potatoes (*Ipomoea batatas),* cassava (*Manihot esculenta*), banana and enset *(Musa* spp.) and elephant foot (*Amorphophallus paeoniifolius).* Table 5.3A3. compares the composition of potato, macaroni and rice with two other major starch root and

Table 5.3A3. Nutrients in 100 g of three raw root and tuber crops, pasta and rice. (USDA NAL. 2015 and Furrer et al, 2018)USDA NAL, https://fnic.nal.usda.gov/food-composition.USDA NAL, , https://fnic.nal.usda.gov/food-composition.USDA NAL, , https://fnic.nal.usda.gov/food-composition

Category	Nutrients	Unit	White potato	Sweet potato	Cassava	Macaroni cooked	Brown rice cooked
Composition	Dry matter	g	21	26	38	38	27
	Energy	kJ	290	361	672	663	466
	Protein	g	1.7	1.6	1.4	5.8	2.6
	Total lipid	g	0.1	0.1	0.3	0.9	0.9
	Carbohydrate	g	15.7	20.1	38.1	31	23
	Dietary fiber	g	2.4	3.0	1.8	1.8	1.8
	Total sugars	g	1.2	4.2	1.7	0.56	0.35
Minerals	Calcium	mg	9	30	16	7	10
	Magnesium	mg	21	25	21	18	43
	Potassium	mg	407	337	271	44	34
	Phosphorus	mg	62	47	27	58	83
	Iron	mg	0.7	0.61	0.27	0.5	0.42
	Zinc	mg	0.29	0.3	0.34	0.51	0.63
Vitamins	Ascorbic acid	mg	19.70	2.40	20.60	0	0
	Thiamin	mg	0.07	0.08	0.09	0.02	0.1
	Riboflavin	mg	0.03	0.06	0.05	0.02	0.02
	Niacin	mg	1.07	0.56	0.85	0.4	1.5
	Vitamin B6	mg	0.203	0.209	0.088	0.05	0.15
	Folate (DFE)	µg	18	11	27	7	4

tuber crops Sweet potato (*Ipomoea batatas*) and cassava (*Manihot esculenta*). These have a higher dry matter concentration mainly due to a higher concentration of carbohydrates resulting in substantially higher energy content, which for cassava is more than twice that of potato.

The protein concentration is lowest of cassava but this crop has, although still modest, the highest lipid concentration and the crops are not noted for the presence of high fiber levels. Sweet potato, obviously, has the highest concentration of sugar and apparently also the highest calcium level. The concentrations of the other minerals, except for the high potassium levels in potatoes, are more or less similar in all three crops. Both potato and cassava contain substantial amounts of ascorbic acid, sweet potato not so and is also relatively low in folate. The energy concentrated in the foods is closely correlated with the dry matter concentration that is highest for cassava and pasta, hence their high energy content of over 650 kJ per 100 g cooked product. Macaroni has a high protein concentration of almost 6%, when corrected for its dry matter to compare it with potato, the concentration was 3.3%, still well above that of potato (1.7% according to these three particular sources). The two cooked cereals have substantial lower potassium levels than the root and tuber crops and higher zinc levels but lack vitamin C and are relatively low in folate.

Potato flour from the samples reported by the various authors (Table 5.3A4) contains less moisture, so appears to be more hygroscopic. It contains more ash which is partly due to its high potassium content. Their carbohydrate concentrations are similar but potato tubers are richer in starch and also in fiber. Mixes of wheat and potato flours are used as basis of dough for bread making (Yanez et al. 1981). Potato flour compared to that of wheat has more favorable concentrations of vitamin C, polyphenols, potassium and most minerals but contains much less calcium.

Table 5.3A4. Composition of potato and wheat flours (average values of Mu et al. 2017, Rahman et al. 2017, Anwaar et al. 2014)

Ingredient per 100 g	Potato Flour	Wheat flour
Moisture g	6.0	12.0
Ash g	2.5	0.5
Carbohydrate	80	75
Starch g	75	60
Protein g	9	11
Fat g	1.0	0.7
Fiber g	5.6	0.6
Energy kJ	1500	1500
Vitamin C mg	13	0
Vitamin B3 mg	5	0.9
Polyphenol (Chlorogenic acid equivalents	0.32	0.00
K mg	400	20
P mg	90	25
Ca mg	25	150
Fe, Mn, Zn, Cu	X typical value in potato flour	0.05X-0.5X Typical value in wheat flour is 1/20th to half that of potato flour

Composition of the potato tuber

Burgos et al. (2020) produced an extensive review “The Potato and Its Contribution to the Human Diet and Health” where they concluded that the bio-availability (fraction of eaten nutrient that is available for utilization) and the bio-accessibility (fraction absorbed by the guts) of potato is higher than that of other staple crops among others wheat and beans. Their tuber contents described, the range of concentrations reported by authors they reviewed and some general remarks from their review are summarized in Table 5.3A5. The health benefits of all compounds mentioned and elaborated at length by the authors are not reproduced here as many seem insufficiently underpinned by scientific literature. The variation in values in general is due to the genetic differences that exist among varieties, to the environment where the crop is grown and to the management practices the crop was subjected to, especially fertilization and water supply. Potatoes are very high in Vitamin C, high in B6, relatively low in protein compared to cereals although their lysine content complements that of cereals, and very low in lipids. The most prevalent mineral is potassium and its zinc and iron content is beneficial where these elements lack in societies and can be enhanced through biofortification. Besides Vitamin C, the antioxidants such as phenolic compounds (phenolic acid), carotenoids in yellow-fleshed tubers (lutein and zeaxanthin) and flavonoids (anthocyanins) in colored fleshed tubers play a positive role of potato in diets (Lachman and Hamouz, 2005). The concentration of phenolic acids, chlorogenic acid being the main one decreases when tubers are peeled before boiling. Losses are reduced when cooking time is diminished made possible by a preceding low power microwaving (Barba et al. 2008). Glycoalkaloids are associated with negative health aspects but their concentrations in raw material can be kept below hazardous levels through choice of variety (choosing low-level varieties), through crop management (avoiding exposure of tubers to light and processing (Friedman, 2006; Friedman and Levin, 2009). In one study (Tajner-Czopek et al. 2014) it was found that peeling reduced TGA concentration by 50% and blanching and frying added another 47%. High levels of the reducing sugars glucose and fructose

Table 5.3A5. Burgos et al. 2020. Range of contents of 100 g fresh weight raw and cooked tuber

Content unit	Range	Remarks
Energy kJ	403 - 517	Cooked potato has a relatively low energy content compared to rice and wheat. Frying triples or quadruples the energy content
Starch g	16-23	Consists of rapidly and slowly digesting starches and resistant (amylose mainly) starches. Retrogradation increases slow and resistant starches and reduce the glycemic index, Bertoft and Blennow (2009).
Glucose +fructose mg	2.75 - 400	Reducing sugars with free asparagine cause formation of acrylamide at frying in the Maillard reaction
Protein g	1.76-2.95	Concentration of protein is low compared that of rice and wheat but its biological value exceeds it. It is high in lysine and low in methionine and cysteine
Lipids	0.1-0.5	Lipids concentration of starchy root and tuber crops is lower than that of endosperm containing crop with seed as harvestable parts.
Dietary Fiber g	1.8-2.1	The 2.1 g/100 g is of unpeeled tubers as the skin has a higher fiber concentration than the flesh. Wheat flour contain less fiber than potato flour (Table 5.3A4)
Potassium mg	150-1383	Potato tubers contain a variety of minerals of which potassium is most abundant, potato is an important source of this mineral. Irion and zinc concentrations vary much with cultivar and soil characteristics. These minerals being crucial for human health, the International Potato Center (CIP) is engaged in biofortification thereof through breeding for high concentrations.
Magnes-ium mg	16-40	
Iron mg	0.29-0.69	
Zinc mg	0.29-0.48	
Phosphorus mg	42-120	
Vitamin C mg	7.8-20.6	Potato is relatively rich in Vitamin C and B6. The vitamin C concentration varies with variety, site and tuber age and decrease during storage and in

Content unit	Range	Remarks
Vitamin B6 mg	0.299	cooking. The vitamin B6 concentration is influence by the environment but does not decrease much in storage and cooking
Chlorogenic acid mg	19-399	Most important phenolic acid for defense in plants and anti-oxidant in humans, its concentration varies much with variety and origin. The concentration decreases with cooking.
Carotenoids microg	1290-1813 Yellow fleshed	Creamy fleshed tubers have about one tenth of the concentrations of the yellow fleshed ones. Lutein and zeaxanthin are stable in cooking., others much less.
Anthocyanins mg	71-543 Dark purple ones	Light red fleshed have about one 10^{th} of such flavonoid concentrations. These compounds are stable in cooking with stable concentrations
Glyco- alkaloids mg	0.7-18.7 mg	α-chaconine and α-solanine play a role in the defense against pests and disease. Have bitter taste and are toxic at high concentrations.

(over 0.3% of dry matter) with asparagine as precursor give rise to the formation of excess acrylamide in the Maillard reaction, which according to one Canadian survey showed the highest levels in potato chips (up to 3700 mg/kg), in French fries (1900 mg/kg) but substantially lower in bread (Becalski et al 2003). Too low, less than 0.1% on fresh matter basis is not wanted for products needing browning when heated such as roast potatoes and hash browns (Biedermann-Brem et al. 2003). Starch is the major component of tubers ranging from 16% to 23%. In general, when a tuber contains 21% dry matter of which 2% is protein, 1.5% fiber and 0.5% other substances. Its starch concentration is 17%. The global consumption rate of potato tubers is about 90 g per day but in Europe and North America with 60 kg/pp/yr (processed included) the consumption is over 160 g /day but in some tropical highlands in Africa and South America where the crop represents a main staple with consumption up to between 300 to 800 g per day (de Haan et al. 2019), there the crop is the main deliverer of the daily energy requirement.

Starch is considered to consist of three fractions as far as its digestibility by the human intestines is concerned. A rapidly digested starch fraction (RDS, digested within 20 minutes). A slowly digested starch fraction (SDS, digested within 2 hours) and resistant starch (RS) not digested but fermented in the colon. First cooking and then cooling leads to the retrogradation of the gelatinized starch thereby increasing the fraction of SDS and RS (Monro et al. 2009). Besides a source of energy and availability of this energy through variation in digestibility a third characteristic of potato starch matters: its glycemic index (Venn and Green, 2007, Ek et al. 2014). Potato tubers have a high fraction of RDS so have a high glycemic index (GI) but there are large varietal differences and retrogradation reduces the fraction of RDS in favor of SDS and RS fractions. The level of glucose increases after consumption of a carbohydrate not only depends on its GI but also on the amount of carbohydrate eaten, the glycemic load. Taking this into consideration potato's glycemic impact is considered to be low to medium (Lynch et al, 2007).

Composition of cooked tubers and selected products

The composition of fresh raw tubers is shown in Table 5.3A6. Their energy content is relatively modest when compared to other root and tuber crops (Tables 5.3A2 and 5.3A3) because potato has the lowest concentration of solids of which carbohydrates represent the majority. Depending on variety and means of cooking tubers loose or gain some water which is reflected in the dry matter concentration. Losing water at frying and adding oil leads to the high dry matter concentration and energy density of

French fries. Dehydrated products chuño and flour have still higher energy contents, but after reconstitution with water the resulting meal ingredient in this respect resembles boiled tubers. Sugars hardly contribute to the carbohydrate and energy content but fructose and glucose when exceeding 0.3 g/100 g in the Maillard reaction are responsible for the formation of acrylamide. The carbohydrate/protein ratio is not unfavorable for potato, when alone responsible for the daily energy supply, the amount of protein is also close to the daily requirement. Potato is a valuable source of dietary fiber of which the highest concentration is in the skin.

Potato tubers contain low concentrations of fat, but fatty acids play a role in the gelatinization process and glycoalkaloids are present very low concentrations and should not exceed levels considered harmful for humans. Raw potatoes contain as much vitamin C as citrus fruits but about half is lost at cooking. The contribution of potatoes to the supply of potassium, phosphorus and iron is substantial but the tubers are low in calcium.

Table 5.3A6. Composition potato tuber uncooked, (m)g per 100 g, average value of four sources (USDA 2015, Chandraseka and Kumar, 2016); Woolfe 1987 , Burgos 2020) cooked processed: data from Woolfe (1987) citing Finglas and Faulks (1984); Watt and Meryll (1975); Paul and Southgate (1978(; Collazos et al. (1974)

Composition	Raw	Boiled peeled	French fries	Chuño negro	Flour	Remarks
Energy kJ	335	301	1165	1393	1231	Relatively low energy content leads to positive balance of micronutrients (Gibson and Kurilich 2013)
Dry matter g	22.1	18.6	54.1	85.9	79.4	Starch mainly, has specific density higher than water processors use this routinely (Haase, 2003)
Carbo-hydrates g	16.9	16.8	36.7	79,4	73.2	Native starch, modified and derivatives made of potato (Singh, 2016) and cassava starches
Total sugars (g)	0.65					Increase during storage at low temperatures (Amjad et al. 2020), cold sweetening
Reducing sugars g	0.20					When exceeding 0.3% risk of acrylamide formation at frying (Muttucumaru et al, 2020)
Protein (patatin) g	1.90	1.7	4.1			Well balanced protein:carbohydrate ratio (Woolfe 1987)
Fiber, dietary g	1.7	1.6	3.3	1.9	16.5	The skin contains 3 x more fiber than the flesh (Mullin and Smith, 1991)
Lipids g	0,2	0.1	12.1		0.8	Concentrations are very low but they affect gelatinating properties (Ramadan, 2016)
Glyco-alkaloids (mg)	6					Countries and unions set upper limits for what is allowed in food (e.g., CONTAM, 2020)
Ash	1.0	0.7	1.8	2.3		Dominant mineral is potassium. Up to 50% of the ash (e.g. this Table)
Vitamin C mg	18	9	10	2	12	About half is lost at cooking, boiling, less at blanching or microwaving (Lee et al. 2018)
Potassium mg	400	280	720	920		Most dominant is potassium in ash of tubers and products 40-45% (this table)
Calcium mg	9	6	15	44	89	Tubers are low in Ca, processors are interested in enrichment (Tiwari et al. 2018)
Iron mg	0.45	0.5	1.1	0.9	2.4	Potato iron is soluble and its uptake is enhanced by ascorbic acid. (Fairweather-Tait 1983)
Phosphorus	60	38	92	203	220	Potato's phytate concentration is low favoring Zn and Fe solubility and uptake (Camire et al. 2009)

Chapter 5

Composition of selected potato dishes

Tubers boiled in their skin contain about the same concentration of nutrients as raw tubers except for Vitamin C of which about half is lost (Woolfe 1987). Table 5.3A7 shows average values from two sources of energy and nutrients in five potato dishes boiled or baked in skin, boiled peeled, prepared mash and French fries from a quick-service restaurant. The energy content of the first three dishes increases more than proportional to the carbohydrate concentration which is explained that there is variation among samples taken from varied sources. To do it correctly the same raw material (tubers)

Table 5.3A7. Nutrient composition of 100 g potato dishes, values provided by EUFIC (2021) from FSA (2002) and FCNT (2008) sources

Nutrient	Boiled potatoes, in skins	Boiled potatoes, peeled	Baked potatoes, in skin	Mashed potatoes, with milk (7 g) and butter (5 g)	French fries, retail from burger outlet
Energy (kJl)	277	323	357	437	1167
Protein (g)	1.4	1.8	2.6	1.8	3.3
Carbohydrates (g)	15.4	17.0	17.9	15.5	34.0
Fat (g)	0.3	0.1	0.1	4.3	15.5
Fiber (g)	1.5	1.2	3.1	1.1	2.1
Potassium (mg)	460	280	547	260	650
Iron (mg)	1.6	0.4	0.9	0.4	1.0
Vitamin B_1 (mg)	0.13	0.18	0.11	0.16	0.08
Vitamin B_6 (mg)	0.33	0.33	0.23	0.30	0.36
Folate (µg)	19	19	44	24	31
Vitamin C (mg)	9	6	14	8	4

should have been subjected to different means of preparation. The trends however are clear. Mashed potatoes contain 15.5% dry matter but the 4.3% fat contribute substantially to the energy content. French fries with 34% carbohydrates and 15.5% fat contain 1167 kJ per 100 g, which is more than 4 times that of boiled tuber in its skin. With the dry matter concentration increasing, and proteins representing about 10% of the dry matter, the remainder fiber and minerals, the protein concentration is highest in French fries and lowest in tubers boiled in their skin. Fat is only present in substantial quantities where added in milk and butter for mash and in frying fat or oil in French fries. Peels contain more fiber than flesh does, so peeled tubers have a low fiber concentration, only fallen behind by a mash where tuber substance is diluted. Loss of water from tubers when making French fries causes the increase of their carbohydrate and fiber concentrations. Potassium (and iron) losses through leaching are substantial when tubers are peeled and boiled, or as is the case with French fries, blanched

Table 5.3A8. Composition of 100 g potato dishes, values provided by FDC (2021)

Nutrient	Unit	Unpeeled Raw	Flour	Peeled boiled	French fries	Chips
Water	g	79.25	6.2	72.1	43.19	1.86
Energy	kJ	322	1493	365	1214	2234
Protein	g	2.05	6.9	1.87	3.49	6.39
Total lipid (fat)	g	0.1	0.43	0.14	14.04	33.98
Ash	g	1.11	4.24	0.92	1.90	
Carbohydrate, by difference	g	17.49	83.1	20.45	37.2	53.83
Total dietary fiber	g	2.1	5.9	1.4	3.9	3.1

Nutrient	Unit	Unpeeled Raw	Flour	Peeled boiled	French fries	Chips
Total sugars	g	0.82	3.52	1.61	0.28	0.33
Sucrose	g	0.17	0.40	0.19		
Glucose (dextrose)	g	0.31	0.44	0.37		
Fructose	g	0.26	0.34	0.30		
Starch	g	15.29	72.65			
Calcium, Ca	mg	12	65	5	17	21
Iron, Fe	mg	0.81	1.38	0.34	0.91	1.28
Magnesium, Mg	mg	23	65	24	29	63
Phosphorus, P	mg	56	1001	48	124	153
Potassium, K	mg	425	535	372	545	1196
Sodium, Na	mg	6	55	4	357	527
Zinc, Zn	mg	0.35	0.54	0.28	0.51	1.09
Copper, Cu	mg	0.11	0.197	0.188	0.112	0.234
Manganese, Mn	mg	0.153	0.313	0.138		
Selenium, Se	mcg	0.4	1.1	0.3	0.4	2.5
Vitamin C, total ascorbic acid	mg	19.4	3.8	12.1	13.3	21.6
Thiamin B1	mg	0.081	0.228	0.106	0.11	0.213
Riboflavin B2	mg	0.038	0.051	0.020	0.057	0.088
Niacin B3	mg	1.033	3.507	1.439	2.564	4.762
Pantothenic acid B5	mg	0.295	0.474	0.520	0.522	
Vitamin B-6	mg	0.298	0.769	0.299	0.184	2.0
Folate, total B9	mcg	15	25	10	15	29
Carotene, beta	mcg	1	6	8		0

before frying. Vitamin B1 (Thiamin) and B6 (Pyridoxal) concentrations seem linked to the concentration of carbohydrates except for French fries so frying reduces their concentrations. Vitamin C (ascorbic acid), which is quite water-soluble, is lost in boiling and blanching and, apparently exacerbated at frying. Table 5.3A8 beside peeled, boiled and French fries reported in Table 5.3A7, from another source, also shows the composition of raw skin-on tubers, flour and chips. Clearly, other samples and analysis methods were used to produce the data in Table 5.3A8 than for those of Table 5.3A7. For boiled peeled most data are within the same range for both sources but The UEFIC data showed double the Folate concentration and half the vitamin C concentration compared to the FDC data. Vitamin concentrations, especially those of Vitamin C depend to a great extent on variety and on tuber age as the concentration diminishes during storage (Galani et al, 2017). The dehydrated potato product, its flour only, contains about 6% water against 80% in the raw material tubers which explains the high energy density of flour, 4.6 x that of the tubers it is derived from. The carbohydrate:protein ratio is 8.5 in tubers and 12 in flour so in making flour some protein is lost. The protein concentration in raw and boiled tubers is of the same order but with decreasing water content from boiled to French fries to chips the protein concentration increases with carbohydrate:protein ratios of respectively 10.6 and 8.4. potato hardly contain lipids so the high concentrations in French fries and chips originate from the oil they were fried in. The carbohydrate concentration of the products is a result of dehydration and is inversely correlated to its percentage of water but this is not so for fiber of which much is lost in peeling, blanching and frying. The bulk of the sugars in the tubers is represented by the reducing sugars glucose and fructose with low concentrations so not of much nutritive value. Recording by the industry is of interest as too high concentration contribute to dark coloration of products in the Maillard reaction upon frying.

The concentration of minerals is well maintained in flour where concentrations of about five times that of the raw tubers indicate that upon reconstitution the mash will have a similar concentration as the starting material. This is more or less valid for calcium, magnesium phosphorus, sodium, copper and selenium but iron, potassium and zinc are partly leached during the production of flour. Boiled potatoes have similar mineral concentrations as intact tubers (the difference for calcium is not accounted for) and blanching and frying in general lead to some losses of most minerals because the increase of their levels is less than proportional to their dry matter concentration. The sodium concentration of the fried products is higher by far than the contribution of the starting material so this mineral was added when manufacturing them.

The concentrations of vitamins in the raw tubers and boiled tubers are of the same magnitude except for Vitamin C, which went from 19 to 12 mg/100 g. Except for Thiamin, Niacin that maintain their level, vitamins and beta-carotene are strongly reduced in the process of making flour. The fried product shows the same tendency as the boiled tubers but because of a loss of water, concentrations increased for all but least so for the Vitamin B's.

The data in Table 5.3A7 were compiled by analyses of samples from supermarkets and restaurants so, with different starting materials. The raw material originated from tubers of different varieties, from different sites where soil, weather and management practices were not the same. Chapter 4. demonstrated how these factors not only influence yield and dry matter concentration, but also all other quality characteristics of the harvested crop. Jimenez et al. (2015) purchased tubers of six varieties from different growers in the same Argentinian Andean valley in the same growing season and subjected them simultaneously to the same treatments (refrigerated storage, peeling, cooking and frying). The energy, protein, ash and carbohydrate of raw tubers were strongly correlated with the dry matter concentration that ranged from 17 to 27%, the fiber concentration ranged independent from the dry matter concentration between 1.9 and 3.3%. Boiling the tubers in the skin hardly affected the parameter values of the raw ones. Upon frying the dry matter concentration on average increased from 20 to 40% and the values of the raw tubers more or less doubled. The vitamin C concentration, independent of the dry matter concentration ranged between 11 and 29 mg per 100 g of which between 14 and 55% was lost when boiled in the skin and between 28 and 64% was lost when boiled upon peeling, both not correlated with the initial concentration in the raw tubers. These figures are indicative of the importance of employing the same starting material when comparing the influence of means of preparation on losses of nutrients and were not done so to treat the data with wariness.

Table 5.3A9. Composition of raw tubers and 13 potato dishes (PotatoUSA, 2021)

Product type	**Water %**	**Energy (kJ)**	**Protein (g)**	**Fat (g)**	**Carbo-hydrate (g)**	**Calcium (mg)**	**Vitamin C (mg)**
Raw potato	78.9	319	2.1	0.1	17.1	7	20
Baked in skin	75.1	391	2.6	0.1	21.1	9	20
Boiled in skin	79.8	319	2.1	0.1	17.1	7	16
French fried	44.7	1151	4.3	13.2	36.0	15	21
Fried from raw	46.9	1126	4.0	14.2	36.2	15	19
Shreds dehydrated-rehydrated	54.2	962	3.1	11.7	29.1	12	9
Mash+milk+fat	78.9	395	2.1	4.3	12.3	24	9
Canned solids+liquids	88.5	185	1.1	0.2	9.8	0	13

Product type	Water %	Energy (kJ)	Protein (g)	Fat (g)	Carbo-hydrate (g)	Calcium (mg)	Vitamin C (mg)
Mash granules+water+milk+fat	78.6	403	2.0	3.6	14.4	32	3
Frozen cooked hash browned	56.1	941	3.6	11.5	29.0	18	8
Frozen French fried heated	52.9	924	1.8	8.4	33.7	9	21
Frozen mashed heated	79.3	391	1.8	2.8	15.7	25	4
Potato chips	1.8	2386	5.3	39.8	50.0	40	16
Potato flour	6.6	1474	8.0	0.8	79.9	33	19

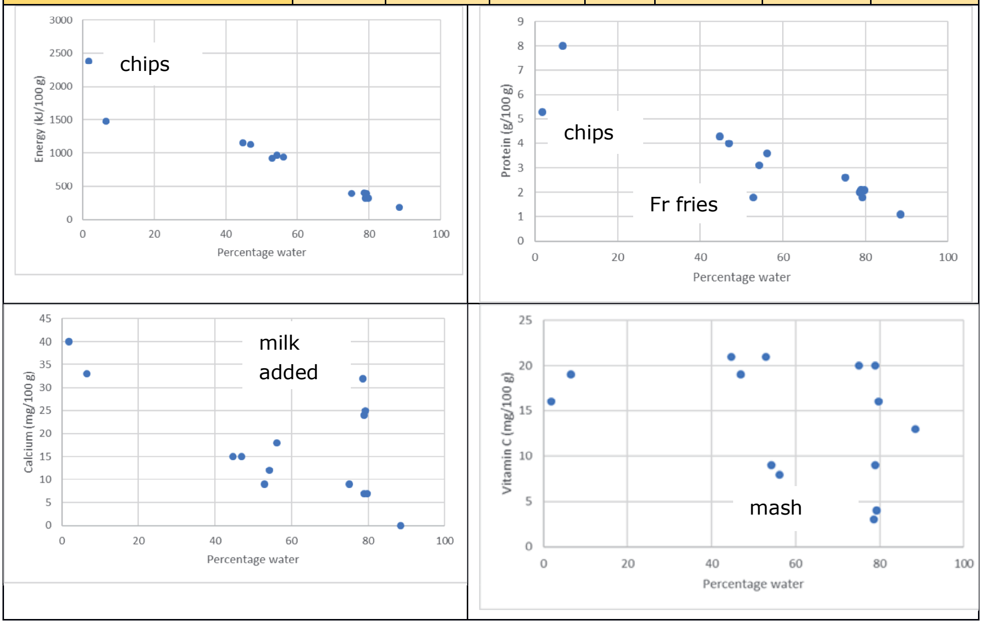


Table 5.3A9. gives data of the presence of water, energy and five constituents in raw tubers and 13 manufactured products. The table also shows the correlations of four constituents with the water content in 100 g. The energy content correlates well with the inverse of the percentage water in the product except for chips because of their high-fat concentration of close to 40%. The protein concentration also negatively correlates well with the water content of the product with some fried products as outliers because there, the potato substance is diluted with fat. The calcium concentration also shows a few outliers because milk was added there. The vitamin C concentration is not correlated with the dry matter concentration; the 20 mg/100 raw and boiled in the skin is reduced somewhat upon peeling but the mash based products have very low retention of Vitamin C.

Health claims and influence of processing

Where the crop plays a role as a staple, its most important attribute is delivering energy (Table 5.3A10) to the human body through respiration releasing carbo hydroxide and water, an inverted process from photosynthesis at the cost of absorbed solar energy. The bulk of the starch in potatoes consists of readily available branched amylopectin chains with a larger area for molecular interaction for digestion than the linear structure of more abundant amylose. Native, unmodified, starches are organized in granules of different sizes and consist of glucose polymers. Upon digestion, they are hydrolyzed to end

Table 5.3A10. Health benefits of tuber components (mainly based on four reviews: Zaheer and Akhtar, 2016; Chandrasekara and Kumar, 2016; Camire et al. 2009; Burgos et al. 2020)

Category	Compounds	Claim	Sources cited
Dietary fiber	Slowly digesting starch	Lowers Glycemic Index, against obesity; increases satiety	Miao et al. 2015 Perry and Ying 2016
	Resistant starch	Anti-tumor, hypoglycemic	Sajilata et al. 2006
	Lignin and non-lignin	Reduces cholesterol levels, protects against acrylamide	Lazarov and Werman, 1996 Dobrowolski et al. 2012
Lipids	Esterified fatty acids	Beneficial nutrients	Gibson and Kurilich, 2013
Glycoalkaloids	α-chaconine α-solanine	Anti-biotic, reduces tumor growth	Friedman 2006, 2015
Protein	Patatin (amino acids) Potato Juice Protein Concentrate	Abundance of key amino acids (lysine and threonine), high biological value (comparable to eggs)	Camire et al, 2009 Kowalczewski et al. 2019
Anti-oxidants	Phenolics, chlorogenic acids (in yellow flesh)	Gut health, bacteria promotion	Mills et al, 2005
	Flavonoids (anthocyanins, in red and purple flesh)	Removes free radicals, enhances efficiency of vitamin C	Townsend and Tew, 2004 Han et al. 2007
	Carotenoids (lutein, zeatin)	In yellow fleshed tubers	Packer, 1995
Vitamins	Vitamin C	Anti-oxidant, against heart disease, cancer	Bates, 1997
	Vitamin B complex (B6 Pyroxidine especially)	Metabolism, brain function	Kennedy, 2016
Minerals	Zinc Iron Calcium Phosphorus Potassium	Co-factor in enzymes Prevents anemia Blood pressure, bone health Nucleic acids component, bone health Lowers blood pressure	Tapeira and Tew, 2003 Abbaspour et al. 2014 Harvard, 2021 HealthLine, 2021 He and MacGregor, 2008

up as glucose molecules ready to be respired and deliver energy. Starches (Englyst et al. 1992) can be distinguished in rapidly (RDS) and slowly digested (SDR) and resistant (RS) starches. Magallanes-Cruz et al. (2017), reviewing the influence of starch structure on its digestibility, called SDR and RS "neutraceutical starch fractions" because of their low Glycemic Index (GI) and contribution to avoiding obesity; RS, moreover, contributes to a healthy gut biota (Keenan et al. 2015). Dietary fibers, roughage, from cell walls play similar roles as RS (Cui and Robert, 2009). Emsland (2021) on its website claims that potato fiber through its three-dimensional network as a natural food additive ingredient for meat, bakery and snacks enriches dietary fiber content, reduces carbs and fat so calories, it easily binds oil and water and improves texture and structure. Fresh potato tubers offer reduction of the carbohydrates per g tuber consumed (hence also the glycaemic (GI) and satiety indices) through a reduction of the dry matter concentration. Potato products (not so much cereal products) through an enhancement of dietary fiber and resistant starches following retrogradation reduces the GI, especially when accompanied by fat, protein and fiber.

Potato glycoalkaloids when present in low concentrations have positive health effects and also its lipids are considered beneficial. King and Slavin (2013) reported that besides digestibility of patatin, its composition of amino acids determine its quality as presence of lysine, threonine, and tryptophan are considered essential for humans and the required levels of all four are exceeded by potato. So potato protein is highly appreciated where cereals do not meet the required lysine concentration. However, the levels of the amino acids cysteine and methionine, both containing Sulphur, are lower in potatoes than in cereals.

All tubers contain vitamin C at effective concentrations and especially tubers with colored flesh contain substantial amounts of other anti-oxidants phenolics and flavonoids. B vitamins also occur in such concentrations as to contribute substantially to the needed daily intake. The most relevant minerals are tabled of which, especially when fortified, zinc and iron where deficient in a population, potato can remediate.

Decker and Ferruzzi (2013) reviewed potential innovations to reduce the energy content of fried products in view of the image of French fries and chips as being responsible for obesity through a reduction of fat uptake and increasing the concentration of resistant starch. They used data of the USDA (2011) National Nutrient Database showing 0.10 g total fat per 100 g tuber of which 0.03 g/100 g saturated fat in raw, boiled, baked and microwaved tubers, 4.7 and 0.9 g/100 in par-fried French fries, 17.1 and 4.0 g/100 in fried French fries and 34.6 and 11.0 g/100 g in chips. The resistant starch concentration is 69% in raw tubers and varies between 1.2 and 10.4% in finished products (Garcia-Alonso and Goti, 2008). Draining water before frying and draining oil upon frying assisted by centrifuging reduces the fat concentration of products. At frying, water in tuber tissue is replaced by oil so diminishing water loss is realized by measures as vacuum frying at lower temperature compared ambient air pressure. Certain batters containing proteins or modified cellulose reduce water loss and fat uptake takes place and less oil is needed when frying with infrared radiation through the Controlled Dynamic Radiant Frying (CDRF) technique that combines evaporation of water with the formation of a brown crust. Reducing fat also alters the organoleptic properties of fried products as fat is a lubricant at chewing and swallowing so is not a desired trait of all consumers. Of the resistant starches, entrapped, ungelatinized and retrograded only the latter is manipulatable in processing through cooling and even more so by freezing upon gelatination with an increase from 3 to 10% of RS of all starch in the products. Concentrations of minerals and vitamins in the finished products stem from the raw material, its variety and site and, according to Decker and Ferruzzi (2013), is not much influenced by adaptation of processing techniques.

Quantification of the nutrients domain

Information of the effort of condensing the nutrients domain expressed in Tables 5.3A1-10 is abbreviated in the heatmap of Table 5.3B where 11 classes of potato products and 3 non-potato classes of products figure with 11 attributes being their concentrations of nutrients. Where products were not mentioned in the tables of the previous section the concentrations were deduced from indirect evidence such as proportion potato and cooling after heating (for retrogradation).

With a mean score of 2.1 rice has the lowest one for lacking Vitamin C, calcium and potassium. Gratins, a kind of diluted tuber, also have a low mean score. Chips score highest (4.0) with only very low scores for retrograded starch and antioxidants concentrations. French fries contain more water than chips so in general have lower concentrations (3.6) but partly make up for this through a relatively high score for its retrograded starch concentration formed upon cooling after blanching.

The lowest mean value of an attribute averaged over the 14 products is for antioxidants, 1.8, with only macaroni having a very high concentration. The low value for the potato vegetable mixtures arises from the probably unjust assumption that the vegetables in the mixture contain no antioxidants.

Table 5.3B Heat map of classes of 14 products and with 11 concentrations of nutrients as attributes. For blanc cells no data were supplied in Tables 3A1-10.

High			Low
	a	Starch	
	b	Resistant starch	
	c	Oil	
	d	Protein	
	e	Fiber	
	f	Vitamin C	

High			Low
	g	Antioxidants	
	h	Calcium	
	i	Potassium	
	j	Zinc	
	k	Iron	

Number	Product classes	A	b	c	d	e	f	g	h	i	j	k	Av
1	Frozen French fries												3.6
2	Frozen formed mash												2.9
3	Frozen formed shreds												3.3
4	Baked tubers												3.1
5	Blanched chilled												2.6
6	Frozen baked gratins												2.2
7	Vegetable/potato dishes												2.5
8	Chips												4.0
9	Stackable chips												2.6
10	Extruded snacks												2.5
11	Flour of potato												2.8
12	Brown rice cooked												2.1
13	Macaroni cooked												2.6
14	Cassava cooked												3.0
Average		3.1	3.3	3.1	3.5	3.1	2.8	1.8	2.4	2.5	2.9	2.8	2.8

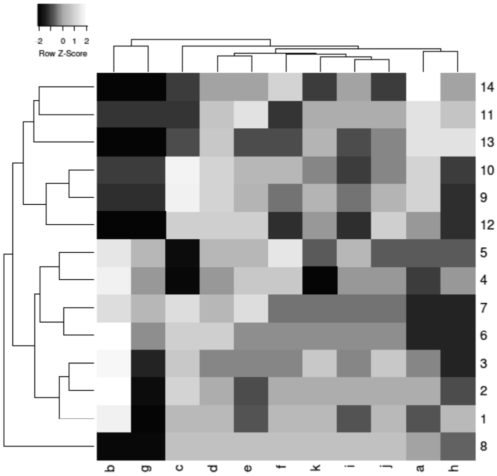
All the other concentrations diverge little from 3 so here the red and green concentrations cross against each other.

Clustering within the nutrients domain

The dendrogram of the products and attributes based on the heatmap of Table 5.3B is represented in Table 5.3C. It readily becomes clear that chips is standing alone and the rest of the products are divided into two clusters. The lowest contains the numbers 1-7 from Table 5.2B, i. e. products containing moisture and the top cluster with 6 members containing the dry products and rice, macaroni and cassava. The twins are more or less the same as in the previous section (Table 5.2C) with a new one, the twins potato flour and cooked cassava.

The concentrations are distributed over four clusters, two of them consisting of the twins starch and calcium and resistant starch and calcium and the oil concentration standing alone. The six members of the remaining cluster in the center contain two twins: protein and fiber, and potassium and zinc.

Table 5.3C Dendrogram of food quality related properties, nutrients, (a-k, see table 5.3b) of selected products (1-14, see Table 5.3B).



Perspectives domain

Formulation of the domain

The expansion of the potato processing industry in Europe and North America is flattening with the markets getting nearer to saturation. New plants are largely aimed at exporting to the countries where the industry is just starting (such as China) or where potato is not available for large-scale processing (for example Indonesia). Chips are produced in countries where the raw material is available, albeit at relatively high costs, which are acceptable for making chips as the proportion of the costs of the tubers in the finished product is relatively modest. Where no tubers are sourced locally, the raw material is imported. In China, India and Brazil manufacturing of French fries started around the start of this century and is likely to follow the trend of Europe and North America in the past century. Perspectives of the different classes of consumers in this domain, so opportunities for the manufacturers, are not about the global expansion of the industry, nor on technological innovations, but focus on concerns and desires surrounding products for consumers.

Drinks: beer, wine, vodka

Condensation of the perspectives domain

Mainstream potato food products are made in large quantities from conventionally grown tubers to satisfy the convenience requirements of most cooks. Consumers, however, from their perspective, increasingly desire food that for them has added value for health, conviction or organizational reasons. Enhancing the zinc, iron (Singh et al. 2021) and vitamin A concentrations through breeding or at processing are examples that benefit populations where such nutriments lack in foodstuffs with deficiencies in populations as a consequence. Similarly, adding a vegetable component broadens the presence of desired components from the health, color and taste points of view. Also, the shape may vary by three dimensional printing of mash (Martínez-Monzó et al. 2019) before frying or serving into new shapes. Sodium reduction (Kongstad and Giacalone, 2020) and replacers (Foodinsight, 2021) such as lemon juice and cayenne pepper and acrylamide-free products (Lacy and Huffman, 2016) and low-fat are examples of a desired reduction of a food component up to a complete absence such as gluten-free. Some consumers become more demanding, the traditionalists preferring the products that were, and adventure-seeking the ones to come. Generic food labelling, besides the conventional label showing energy, fat, carbohydrates and salt content, is coming up, such as the Nutriscore first launched in France and now gradually spreading. Specific new products with more fiber, resistant starch and protein (potato milk, sports drinks) are preferred by various consumers for different reasons. Vegetarians want to be assured that no animal products are present in any additive and are likely to

Table 5.4A. Perspectives various consumers have and a brief explanation of classes and appropriate attributes

Perspective class	Description of some instances	Attributes
Biofortification	Added zinc, iron vitamin A	*Attainability*: ability to satisfy the desire of the consumer *Distance in future*: early or late moment in the future to realize *Market share*: likelihood of becoming a major global market or a substantial regional market
Food-to-food fortification	Vegetable added to formed and flour	
Personalized nutrition	For groups (elderly, halal) or persons	
Printing dish components	Mash from flour in designs	
Low-sodium	Low salt or salt replacers	
Low bruise, acrylamide	GM: avoidance undesired compounds	

Gluten-free	Tubers contain no gluten, additives idem	*Desire*: degree it is experienced as a need *Threat:* for the conventional industry (or opportunity) *Costs*: to make desired products *Initiative*: with consumers or with the industry *Newness*: need to make new products or adapt current ones *Opportunity* for start-ups to jump in *Regulation*: chance that governments intervene with legislation
Demanding consumer	Ranging from tradition to adventure	
Nutriscore	Food labelled with health score	
Low-fat	High fat has risk of overweight	
Potato milk	Vegetarian and low fat	
Vegetarian, vegan	Food additives and meat replacement	
Fiber, resistant starch	Low energy and enhances gut biota	
Protein enhancement	Enhanced patatin	
Organic production	Raw grown devoid of chemicals	
Low footprint	Efficient use of energy, land and water	
Fairtrade	Sourcing from smallholders	
Local for local	Outlet deploying locally grown raw	
At-home delivery	Fried products hot and crispy at home	
Homes without kitchens	Products heated in oven-microwave	
Fried products machine	French fries fried in vending machine	

consume more French fries when more restaurants serve meat replacements (Linchpinseo, 2022). Consumers have opinions on how the tubers are produced, preferring locally grown and/or organic and/or with demonstrated low land, water and energy (CO_2) footprints. Homes without kitchens want the food delivered hot and crispy or ready to place in the oven-microwave or buy it at a nearby vending machine. Table 5.4A lists and illustrates these perspectives and shows the attributes which the processing industry has to take into account when altering current, or making new products. Is it easily doable, soon or late, will it be a niche or a major market, a regional or a global market, is it a necessity or just interest, is it a threat or an opportunity, will the cost be high or low, does it require innovation or just adaptation, will start-ups or the major companies expand and finally are regulators going to enforce a particular development?

Quantification of the perspectives domain

The 21 classes of perspectives and their attributes are scored with values from 1 (dark red) to 5 (dark green) as is shown in the heatmap of Table 5.4B. A high score signifies that the industry is favored

Table 5.4B. Heatmap of 21 classes of perspectives of consumers and 11 attributes regarding the consequences for the processing industry

High value	a	Attainability, (easy = high value of score)	Low value
	b	Expected future to upscale (soon = high score)	
	c	Global market share expected	
	d	Regional market share expected	
	e	Necessity for certain consumers (great is a low score)	
	f	Opportunity	
	g	Low costs for industry	
	h	Initiative with processing industry	
	i	Newness	
	j	Competition from start-ups (much = low score)	
	k	Chance of enforcement by regulation (great is low score)	

	Class of perspectives	a	b	c	d	e	f	g	h	i	j	k	Av.
1	Biofortification												2.5
2	Food-to-food												3.5
3	Personalized												2.5
4	Printing												2.8
5	Low-sodium												3.5
6	Low acrylamide												3.1
7	Gluten-free												3.3
8	Demanding												2.6
9	Nutriscore												3.5
10	Low-fat (light)												3.1
11	Potato milk												2.9
12	Vegetarian												3.5
13	Fiber												3.2
14	Protein												3.2
15	Organic												2.8
16	Low footprint												3.2
17	Fairtrade												2.3
18	Local for local												2.5
19	Delivered												3.3
20	Kitchen-less												3.5
21	Vending machine												2.8
Average		3.6	2.8	2.9	4.0	2.2	3.0	3.0	2.7	3.2	2.4	3.6	

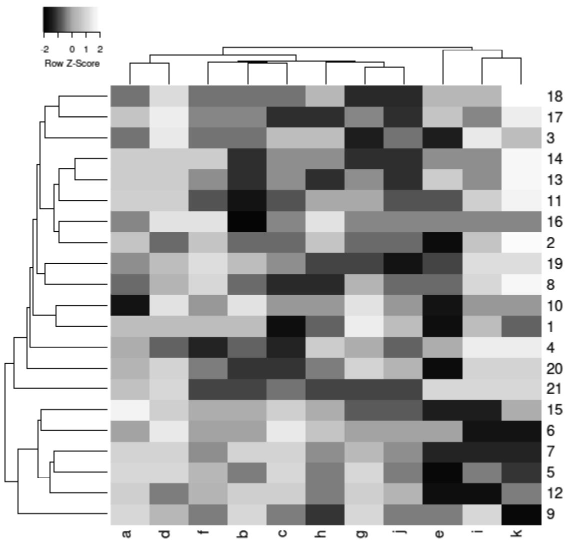
when the perspectives of the consumers are easily and rapidly attained at low costs with a large market share with new products where the manufacturers take the initiative. Threats are specific consumer demands, competition and regulations, their absence leads to a high score as it also favors the industry. Regulations, however, when delivering a level playing field may also be perceived as an advantage. The table clearly demonstrates, with average scores of 3.5, that realizing food-to-food, implementing the Nutriscore and catering for vegetarians and the kitchen-less consumers are most feasible for the processing industry. Fortifying products, satisfying specific consumers, fair trade and local for local are most difficult to meet.

Clustering within the perspectives domain

The dendrogram in Table 5.4C shows three main clusters. The top one consist of three members, among them fair trade and local for local, which is meaningful as fair trade is easiest realized in a local setting. Fiber and protein are close twins, as they both when enhanced in food, improve its quality for those benefitting from it. Demanding customers are associated with those aspiring to delivery at home. Low salt and gluten-free are twins for logical reasons and the Nutriscore stands alone, which reflects that it is not a perspective of a group of consumers but an initiative of regulators.

The attributes show three clusters, the left one consists of the not implausible twins attainable and regional market. Low costs and competition from startups are associated, also new small companies can meet a need if investments are reasonable. Opportunities are largest when a global market is reached in the near future (fbc). New products are associated with regulation, probably because they are potentially going to be scrutinized.

Table 5.4C Dendrogram of the 11 consequences for the industry (a-k, Table 5.4B) of the classes of perspectives of consumers (1-21, Table 5.4B)



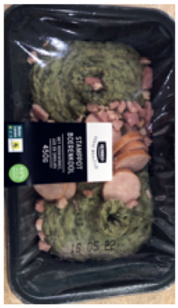
Deliberations and conclusions

Research question about potato dishes

Some 175 potato dishes are listed in this chapter but this of course only represents a fraction of all globally available dishes. So the list can be extended on the one hand but may also be condensed to thirteen applications with similar features. Dishes include soups, boiled tubers, mashes, fried to various degrees of crispiness, formed or shaped such as hash browns and patties and a few more including baked. Exactly these features were picked up by the potato processing industry and marketed in retail and food outlets and used by cooks in kitchens for convenience and to extend their diversity of plates. Home preparations with products are cooking stews where freeze or drum dried products are used as an ingredient, for jacket potatoes made in the oven, grill or microwave prebaked products are bought, for pan-frying pre-sauteed tuber cuts exist, for deep-frying French fries and formed products and some dishes are complete like kugel, pancakes, gratins and scalloped potatoes ready to fry and bake. The available snacks are ready to eat but prepared from different semi-raw materials (raw slices, dough and pellets) in various ways (frying, oven heating, popping, expanding) resulting in different products. Fiber for low carb diets and protein as sports supplements are products not normally found in kitchens but serve as diet supplements. From this summary, the versatility of potato derived products becomes apparent, the range of dishes and snacks, the variety in preparing them from an array of bought processed ingredients.

Research question about sensory perceptions

The typical potato taste from (non)volatile and alkaloid compounds is diminished compared to cooked tubers when producing mash from flour but intensifies with decreased water content going from boiled tubers to French fries to chips. The mouthfeel following tuber texture and its elements such as consistency dryness and mealiness are altered when producing mash (softer, moister and finer than tubers), French fries (firmer, drier and coarser) or chips (completely disintegrated, crispy and dry). Processing tubers evidently can enhance aspects of flavor and texture and lessen them, both, depending on product and use are of advantage or not. Besides the olfactory characteristics brought about by basic production operations and additives (influencing product quality) and flavoring (influencing product taste) the physical appearance plays a role in production and marketing. Products of the same category differ in size (long and short, thin and thick French fries), shape (straight or corrugated) and in color (white and cream fleshed tubers, degree of browning and addition of colorants. Products vary in the number of shapes they are produced in with few variations in size for baked tubers and many shapes for French fries and extruded snacks. Flour as a rule contains no additives nor flavorings whereas French fries contain many of both. Individual particles, chunks and shapes vary in size with flour containing the smallest and baked tubers and gratins the largest. So it was shown that all basic senses are appealed upon when exposing and eating potato products and their dishes.



Dishes

Research question about the nutritive value of potato products

The section on the condensation of the nutrients domain contains 10 tables: 1 on the conversion of energy and the results for potato constituents. The following three tables compare potatoes with a few other crops or their products. A table is inserted with ranges of nutrient concentrations found in tubers with different backgrounds (crop variety, environment and management. The concentrations in tubers bought on the market in New Delhi grown in winter on irrigated clay soils in lowland Utter Pradesh differ considerably from those in Kigali grown in rainfed volcanic tropical highlands. Potato usually is served as a (side) dish so then the nutrient composition of a dish is relevant is as shown in the three tables with data of different origin and composition of dishes. The section concludes with a table demonstrating some potential health benefit claims of some potato constituents.

Fat in prepared potato dishes has the highest energy density of 37 kJ per g, carbohydrates and protein have similar densities of 17 kJ/g and fiber the lowest, 8 kJ/g. So obviously chips with over 30% are richest in energy and skin-on boiled or baked tubers without dressing have the lowest. With the lowest carbohydrate concentration of the five major root and tuber crops potato therefore also has the lowest energy density, almost half of that of cassava on crop fresh weight basis. Potato contains more protein than cassava but is lowest in calcium of the five crops and lets cassava go first concerning the vitamin C concentration. Of the other root and tuber crops, only sweet potato is processed into e.g. frozen fried sweet potato among others in the USA and South Africa, and cassava is a major raw material for starch production in countries like Thailand.

Besides energy from carbohydrates mainly, the concentrations of protein, lipids, dietary fiber, minerals especially calcium, phosphorus, iron and zinc and vitamins A, B and C are determinants of the quality of food. Potato has a lower dry matter and energy content than sweet potato, cassava, wheat (eaten as macaroni) and brown rice. Macaroni is highest in protein and lipids, sweet potato in sugars and fiber. The cereals are lower in calcium and magnesium but higher in zinc and iron concentrations than the root and tuber crops but contain no vitamin C and are low in folate.

Producing boiled or baked tubers whether or not in the skin, French fries, various mashes, chuño, flour or chips strongly influences the nutrient composition. The energy content compared to boiled tubers up to quadruples in French fries and dehydrated products but upon reconstitution of dry products and powders, these are brought back to the level of boiled tubers. Chips contain seven times more energy per 100 g than boiled tubers. Dry matter in tubers is around 20%, in fries 50% and around 80 in dehydrated products. Comparison of 14 products (three of them non-potato: cooked rice, cassava and macaroni with 11 nutrient concentrations showed that protein and starch concentration are the most frequent descriptors of most products and antioxidants least. Products are clustered more or less according to their dry matter concentration (degree of dilution) and concentrations of nutrients seemingly according to their solubility.

Research question about consumer perspectives.

Consumer perspectives concern health (fiber, minerals), convenience (at-home delivery), availability (vending machines), environment (footprints) and idealistic (fair trade, local-for -local) motives. The industry likely reacts by seizing opportunities through innovation and capturing a substantial market share, especially in currently saturated markets. Easily reachable goals for the industry are food-to-food enrichments, implementing food health lables,and satisfying vegetarian and kitchen-less consumers. Biofortification, fair trade and local for local production are met with much more exertion.

In conclusion, this chapter reviews existing dishes worldwide and how the processing industry derived thereof products for kitchens and the food industry. The nutritive value of tubers and its products was explored. In general the density of nutritive components of the products is correlated with their water content that decreases from blanched or baked, to frying French fries, chips and production of flour. Starch, minerals, some vitamins and ant-oxidants become less diluted and appear in higher concentrations in products than in the raw material derived from. The energy content increases more than proportional in fried products because of adhering oil that per unit weight almost has more than double the energy content of starch. Additives such as SAPP, batter and dextrin improve the flesh color of French fries, their crispiness and staying hot time and give the golden hue. Flavoring creates a wide range of tastes of French fries and chips. Blanched and chilled products whether or not mixed with vegetables are often supplied with sachets of seasoning to be spread on the product while preparing a dish in the kitchen as the seasoning effect would partly disappear when mixed with the chilled product.

Chapter 6.

SOCIETY
Domains of benefit, stewardship and surroundings

Slightly modified article accepted by Potato Research as:

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Abstract

Wheat, the most important food crop can be stored for a much longer time than potato. It is ground and made into flour or pasta, can be turned into bread or a dish any time. Potato is only storable for a limited period so floods the market at harvest. Major benefits of processing for growers include regulating availability of markets and price through contracts, and the decrease of the number of consumers buying fresh tubers is compensated by processors buying raw material. Processors add value and employment and consumers are offered a wide array of affordable and convenient products. Large potato processing companies produce annual sustainability reports advocating measures for growers to spare the habitat, more efficient processes in factories, newer and healthier products and supporting communities. These are recorded and viewed in a theoretical triangulation from angles of processors, of policymakers and of those trying to bend the rules. The industry, especially when expanding to new (developing) markets face Policy, Economic, Social, Technological, Environmental and Legal (PESTEL) issues that fluctuate according to the presence of a raw material base, competition and buying power and culture of the consumers.

Inception and research questions

Justification of a potato specific approach

Beside the local eating culture that determines the choice of products, societal aspects of processing potato are its benefits, its sustainability and its setting in societies as perceived by the stakeholders, participants in the supply chain of whom there are more than growers, processors and users. The reasons to study potato instead of food processing in general are the following. Cereals, the main staples processed, are relatively low tillage, low input, low risk, usually rainfed crops, with few specs, upon harvest crops are collected by buyers in silos where they store it for up to some years without refrigeration. Before processing the produce is hauled to mills by boat, train of lorry. Upon milling the flour is distributed as raw material to an extensive network of outlets: bakeries that sell directly to their customers, retail and food service. The market is mature and evolves mainly along the lines of population development. Bread making is over 10,000 years old (Arranz-Otaegui 2018), whereas potato processing at industrial scale only took off in mid last century (Chapter 1). Contrary to potato that is bought by users in kitchens as untreated harvested 'raw material', cooks only sparsely buy grains of wheat for salads, popcorn or brown rice.

The potato crop, however, requires the best, light, preferably stoneless soils with a deep rooting zone. Crops are planted with a few tons of costly seed potatoes per hectare, crops destined for processing are irrigated in most instances (from a low percentage in Belgium, about half of the crops in the Netherlands, UK and Eastern Canada to all crops in the rest of the Americas, Africa and the winter crops in subtropical climates) and, they are intensely protected against pests and diseases. Soil is moved several times as deep tilling is required to create a seed bed, planting is in shallow furrows and hilling is done in a few operations. At harvest many hundreds tons of soil are lifted to retrieve the tubers that need to be stored under ventilated and refrigerated conditions maximum eleven months while sprouting is controlled chemically. Adverse weather conditions (heat, drought) negatively affect yield and processing quality. For growers it is an expensive risky crop with many specifications for which they remain responsible until the tubers are collected by the factories of which there are only one or two near enough to deliver to. Potato is ground for starch production and peeled and cut for other products comparable to milling of grains but the potato processor, contrary to cereal millers are also responsible for making the final product, that, with the exception of starch is only storable for a limited period and the bulk of it is frozen or stored chilled. Processing potato is a rapidly expanding industry venturing into new countries and regions constantly, meeting new societal demands. The link between raw material, the tubers to be harvested and the processors is a strong one as was outlined in Chapters 3 and 4. All these factors make potato processing of more relevance for communities involved than for cereals. Once this observed, a potato specific approach is defensible.

In the light of the special agricultural and industrial situation of potato and its setting (its place in society, embedment in its social surroundings) the following research questions arise:

Research question about benefits of potato processing

Potato processing is a well-established industry in the major producing well developed markets. It has not yet been exhaustively investigated and determined what the advantages are for growers, processors and users of potato products over users having access to fresh tubers. The impression exists that the trade is thriving and interest of people seen their internet searches (Introduction of the book) but can the driving forces including sourcing further afield be elucidated and analyzed?

Research question about sustainability

To sustain processing in the future, sustainability measures such as increasing efficiencies (Chapter 3) are being taken. Is it possible to systematically itemize which measures growers, processors and consumers are taking or need to take to assure the future for the market and to learn who else take part in the steering, carrying out and monitoring of sustainability related issues? How can the stakeholders when they a target of the measures (growers usually), or advocates of the sustainability measures (processing industry and policymakers) or when they oppose them (recalcitrant growers and processors), influence the type, size and relevance of interventions?

Research question about social surroundings and embedding

Beside sustainability the industry in each societal setting (background) is coping with governmental policies, with the national or regional economic situation, with how society is organized, with opinions of the people, with the technological opportunities and aspirations and the laws and regulations that are in place and how compliance is monitored and enforced. How can the setting of a processing industry in its social surroundings be systematically and scientifically researched? and what are the wishes of the three central parties (growers, processors and diverse users) and the role of breeders, and makers of policies and laws?

Research question about degree of market development

The subjects mentioned previously are likely to differ in the various stages of availability and use of products and the of the industry itself, it being cottage industry, upcoming or operating in a well-developed almost satisfied market. What settings exist where processing at cottage or corporate level takes place with and without available local raw material and with or without an affluent society able to afford to buy products. When establishing potato processing and to continue current operations, which hurdles need to be taken regarding national government policies, local economies, societal conditions, levels and need of technology and environmental and legal concerns? By what means can it be described how these markets look like and which societal issues the industry faces if needing to expand there?

Domain of benefits of processing

Formulation of the benefits domain

Cooks buying products rather than fresh tubers has several consequences. In the kitchen it affects the time needed for cooking, efforts and water and energy needed in kitchen operations. Saving time is only one aspect of convenience. Not having to think about the composition and ingredients and having to buy them are other aspects and so are reduced costs and losses. For manufacturers it is an opportunity to add value and for growers it offers additional growing and outlet opportunities. For all parties: processed products in general have a longer storage time span than fresh tubers so they even out the prices by reducing the peak at harvest.

Condensation of the benefits domain

In the kitchen: convenience and choice

The most important reasons to make use of manufactured potato products are the satisfaction of them and the time saved in preparing a meal. No need to wash, peel, cut and par-fry purchased tubers when employing frozen or chilled French fries. Not having to do tedious tasks according some, such as peeling and waiting for a process (cooking) to finish. In restaurants where all time dedicated to processes has to be accounted for, buying factory processed food there in large quantities and partly automated, is at a fraction of costs compared to making it there from fresh tubers. Cooks, however, may have other culinary considerations to start with fresh tubers rather than processed products. An estimation of time per task, the total time of all tasks per meal component and preparation time of the manufactured dish upon unpacking is presented in Table 6.1.A1 Preparing chips in the kitchen needs 51 minutes to produce 330 g of chips from 1 kg where it takes no time at all to prepare when ready made.

Table 6.1A1. Estimation of time in minutes per kitchen task and summed per dish, compared to preparing the purchased dish in the kitchen (based on 1 kg of fresh tubers). Last column: heating time of the purchased product

Task	Number	Minutes per task	Meal Component	Tasks involved in preparation	Total	Minutes heating
Washing	1	2	Boiled	1+2+5	37	10
Peeling	2	10	Mashed	1+2+5+6	42	5
Cutting	3	3	Pan fried	1+2+5+7	47	10
Slicing	4	9	Chips	1+2+4+11 (5 x)five batches	51	0
Boiling	5	25	French fries	1+2+3+9+10+11	37	6
Mashing	6	5	Hash brown	1+2+12+11	33	6
Pan frying	7	10	Jacket	1+8	32	10
Baking	8	30	Hasselback	1+3+3+8	38	10
Par-frying	9	6				
Cooling	10	10				
Deep frying	11	6				
Grating and forming	12	15				

Especially the frying procedures in several batches and monitoring the process is time consuming. All the other components need some heating time from 5 to 10 minutes in water, oil or oven. Washing other utensils, pots, bowls and plates than needed for heating the purchased meal component is not accounted for in Table 6.1A1 On average buying the processed potato product for a dinner of 4 persons saves about 30 minutes, to be dedicated to other tasks in or outside the kitchen.

Some dishes are hardly made in kitchens but only purchased such as most formed ones, croquettes for instance. Health reasons are other considerations for some consumers wary of substances such as gluten, glycoalkaloids and acrylamide. A main advantages of using manufactured processed food is also the wide choice, especially in areas where the crop is not grown and tubers not sold, access to products is indispensable. Beside convenience, other aspects play a societal role that are an advantage for processed potato products. In a factory there is no waste. Peels are made into feed, peeling there is done by steam with minimal losses whereas when peeling and trimming by knife in a kitchen a considerable proportion of the tuber (about 20%; De Thouars 2018) is wasted. For abrasive peeling in factories this is about 12 % and weight loss with steam peeling is about 7 % (Pelletier et al. 1964; Singh and Shukla 1995; Somsen 2004; De Thouars 2018). Using processed tubers reduces peel losses by 13%. When dosing needed amounts for a meal from a purchased wrapping, these are easily targetable compared with starting from fresh tubers, so this reduces the quantity of leftovers, hence waste and losses by 13%. When dosing needed amounts for a meal from a purchased wrapping, these are easily targetable compared with starting with fresh tubers, so this reduces the quantity of leftovers, hence waste and losses. Preparing a potato meal component in the kitchen is not a continuous process but comparable to processing a small batch. For such a small batch specifically an amount of water or oil needs to be heated and cooled without saving the energy for the next batch or to use the energy for another process such as drying as happens in potato processing units. So from the environmental point of view using processed food in the kitchen is an advantage. For this very reason and because processors through contracts, procure their fresh matter at a fraction of the prices that consumers pay, about 25-30 % of the price, the costs of buying processed products is often lower than preparing at home when including the costs of energy and ingredients.

On farms and in factories: value addition

For consumers and the potato industry at large being able to process tubers has multiple advantages. Tubers under refrigerated conditions can be stored for not more than some 11 months (maximally some 10 months on average) and to avoid sprouting, chemical inhibitors (Paul et al. 2016) are applied. Chilled products under controlled atmosphere can be stored for a few weeks, when pasteurized for a few months and when sterilized for a few years, frozen for two years and as powder (starch, flour) for several years (Dev 2011). Being able to store potato derived products enables the industry to build up stocks when there is excess and to release to the market when there is short supply. So for growers who produce the tubers and who have contracts with manufacturers the benefit is in evening out fluctuations among years. This also holds for processors. For users there is benefit in being able to take a dose and leave the remainder in the freezer or box for an undetermined period whereas before they had to make sure the perishable tubers were used up in time. These are economic and efficiency benefits, but socioeconomic considerations also play a role such as assurance that production takes place in environmentally friendly conditions, that food is safe, produced organically if so desired devoid of synthetic agents and genetic modification as examples.

The economic and environmental considerations of processing have several aspects. Tubers destined to be processed need to meet specifications to manufacture the final product. This avoids transport of undesired tubers with aberrant sizes and with defects. Many finished products only contain a fraction of the amount of water in fresh tubers which also reduces the need for transport. Consumers replace fresh potato by its products which boosts the industry and also gives all cooks in a household more time to spend on income generation. Uneconomic peeling, washing heating in small portions and not reusing the water and energy leads to sub-optimal use of resources and losses as in factories steam peeling is more economic and the peels are use as feed, while water and energy are reused. Manufacturing products from potato that usually are not made in the kitchen widens the range

Table 6.1A2. Benefits of processing potato tubers

Origin	Effect	Impact	Advantage
Prolongation of storage time	Tubers are stored maximally 11 months. Frozen fries 2 years more, dry products many years, buildup of stocks possible	Reduction of fluctuations in supply and demand and prices	Reliable markets for growers and consumers
Widening range of use	The industry makes more products than cooks prepare in kitchens	Increase of product range	Greater consumer satisfaction
	Modified starches as e.g. thickening agents and wheat flour additive		Extension of applications in cuisine
	Extrusion of pellets and subsequent expansion creates many different snacks		More applications in snacks
	Raw parts for ruminants (raw peels, slivers), cooked parts (rejects) for non-ruminants	All is used by humans or animals. No waste	More applications as feed, benefits for the environment
	Native and modified starches are used in the paper and fabrics industry	Reduction of ink, extension of longevity	Benefit for the environment
Cuisine benefits	No peeling, boiling important at home but especially in restaurants and institutes	Less time needed cooking per course with potato	Convenience, time saving for cooks
	Gluten-free for example	Products for coeliac patients	Catering for special diets
	Glycoalkaloids are present in green tubers and acrylamide in fried products	Avoidance of undesired substances	Health benefits for consumers
Economy	Dry matter of tubers on average is 21 % of starch and flour 90 %, of frozen fries 45 %	Reduced bulkiness	Reduction of transport linked costs and negative aspects for the environment
	Transport only of tubers meeting specifications (no tare, right size)	Less transport than for ex-field (applies to chipping tubers mainly)	
	Consumer satisfaction of products stabilizes total tuber production rather than decline	Fresh tuber replacement	Labor and value creation
	Labor saving at home, more time for salaried job	Increase of labor	Increase size of economy
	Many potato specific patents exist	Increase of range of processes and products	Innovation
	Manufacturing leads to less transport, losses of tuber mass, water and energy	Improved use of resources, no waste	More efficient way of food preparation

of dish and meal ingredients, snacks and use as non-food (feed and industry). Modified starches are applied as additives in bakeries and extruded potato pellets provide an assortment of expanded snacks. Peels and rejected tubers, rejected tuber parts, intermediate or finished products are used as feed, raw for ruminants but cooked also for non-ruminant animals. So there is hardly any waste in the industry whereas in kitchens peels and unconsumed tubers are squandered since the collector of food waste as feed with his horse and wain disappeared from the streets. Such considerations and more, especially economic reflections are summarized in Table 6.1A2.

Quantification of the benefits domain

The advantages of processing of Table 6.1A2 are the attributes of the classes potato products illustrated in Table 6.1B. Most attributes are obvious but some need clarification. The market size of a

Table 6.1B. Heatmap of 21 classes of potato products and their 15 attributes, the degree to which they contribute to benefits

1			
Substantial benefit	a	Storage period after processing, the longer the better	Hardly any benefit
	b	Market size of product, larger share is better for economy	
	c	Stabilizes market flow, large market of long storable product	
	d	Bulkiness minimized reduces transport, among others	
	e	Favorable distance to processor, the shorter the better	
	f	Favorable distance to consumer, the shorter the better	
	g	Maintaining national tuber production, better if more tubers produced	
	h	Labor need for processing, more employment is better	
	i	Innovation speed in the food industry, innovations enhance economy	
	j	Minimizing losses in handling and storage, less graded, sorted and stored	
	k	Reduction water need for washing and cooking	
	l	Reduction of energy for heating in the kitchen	
	m	Minimizing tuber losses (peel, cuts) in processing	
	n	Variety of products, the more variety the more consumers can chose	
	o	Convenience for user (time saving, see Table 6.1A1	

	Product classes	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	Average
1	Chuño																2.6
2	Freeze dried cooked																2.5
3	Freeze dried uncooked																2.3
4	Ambient air dried																2.5
5	Hot air dried																2.1
6	Starch																3.5
7	Flakes																3.2
8	Flour/granulates																3.1
9	Pellets																3.3
10	Extruded baked																3.4
11	Extruded expanded fried																3.4
12	French fries frozen																3.3
13	Mashed/formed frozen																2.7
14	Shredded/formed, frozen																2.7
15	IQF dices, shreds, fried																2.8
16	Pre-cooked chilled																2.7
17	Canned																2.9
18	Gratinated frozen																2.6
19	Rissole, frozen																2.5
20	Chips																3.9
21	Alcohol																3.2
	Average	3.2	2.0	2.2	2.6	3.5	2.3	2.5	3.7	2.9	3.4	4.0	2.6	3.0	2.7	3.1	2.9

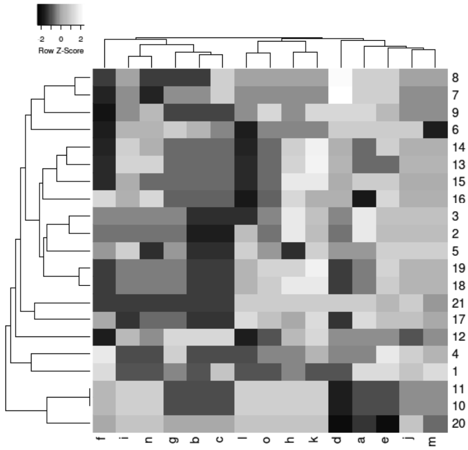
product is not a benefit *per se* but a larger market share has a greater economic impact. Transport of raw material to the processing unit and finished product to the consumer is more beneficial for the environment and cost reduction when the distance is more favorable (shorter). Losses in handling and storage are considerable in chips production (stringent grading) so minimizing their losses is insubstantial but is substantial in starch production where handling and storage hardly play a role. Minimizing losses in starch production on the other hand are quite substantial in starch production with skin and protein ending up as low cost products (feed). The heatmap of Table 6.1B shows the lowest score for tubers and parts (cubes usually) that are cooked and dried in hot air. They need to be reconstituted and heated, have a small market share, need more energy for cooking and in total deliver the lowest advantage. They share such properties with the other dried products of which chuño has the advantage of short distance to processor and consumer, as often these are the same individual. Chips have the highest score (3.9) with high values for employment, innovation (especially the expanded variants), variety of products (shape and flavorings) and water, energy and time saved. Starch production has a high total score with only low values for distance to client, usually non-food and food industry and the amount of water involved in washing the starch. Only a few products have such large market shares, in increasing order flakes, starch and chips with frozen French fries at the top that they have a regulating effect on prices and total potato production in a region. For the same reason that many products only represent a small market, also maintaining tuber production in a country ends with a relatively low score.

The energy saved in preparation in kitchens is none (Table 6.1B red color) for products that need to be reconstituted and boiled, similar to raw tubers. When the product contains gelatinized starch and only needs to be heated the amount of energy saved in the kitchen is moderate (yellow) and ready to eat or drink products need no energy at all (green). Saving water in the kitchen takes place when the tubers of the product have already been washed prior to processing, so chuño is the only exception. When no water is needed for cooking as this took place at the factory, then more water is saved, consequently saving water has the highest score (4.0). Producing and processing tubers is a relatively labor intensive economic activity. It takes more time to manage the crop from ploughing to harvest and handle the tubers post-harvest than is needed for cereals (Haverkort 2018). Also the factory operations are more labor intensive than grinding wheat and baking bread. Consequently creating employment has the second highest average.

Clustering within the benefits domain

The dendrogram in Table 6.1C does show a few clear clusters of the products. The top four products are related dry powders and pellets. Just below there is a group of formed frozen products with blanched chilled at some distance. At the bottom are the snacks grouped together. Extruded baked and fried products have been given identical weight to each attribute so are twins without any distance with distant chips in the same group. Frozen French fries do not belong to a particular cluster but there are a few more closely related twins such as gratin and rissole, raw and cooked freeze dried, formed from mash and shreds (croquettes and hash browns/rösti) and flakes and granulates.

Table 6.1C Dendrogram of all classes of products (1-21 see Table 6.1B) with attributes the degree to which they contribute to benefit (a-o, see Table 6.1B)



Clustering the attributes reveals that a shorter distance from the processor to the user is not related to any other descriptor of benefit. Innovation and a variety of products are obviously linked and grouped with the other market related attributes market size and price stability. The cluster in the middle consists of two twins energy need and convenience (rapid cooking costs less energy) and employment and water need: the less water is needed in the kitchen the more labor is needed in the processing plant. The five remaining attributes mainly concern the raw material: its bulkiness and transport and losses in handling and operations and storage of the tubers and products.

Sustainability Domain

Formulation of the sustainability domain

This section discusses sustainability concerns of the potato processing industry. The three principle stakeholders are the partners in the supply chain: growers, processors and users but other interested parties have stakes as well. These are breeders of the varieties, the seed producers, retailers, food service, food industry, consumers, regulators of governments and certifying bodies. Some are lumped with adjacent participants, seed producers with growers and cooks with consumers as they are suspected to have the same interests. Making the Tables B based upon table 6.2A was done through environmental triangulation from the position of stakeholders being 1) targeted by sustainability measures, 2) steering the measures in a direction they think is favorable and 3) stakeholders trying to disturb the measures for opportunistic reasons. The sustainability domain only took data from companies' sustainability reports and was spread over the headings production of raw material, processing, food and serving the community.

Formulation of the sustainability domain

Reporting by the industry and compartmentalization

Over the recent years in the present century an increasing number of globally operating potato processing companies published sustainability reports, separate from their financial and human resource reports. These reports are more of interest for the potato industry than for most other ones because of the intricate continuity of breeding-seed production-tuber production-processing-chilled and cold distribution-cooking where in many products the original tuber structure (chips, French fries) is still visible. For wheat and corn, both ground and more anonymously disappearing into the food industry the links are much less clear, less interdependent, hence less responsibility is felt for performance of the various parts of the chain. Tubers cannot be stored for a prolonged period so fine-tuning of supply and demand is more important for this than for any other staple. Processing of tuber parts in the potato industry compared to working with powders (wheat and corn) is another distinct feature meriting its own approach regarding sustainability.

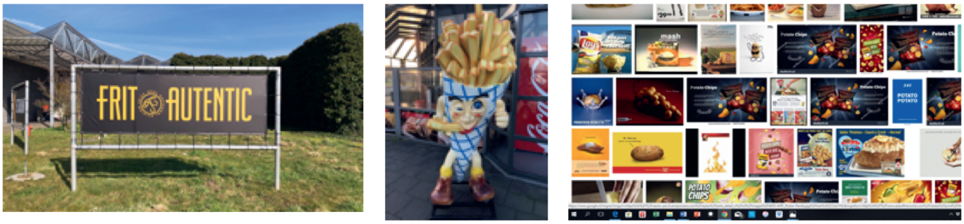
The processing industry of potato has in common with the other food processing industries the dealing with personnel such as training, fair payment, recruiting issues such as ethnicity, equity, and gender. So, this not being potato specific it is not treated here. Nor is charity and contribution to welfare of communities considered except where explicitly potato production and/or processing features. The sustainability reports often are not annual but biennial or the first and last one dates from more than ten years. Data were not retrieved triangularly but only through one single method: consulting and condensing the sustainability reports of the companies. These were Avebe (2020), Aviko (2020), Farm Frites (2020), Fritolay (2020), Pepsico (2020), Simplot (2020) and LambWeston (2020).

All companies in their sustainability reporting more or less follow the order of the production of raw material, processing in production plants, food quality and benefits for communities. Predominantly regarding sustainability, the efficient use of resources is considered, next reduction of emissions, then making safe and healthy food available, followed by community and shareholder values. In general most of the information regarding performance of sustainability through key performance indicators comes from the companies' own sources that could not be verified through independent sources or agents. Data such as "20 % less water used over the last 5 years" or a "2% increase of renewable electricity" presented as key performance indicators (KPI) lack coherence and checkability to be represented in a scientific work. The most important sustainability issue of a company is its competitiveness expressed as its profitability, return on investment. The better it performs the longer it will be in business, sustain. Such information, however, is not presented in the sustainability reports. The financial reports for owners of the companies, the shareholders, is more explicit but the tables in this section also address this point.

Production of raw material

Regarding sustainability there are four major concerns, the efficient use of resources, maintenance of these resources, emissions and intelligence (information).

The principal resources used in the primary production of tubers are land, water, minerals, crop protection agents and propagation material. When managed more effectively, usually with the assistance of DSS (Decision Support Systems) and breeding of tolerant and resistant varieties, their efficiency increases through a reduction of input and/or an increase in crop yield. This is treated



Attracting attention

extensively in Chapter 4. The water use efficiency ameliorates with better soil structure, irrigation scheduling and distribution (drip versus rain gun). Resource conservation measures handle soil matters when its erosion decreases, its structure is improved with machinery less compacting the soil, with measures that increase the organic matter concentration and improve the water holding capacity and rooting depth. Reduction of emissions of chemicals and CO_2 also aim at resource conservation by enhancing biodiversity and by mitigating climate change. Intelligence concerns monitoring pests and diseases and DSS guided dose and timing assist in reducing amounts of biocides, water and fertilizers.

The industry guides growers through science, demonstrations, training and monitors through certification schemes such as SAI-FSA and traces and tracks incoming lots of raw through GLOBALGAP certificates. A significant point not mentioned in the reports of the companies but essential for growers is their position in the market and their dependence on fluctuations. Their indicators are satisfaction with procurement expressed in guidance, price and continuation year to year. An unreliable raw material base is a hazard for sustained processing.

Processing

The equivalent of yield in tuber production is recovery in processing, also expressed as potato utilization: the quantity of finished product produced per ton raw material. The highest value is achieved when less of the material ends up in the lower part of Moerman's ladder (Aramyan and Valeva, 2016 represent an adequate example) where food has the highest value, followed by feed, biobased materials, fuel and dumped in landfills even representing a negative value. Also recapturing of starch and minerals (struvite) contributes to recovery. Concerning processing operations the foremost resource use efficiency to be improved is that of energy used for heating water and oil from fuel mostly, and from electricity for conveying and cooling. Re-use of heat from cooled steam for drying for instance assists in decarbonization and so does production of biogas from waste water and the use of electricity from renewable sources by placing solar panels over the purification basins. More efficient use of water in washing before and after peeling and blanching has high priority with enhanced cleaning and re-use. Re-use of carton packages and recyclable plastics helps in reducing the environmental impact of wrapping and reduction of road kilometers is accomplished by shortening sourcing and distribution distances and transportation by trains and boats. Not mentioned in the sustainability reports of the companies, but yet a significant issue when it comes to sustaining the business, is procurement. Nor are profits mentioned, needed to outsmart competition but also to ensure sustained support from the owners.

Scale

Food quality of products

Food quality is considered a crucial sustainability matter, as safer, healthier, tastier and more convenient products ensure a greater and continuous market. So does a continuous flow of new products of which relatively recent innovations such as fried dough based emoticons, street fries, higher fibers content and air-fry ready products are examples. Others are healthier offerings some of which have less indulgence but more health consciousness appeal. Sustainability issues of the products regard the lowering of concentrations of ingredients considered unhealthy or undesired when eaten at relatively great quantities such as fat (striving for light) especially saturated fatty acids, salt and certain additives such as wheat flour in batter which renders the product not gluten-free. Skin-on and thicker cuts products absorb less oil as they have less surface for oil to adhere to. Better informing the consumer is done by more extensive, informative and accurate labelling including the recently developed Nutri-Score (Julia et al. 2018). There are also claims that the ingredients are recognizable and respected, seemingly hidden signals that no synthetic chemicals (some E-numbers) nor products from genetically modified plants are deployed.

Table 6.2A. Description of the sustainability domain super class (objects) with classes of sustainability indicators with attributes for stakeholders

Class	**Attributes (about sustainability)**	**Examples**	**Key performance indicator**
Production of raw	Resource use efficiencies	Land, water, fertilizer	kg tuber /unit resource
	Emissions of substances	CO_2, chemicals	kg substance/ton tuber
	Resource conservation	Soil, biodiversity	Relative numbers
	Intelligence	Certification, tracing	Proportion growers
	Certification (GLOBALGAP)	SAI-FSA, GlOBALGAP	Proportion growers
	Satisfaction with procurement	Reliability, continuity	€/ton, years associated
	Profitability	Lower costs, greater scale	€ return on investment
Processing	Recovery	Flakes yield	kg/ton
	Resource use efficiency	Energy, water	kg finished/MJ, m^3
	Packaging	Re-use cartons, plastic	Proportion re-usable
	Reduction of road kilometers	Replacement by train	km/ton
	Procurement of raw	Price and conditions	€/ton raw material
	Profitability	Cost reduction	€/ton finished product
Food	Safety (HACCP)	Contaminant	Number of recalls
	Quality	Fat, salt, components	Labelled ingredient
	Health	Offerings, allergens	Nutriscore
	Innovations, new products	Street fries, air-fries	Number per year

Class	Attributes (about sustainability)	Examples	Key performance indicator
	Labelling	Organic, non-GMO	At label
	Benefit for company	Profitability	€ return on investment
Community	Products for developing markets	Adapted, biofortified	Turn over
	Raw from vulnerable growers	Indigenous tubers	Amount sourced
	Sudden events	Crash, pandemic, drought	Drop in % sales
	Gradual events	Fashion, ageing	Shift in % sales
	Industry resilience	Benefit for company	€ return on investment

Serving the community

Some sustainability reports mention contributions to charity with funding, donating to food banks or volunteer's time. These are not potato specific and, like human resource issues are generic for any industry, so not to be discussed here. Other relevant community related subjects regard the raw material base, consumers and processing company strategy. Aiming for products for developing markets that are distributed under ambient conditions (dried, powders, snacks) rather than cooled and chilled or frozen assist in making such products available for less well-off consumers not connected to the grid of cold chains or even to the electricity grid. Innovations specifically aimed at such markets with one sided food like fortified powder as ingredient for fufu in Africa is another class of sustainability measures. Using indigenous colored tubers in the Andes serves both growers with an additional outlet and consumers with a new product to choose from. Investing in watershed management to replenish ground water levels is an illustration of serving growers. Societal issues directly regarding companies' strategies are affairs around sudden changes like a pandemic, widespread climatic events and imposed taxes; slower developing events are market penetration, saturation and altered preference stemming from population built-up and fashions in food. These are only evaluated in Table 6.4B where potato specific.

Quantification of the sustainability domain (1)

The class of sustainability indicators has four sub-classes (production of raw by growers, processing by manufacturers in factories, food quality and serving the community) and each sub-class is supplied with instances taken from the sustainability reports. These are shown in the Tables B of this chapter and number 34 in total. Three types of attributes are distinguished, expressing three points of view. First tabled is the degree to which stakeholders are targeted by the indicator, having to abide by them or benefit from them. Next the degree to which they are able to steer the indicators, to directions they favor is expressed, followed by a third assessment with the degree they are able to bend the rules favoring short term gain rather than long-term tenability. The attributes also concern several points of view of the stakeholders concerned. In the production of raw these are potato breeders and growers. In processing and utilization these are the processors, traders (retail), food service, food industry and (cooks and) consumers. Not exclusively potato addressing stakeholders are regulators (policy and law makers) and certifying bodies such as GLOBALGAP and organic schemes for the production of tubers and a HACCP based Food Safety Management System (FSSC ISO22000) for the industry.

Stakeholders targeted

Table 6.2B1 displays the heatmap of the degree to which stakeholders are targeted by the sustainability measures of processors and their suppliers of tubers including breeders of varieties they are in close contact with to adjust or improve the processing quality of the tubers and their tolerance of biotic and abiotic factors and resistance to pests and diseases. All these properties favor the environment with higher recovery in factories and better use of resources on farms. The heatmap in Table 6.4B1 shows green colors only for growers of tubers for the attributes of the class 'raw material production' and only green colors for the attributes of the classes 'processing, food quality and

Table 6.2B1 All 34 classes of sustainability measures with attributes the degree to which the 9 stakeholders are targeted

Very much targeted			Not targeted at all
	a	Breeder	
	b	Grower	
	c	Processor	
	d	Retailer	
	e	Food Service	
	f	Food Industry	
	g	Consumer	
	h	Regulator	
	i	Certifying, monitoring body	

Object	Nr	Classes of sustainability measures	Attribute a	b	c	d	e	f	g	h	i	Av
Raw material production	1	Improved resource use efficiency										3.0
	2	Resistant and tolerant varieties										2.4
	3	Reduced CO_2 emission										2.7
	4	Increased biodiversity										2.3
	5	Better soil conservation										2.0
	6	Model farms										2.1
	7	Increased science base										2.1
	8	More growers trained										1.9
	9	More growers certified										2.6
	10	Improved tracking information										3.9
	11	Greater profitability for growers										1.8
Processing	12	Improved resource use efficiency										2.2
	13	More renewable energy										2.1
	14	Increase of recovery										1.8
	15	Less waste: more food, less feed..										1.4
	16	Reduce packaging, renewable										2.1
	17	Reduce road and air kilometers										2.4
	18	Greater profitability for processors										1.8
Food quality	19	Innovation, new products										3.3
	20	Tastier, more convenient										3.1
	21	Safer food										4.2
	22	Healthier offerings, NutriScore										3.7
	23	Known and respected ingredients										4.1
	24	Clearer nutritional information										3.4
	25	Gluten-free batters										2.9
	26	Profits through new products										1.4
Community	27	Venturing into developing markets										2.6
	28	Sourcing from vulnerable growers										2.7
	29	Mitigating variable weather										2.1
	30	Adapting to climate change										2.3
	31	Mitigating effects of pandemic										3.1

Very much targeted	a	Breeder	Not targeted at all
	b	Grower	
	c	Processor	
	d	Retailer	
	e	Food Service	
	f	Food Industry	
	g	Consumer	
	h	Regulator	
	i	Certifying, monitoring body	

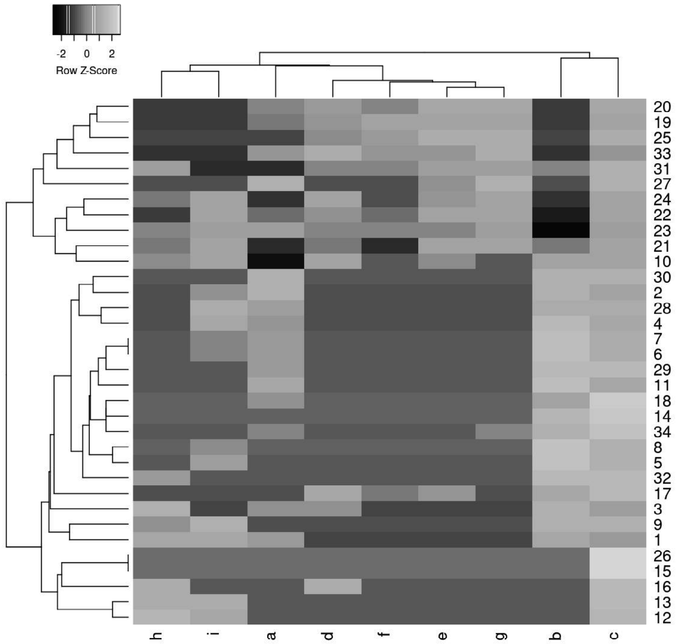
Object	Nr	Classes of sustainability measures	Attribute									Av
			a	b	c	d	e	f	g	h	i	
	32	Resource conservation										2.1
	33	More ambient, less frozen										2.6
	34	Increase profits by bold operating										2.0
		Average	2.4	3.2	4.6	2.1	2.1	1.7	2.2	2.1	2.4	2.5

community'. The 34 sustainability measures are specifically intended for these two target audiences so also reach the highest scores mean value 4.6 for the degree to which processors are targeted and 3.2 for the growers. Least targeted is the food industry deploying intermediate products as ingredients for whom mainly food safety and health is an issue. Although many measures are directed by regulators, especially around environmental and food safety they are only targeted there where actors comply with such directives. Food quality is least a concern of growers with the exception of food safety where they have to make sure that unwanted substances are absent (glass) or below acceptable levels (MRL). Breeders are more involved as some properties have to do with safety (level of glycoalkaloids) others with processing quality (dry matter concentration) and suitability for new products (roast baby potatoes). Of the 34 classes, food safety reaches the highest score with 4.2 points followed by respected ingredients (4.1) and the desire to be able to trace and track how food is established. All three stem from the concern that food should be safe. The lowest score receive the pursuits of increased recovery and making profit with new products, only the processors are targeted.

Clustering the sustainability domain (1)

Clustering the classes as is done through the dendrogram in Table 6.4C1 shows two main clusters with the top one presenting two sub-clusters where [10, 21, 22, 23, 24] deal with food safety and [27, 31, 33, 25, 19, 20] with innovation. All other classes belong to the second cluster at the bottom composed of an array of sub-clusters and sub-subclusters. One shows obvious coherence between recovery and profits, another between variety tolerance and climate change in the same sub-subgroup with biodiversity and sourcing from vulnerable growers. The factory pursuits improving resource use and renewable energy are closely related and so are better soil conservation and model farms for less obvious reasons. The dendrogram in Table 6.4C1 shows that the processors' recovery and profit for new products only target themselves. The same situation applies to the processors' pursuit of promotion of model farms and use of science with identical scores from all stakeholders. Stakeholders show two distinct twins: regulators and certifying bodies quite similar on one side and growers and processors at larger distance at the other.

Table 6.C1. Dendrogram of all classes of sustainability indicators(1-34 see Table 6.2B1) with attributes the degree to which stakeholders are targeted (a-f, see Table 6.2B12)



Stakeholders steering

Quantification of the sustainability domain (2)

Sustainability indicators when directed at interested parties leads to the heatmap provided in Table 6.2B2. These indicators, however, are also prompted with a varying degree of urgency by stakeholders; they are able to steer which indicators apply and set performance indicators. Breeders determine resistance of their varieties but have no say over soil conservation measures on farms. Growers are able to reduce the CO_2 footprint of their enterprise but cannot influence processors in the other classes. Processors who are core target of almost all indicators easily influence production and product quality but hardly how growers increase biodiversity, here regulators come in with incentives. Retailers and consumers hardly influence farmers' practices but are relatively in command where it comes to food safety and quality. Foods services and the food industry dictate gluten absence of gluten but have no power nor interest in recovery of finished products of firms. Legislators may forbit varieties susceptible to wart (*Synchytrium endobioticum*) but cannot oppose or command the establishment of model farms. Certifying organizations, finally, being at the request receiving end of the supply chain,

Table 6.2B2 All classes of sustainability indicators with the degree to which stakeholders are able to steer as attributes

1			
Vary easy to steer	a	Breeder	Near impossible to steer
	b	Grower	
	c	Processor	
	d	Retailer	
	e	Food Service	
	f	Food Industry	
	g	Consumer	
	h	Regulator	
	i	Certifying, monitoring body	

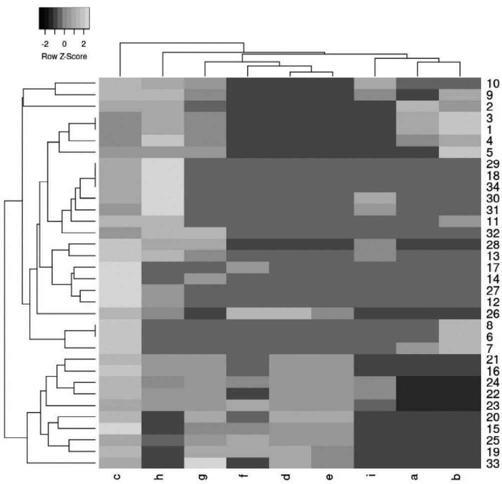
Object	Nr	Classes of sustainability measures	Attribute									
			a	b	c	d	e	f	g	h	i	Av.
Raw material production	1	Improved resource use efficiency										2.0
	2	Resistant and tolerant varieties										2.4
	3	Reduced CO_2 emission										2.0
	4	Increased biodiversity										1.9
	5	Better soil conservation										1.6
	6	Model farms										1.8
	7	Increased science base										2.0
	8	More growers trained										1.8
	9	More growers certified										2.7
	10	Improved tracking information										2.6
	11	Greater profitability for growers										1.6
Processing	12	Improved resource use efficiency										1.6
	13	More renewable energy										2.0
	14	Increase of recovery										1.6
	15	Less waste: more food, less feed..										2.1
	16	Reduce packaging, renewable										2.4
	17	Reduce road and air kilometers										1.6
	18	Greater profitability for processors										1.3
Food quality	19	Innovation, new products										2.7
	20	Tastier, more convenient										2.6
	21	Safer food										2.9
	22	Healthier offerings, NutriScore										3.1
	23	Known and respected ingredients										3.4
	24	Clearer nutritional information										3.1
	25	Gluten-free batters										3.0
	26	Profits through new products										1.9
Community service	27	Venturing into developing markets										1.4
	28	Sourcing from vulnerable growers										1.9
	29	Mitigating variable weather										1.3
	30	Adapting to climate change										1.4
	31	Mitigating effects of pandemic										1.6
	32	Resource conservation										1.6
	33	More ambient, less frozen										2.0
	34	Increase profits by bold operating										1.3
		Average	1.4	1.8	3.9	1.9	1.8	1.6	2.3	2.6	1.4	2.1

exert little influence but for some aspects for which they are responsible, including transfer of intelligence in tracing and tracking systems and defining performance indicators for e.g. food safety. The strongest role for steering is with the processors with a score of 3.9 points approaching the score of Table 6.2B1 but now not the grower is at the second position but the regulator is with 2.6 points. The breeders have the lowest influence and are the weakest actor where it comes to influencing sustainability of processing potato. Of the attributes profitability is least steerable (1.3 points) and demanding safer, known, traceable food is quite doable (about 3.3 points).

Clustering within the sustainability domain (2)

Clustering of the four classes and their attributes with the aid of the dendrogram (Table 6.2C2) also shows two main clusters with the lower one indicators related to food quality and safety. There are a few sub-subclusters with two members such as the association of healthier offerings and clearer information. The top cluster with most indicators not related to food safety and quality shows 6 subclusters. The bottom one with processors' direct involvement in raw material production with more farmers trained and model farms established seen as identical with a slight distance from asking assistance from science. Profits from new products is a single member cluster without associates. The next sub-cluster consists of three pairs two of which with a class from the class processing and of the class serving the community: resource use efficiency-developing markets and renewable energy-sourcing from vulnerable growers. These happen to have about the same stakeholders' interests. The sub-subcluster above contains four members sharing concern for growers and their community and an identical triplet with profits for processors and reducing the impact of variable weather, three things few stakeholders think they can steer. One sub-sub cluster higher handles assets on farms with resource use efficiency and reduced CO_2 emission scoring identical. The top sub-subcluster contains the three classes varieties, tracking and certification but at large distance from each other so rather meaning less.

Table 6.2C2. Dendrogram of all classes of sustainability indicators(1-34 see Table 6.2B2) with attributes the degree to which stakeholders are able to steer (a-f, see Table 6.2B2)



Stakeholders obstructing the rules

Quantification of the sustainability domain (3)

Sustainability efforts, shown in the two previous sections are targeting stakeholders or they can steer them. But stakeholders can also ignore or even obstruct them when they prefer short term advantage over long-term survival. It may be bending the rules a bit by exaggerating the performance of a variety by a breeder, by registering a lower dose of a crop protectant than actually applied, by a processor obscuring the presence of certain ingredients, a retailer refusing a new more environmentally friendly product for fear of scaring off clients, food services and industry for the same reasons. Consumers can buy at lower prices when taking home products without green labels. Policymakers can be too lenient to make laws or do not enforce them. The same holds for certifying agencies. The tendency to ignore is stronger for attributes that cannot be detected easily and, where the penalty of an offence does not outweigh the gain.

The heatmap with easiness to ignore sustainability measures by participants in the potato products supply chain is illustrated in Table 6.2B3. As in Table 6.2B2 the processors operating in all classes involved receive most points and breeders operating in one class mainly and, with only a small number of classes, receive fewest points. Processors are followed by retailers where it comes to obstructing ability.

Regarding the classes, no participant ventures to declare a product gluten-free while adding wheat flour on purpose, because detection would be certain, this explains the low score of 1 point for this aspects only. Low scores are measures of the processing company itself without involvement of other participants in the supply chain. Training growers and serving the community clearly illustrates this with about 1.4 points. High scores are given to measures that touch several stakeholders such as packing and supply chain information.

Table 6.2B3. All classes of sustainability indicators with the degree to which stakeholders are able to obstruct them a to a certain degree

Easy to obstruct			Hard to obstruct
	a	Breeder	
	b	Grower	
	c	Processor	
	d	Retailer	
	e	Food Service	
	f	Food Industry	
	g	Consumer	
	h	Regulator, policymaker	
	i	Certifying, monitoring body	

Object	Nr	Classes of sustainability measure	Attribute									
			a	b	c	d	e	f	g	h	i	Av.
Raw material	1	Improved resource use efficiency										2.3
	2	Resistant and tolerant varieties										2.8
	3	Reduced CO_2 emission										2.3
	4	Increased biodiversity										2.3
	5	Better soil conservation										2.3

Easy to obstruct			Hard to obstruct
	a	Breeder	
	b	Grower	
	c	Processor	
	d	Retailer	
	e	Food Service	
	f	Food Industry	
	g	Consumer	
	h	Regulator, policymaker	
	i	Certifying, monitoring body	

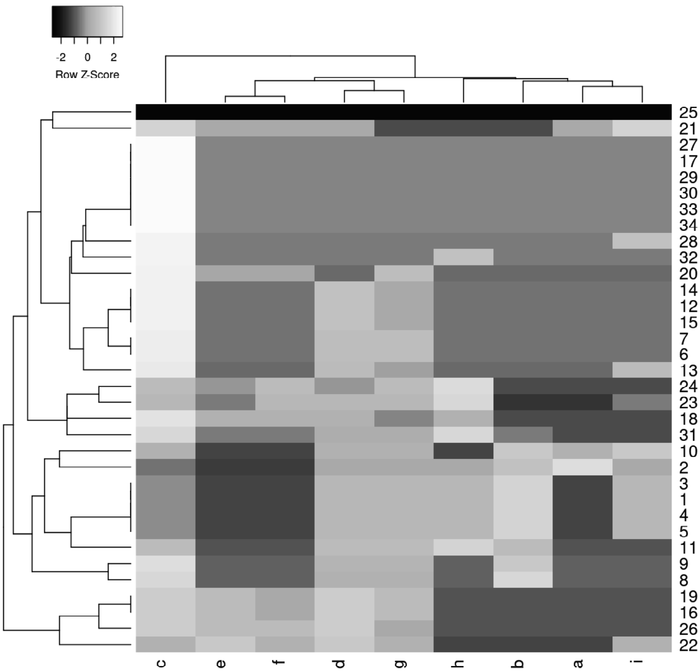
Object	Nr	Classes of sustainability measure	Attribute									
			a	b	c	d	e	f	g	h	i	Av.
	6	Model farms										1.9
	7	Increased science base										1.9
	8	More growers trained										2.3
	9	More growers certified										2.2
	10	Improved tracking information										2.6
	11	Greater profitability for growers										2.2
Processing	12	Improved resource use efficiency										1.8
	13	More renewable energy										2.0
	14	Increase of recovery										1.8
	15	Less waste: more food, less feed..										1.8
	16	Reduce packaging, renewable										2.8
	17	Reduce road and air kilometers										1.4
	18	Greater profitability for processors										2.4
Food quality	19	Innovation, new products										2.8
	20	Tastier, more convenient										1.9
	21	Safer food										1.9
	22	Healthier offerings, NutriScore										2.6
	23	Known and respected ingredients										2.4
	24	Clearer nutritional information										2.2
	25	Gluten-free batters										1.0
	26	Profits through new products										2.8
Community	27	Venturing into developing markets										1.4
	28	Sourcing from vulnerable growers										1.7
	29	Mitigating variable weather										1.4
	30	Adapting to climate change										1.4
	31	Mitigating effects of pandemic										2.7
	32	Resource conservation										1.7
	33	More ambient, less frozen										1.4
	34	Increase profits by bold operating										1.4
		Average	1.7	2.6	5.8	3.6	2.2	2.2	3.3	2.5	2.3	2.1

Clustering within the sustainability domain (3)

Clustering (Table 6.2C3) does not present a clear picture of a few sub-clusters. There are a few twins such as more growers trained-and certified at close distance, known and respected ingredients-clearer nutritional information at greater distance from each other and safer food-gluten-free and at very large distance indicative of fewer stakeholders attaching less weight to the subject. There are quite some groups of classes of sustainability measures with the same score from the various stakeholders. Most of the community activities fall into the same category, so do model farms and science involvement, the three factory resource measures and the two classes new products and packing.

Grouping attributes is shown on the top of Table 6.2C3. The similarities among them is greater than among classes, because the distance from the axis is shorter in general. Two clusters are seen in Table 6.2B2 with two groups consisting of the processors in one and the other eight in the second cluster. Two sub-subclusters with two closely associated attributes are food service and industry and the other one retail and consumers.

Table 6.2C3 Dendrogram of all classes of sustainability indicators(1-34 see Table6.2B3) with attributes the degree to which stakeholders are able to obstruct (a-f, see Table 6.2B3



Processing potato in its surroundings domains

This section contains two domains: the PESTEL-Actor domain and the PESTEL-Environment domain

Formulation of the PESTEL-actor domain

A societal-interest based interdisciplinary study is aimed at gaining insight and developing a methodology from different disciplinary perspectives: on-farm production of potato tubers, the raw material, food processing technology, food science, environment and socio-economics. The analytical frame used here (PESTEL) allows gathering of the various disciplines. The PESTEL approach among others is explained in B2U (2020) and the website of Pestlanalysis.com where it is combined with a

SWOT (Strengths, Weaknesses, Opportunities and Threats analysis per PESTEL element. Examples of its use are given by Nurmi and Niemelä (2018) and Roman (2015). The PESTEL approach analyses the external influences on processes and decisions to be taken whereas the SWOT analysis addresses both the internal (SW) and external (OT) influences. Potato products are brought about in **P**olicy, **E**conomic, **S**ocial, **T**echnological, **E**nvironmental and **L**egal surroundings. Policy deals for example with protection of trade and promotion of production, Economics with value chains and consumer expenditure on food, Social aspects are for instance green production labels for farmers and convenience food for consumers, Technology concerns scale and innovation, Environment considers resource use and climate change and Legal aspects take into account human and environmental health. Table 6.3A exemplifies, with key words, the kinds of issues that arise per group of actors that in subsequent tables are explored at greater length and for an array of actors that exist for the various markets.

Farmers are the first in the flow of material in the supply chain of potato products The setting of the industry in its social surroundings is strongly determined by the farmers who cultivate and store raw material. Tuber production involves the resources labor, equipment, land, water, minerals and energy and is associated with emission of nitrogen compounds and greenhouse gases. These are all expressed as unit per ton raw and vary with system such as high and low input, corporate or family farming, organic or conventional, rainfed or irrigated. Processes also vary in resource use efficiency and losses (peel, defects) as depending on scale (cottage and industry) and method (dehydration, heating) all expressed in units per ton product. Performance of cultivation and processing further depends on the PESTEL elements Policies (trade, taxes, labor) and Legislation (food safety and Environmental requirements). Production ecology, value chain and use of resources among others is extensively described by (Haverkort 1990; Haverkort 2018; Haverkort and Hillier 2011) as well as the influence of climate change on the potato supply chain (Haverkort and Verhagen 2008) and on production (Haverkort et al. 2013).

Processors in factories dehydrate tubers to mainly produce flour and starch, ingredients used by consumers, but to a greater extent used by manufacturers to transform it into flour and starch based derivates such as mash-based croquettes and pellet-based extruded products. Tubers peeled, cut, blanched and cooled provide convenient chilled food for households. Frying tuber cuts partially dehydrated yields chips delivered frozen as meal component and sliced and fully dehydrated produce snacks as chips. History and development were described among others by (Woolfe 1987), Rana et al. 2017; Willard 1993). Of the PESTEL elements Technology (innovation, research and development) is most prominent, coupled with Economy (competition, pricing) and Environment (efficiency of use of resources).

Consumers are the last in the flow of material in the supply chain of potato products as food. With 400 million tons of global production for 8 billion inhabitants global availability of potato is about 50 kg per person per year. Actual consumption is less because about 10% is used as propagation material (seed tubers) to be planted and part goes to the starch industry for non-food applications. There is an increase of consumption in Asia and Africa and there was a decrease of freshly prepared tubers in the rest of the world, where processing took an important place. So, in monetary terms consumer expenses on potato have increased relatedly (Factsheet 2017). The contribution of potato and its products to the energy and protein balance in diets and health (Chandrasekara and Kumar 2016) accordingly differs in the environments where the role of crop is that of food, cash or industrial crop, convenient or snack food. Beside the beneficial aspects of contribution to food availability and intake, where consumed as fried product it leads to obesity, especially by low income consumers in high income societies (Borch et al. 2016; Blakely 2019). Of the PESTEL elements, Economy (food affordability), Society (food quality, health) and Legal (compliance and food safety) are dominant matters for users in kitchens in houses, restaurants and institutions.

Disclaimer: the domains of PESTEL matter per principle actor and in diverse environments as approached here are delimited by the personal experience and vision of the author through methodological triangulation with reference to other research and literature de-emphasized and systematic empirical research lacking.

Condensation of the PESTEL-Actor domain

Farmer

Important policy decision that influence growers of tubers destined for the processing industry are imports of tubers for seed production or raw material and the import licenses and tariffs that apply to finished products. Some countries prohibit the imports of seed potatoes for plant health and competition reasons although more suitable varieties are required by the industry. Farmers and processors have fear of imports at low tariffs. Governments decide on the type of crop protectant agents that are allowed by farmers and occasionally crucial agents to control late blight or sprouting are forbidden with substantial consequences for the industry. Subsidies on inputs such as free water and electricity, low taxes and a financial allowance per unit farm area strongly influence profitability and financial sustainability. The costs of inputs such as nitrogen fertilizers, following energy prices (Economy matter) and partly determined by taxes and subsidies (Policy matter) fluctuate. Yields and prices of the raw material also fluctuate due to variation in supply because of weather events (Environment) or overproduction (Economy). Access to credit from banks varies among countries, type of farmers and of banks and changes with time as a function of global crises. Socio-economic factors influencing decisions to grow the crop are farm scale, too small does not attract attention of a processor and does not allow mechanization. The sourcing range of a factory roughly speaking is 100 km for starch, 250 to 300 km for tubers destined for making French fries and even up to 1000 km for chips tubers. Urbanization has two repercussions: it takes up arable land and it removes population (workers) from the rural area. Technological developments are mechanization with ever larger machinery, the use of decision support systems based on information from crop, weather and soil to plant, irrigate, fertilize and protect the crops. Beside automation regulating time and dose, precision farming also allocates inputs to parts of the according to sensed requirements. Environmental concerns of growers concern daily weather and the effects of climate change with rising temperatures, and increasing erratic temperature and water events. Legal obligations are restrictions on the use of certain inputs, information supply on the use of inputs to institutions of governments and certifiers and compliances with tax, food safety and environmental laws.

Processor

Policy makers make it of interest for potato processors to establish a factory as they provide a sales market for growers, employment for workers and taxes for themselves. Through tax tariffs they make it attractive or not, to import raw material which is valuable for processors when local raw is more expensive. Also export of finished products (export taxes or subsidies) and import (trade barriers or high tariffs) determine the business climate to a great extent. The more corruption exists by officials turning a blind eye, the more processors hesitate to enter a country at all. A major determinant of profit is the presence of competition both for procuring raw material that hinders processors of chips and French fries to the same degree, but not for sales as they supply different markets. The price of raw is of major influence as well. The bulk of factories of frozen products are in the regions with cheapest raw: North West Europe and East and West North of the USA and the South of Canada. Here the resource use efficiencies are highest. Plants of chips are in the vicinity of large cities and the price of raw is less important because the on-farm potato part in the product is marginal because costs of transport, oil and packaging (bags, cartons) are considerable. Labor costs also determine profitability but there is a level playing field because, they in general are in regions with fairly well remunerated employees as processing food is not easily put at distance in low income countries. Another social aspect is the outlet of the products, in bulk to the food or non-food industry, in large package to the food service or via retail to the consumers. The aspiration to recycle and optimize the use of resources also have repercussions on processors' behavior. Technical challenges are innovations in operations and equipment and their automation aimed at the possibility to increase recovery, make new products and to allow automation and reducing the need for labor. Environmental concerns were addressed in the section on sustainability in this chapter. Legal matters regard food safety (abide by HACCP) and safety of workers, two pre-competitive issues but checking and enforcement are not the same in each environment

User

Users of potato products expect policymakers to make sure the national food laws comply with those of the Codex Alimentarius and that proper information flows (tracing and tracking) and labelling are in place. Where appropriate consumers want policies that enhance low prices by allowing competition and not fluctuating prices by maintaining stocks of inputs such as energy. Economic consideration are buying power, so the affordability of the products that depend on income and price. Household cooks with jobs need products to save time in the kitchen. The degree of economic development of a country is of influence on households, and shops having fridges and freezers needed to supply frozen products.

Spending on products that are more expensive than fresh tubers is also determined by the economic sentiment such as (financial) crises and pandemics where one category of users, the food service, all of a sudden falls away. Food ethics of societies deliver bans such as "this is devoid of cow, porc, GMO's" which put restrictions on raw, batter and flavorings. Where to find a potato product is a focal point as street markets, small shops and super markets have an increasing array of products but distance from the user varies among economies and districts. Regarding technology, the availability of basic (stove and pans) or more advanced (oven, air fryer) equipment and storage (ambient pantry, fridge, freezer) for a great deal determine the absorption capacity of products. The internet is a driver for many consumers to make choices (dish, needed ingredients, prices) and so is circularity of production, beside an environmental issue, also a technological consideration for consumers who are aware of the possibilities. Using and consuming all of the product, so avoiding waste, is a most relevant social and environmental matter. So is re-use, avoidance of delivery to a landfill of packages and minimizing the use of energy and water in kitchens. Legal affairs touching users of products are food safety regulations, waste management (organic, plastic, paper and residual waste) and age restrictions such as potato-based beers and vodka not to be sold to minors.

Table 6.3A. The three principle actors, their main interest and three examples of PESTEL interference

	Actors, do			
	Farmers grow	**Processors use techniques, make products**		**Users choose, decide**
	Production, sorting and storing of potato tubers as raw material	Dehydration	Tuber, flour, starch	Ingredient
		Transformation	Flour/starch-based	Derivate
		Blanching	Chilled potato (parts)	Convenience
		Frying (freezing)	Chips	Snack
			Chips(frozen)	Meal component
P	Importation of seed and raw Type and dose of chemicals Subsidies on inputs	Business climate Tariffs Corruption		Compliance with CODEX Labelling, information Pricing
E	Input costs Price fluctuations Credit	Competition Availability and price of raw Labor costs		Buying power, convenience Cold chains Sentiments (pandemic)
S	Scale of operation, farm size Vicinity to markets Urbanization	Distance from raw and users Market fabric: food industry, service, retail Sustainability aspiration		Health, diets Food ethics Fabric of outlets
T	Mechanization Decision support system Automation, precision	Innovation Automation Recovery		Appliances Internet Circularity
E	Conservation of land, water Fluctuation weather Climate change	Use of resources Emissions and waste Footprint of raw		Use of water, energy Wasting food Package: type, disposal
L	Certification, labelling Compliance with rules Supplying information	Rights of workers Safety in plants Food additives, safety		Food safety Dealing waste Age restrictions

Quantification of the PESTEL-Actors domain

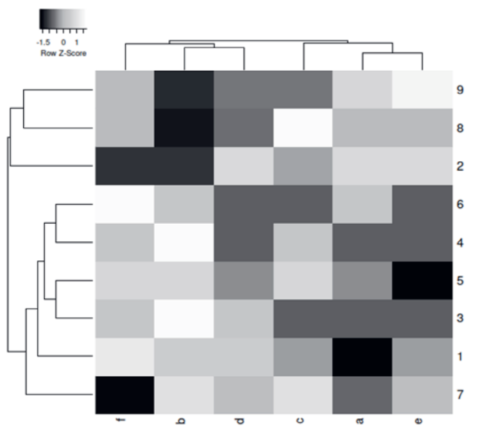
The heatmap of the classes of stakeholders and PESTEL elements as their attributes is shown in Table 6.3B1. There are two versions of the heatmap. On top a version where it is assumed that the stakeholders are subjected to an existing situation with current PESTEL matters. At the bottom the same stakeholders are listed but now scores are allocated assuming the stakeholders are able to exert an influence into a direction that favors them. The average of all scores 3.0 at the top and 2.4 at the bottom, so in general stakeholders feel more subject than master of their surroundings. Especially growers seem most affected by policies regarding subsidies, imports regulations of chemicals and water to name a few. On the other hand, together with consumers, an even more numerous group they also can exert an influence on policymakers through actions and democratic processes. The various stakeholders although allotted very different scores Regulators are not affected by the

Table 6.3B1. Classes of stakeholders with attributes the degree to which they are subjected to PESTEL elements (Top) or influence them (Bottom)

Table 6.3C1. Dendrogram of the classes of stakeholders with attributes the degree they are subjected to PESTEL elements (Top) or influence them (Bottom)

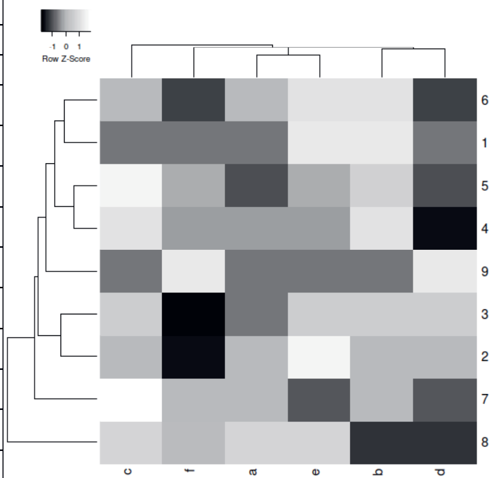
Relevant PESTEL elements Irrelevant

	Subjected class	P	E	S	T	E	L	Av.
		a	b	c	d	e	f	
1	Breeder							2.7
2	Grower							4.2
3	Processor							3.7
4	Retailer							2.7
5	Service							3.3
6	Industry							2.7
7	Consumers							2.8
8	Regulator							2.8
9	Monitors							2.2
	Average	2.9	3.2	3.3	3.0	2.7	2.9	**3.0**



Relevant PESTEL elements Irrelevant

Influencing class	P	E	S	T	E	L	Av.
	a	b	c	d	e	f	
Breeder							1.3
Grower							3.0
Processor							2.5
Retailer							2.2
Food service							2.2
Food Industry							2.0
Consumers							3.0
Regulator							3.8
Monitors							1.3
Average	2.2	2.6	3.0	1.8	2.8	1.9	**2.4**



economy, processors very much, monitors not by the environment, growers are) the average of scores hardly fluctuate with values around 3.

When it comes to influencing the surroundings through PESTEL matters there is more variation. Stakeholders are not very able to change technology and legal matters with a an average score of 1.9 but are capable to influence their societal setting and to a slightly lesser degree also the environment. Breeders and monitors are more serving the surroundings than mastering them (average 1.3) and regulators, obviously are superior with a sum of 3.8.

Cottage industry

The classes of stakeholders subjected to PESTEL matters, regulators and controllers, are clustered as rather distant twins. Processors, retailers, the food services and food industry have much in common. Consumers are not clustered with any other stakeholder. The PESTEL elements show two clusters, policy economy and environment being one of them. Where stakeholders exert an influence the four that are most in control (growers, processors, consumers and regulators) are one cluster, the other five with the close twin processors and growers in the other.

Each class of PESTEL elements in Table 6.3B2 is supplied with details (producing subclasses) pertaining to the three principal participants in the supply chain. Theoretically this leads to 6 PESTEL elements × 3 subjects × 3 participants = 54 subjects. These and a few more added are tabled and heatmapped according to their relative relevance and dependency for the 9 stakeholders, alphabetically in Table 6.3B2 and clustered in Table 6.3C2.

There are five average scores lower than 2.2. This in general because they are only of interest to one or two interested parties such as the availability of and recovery from raw material (only growers and processors), only households are interested in appliances and only growers in credit (and in some cases processors too). Mean values between 2.2 and 3.3 dominate and are valid for about half of the classes, typically values of 2.8 are business environment, circularity, distance of outlets, mechanization and vicinity to clients found of interest for a few parties. Typical representatives of the range of averages of classes between 3.3 and 4.4 with a value of about 4 are related to policy and legal matters (allowed additives, certification corruption and compliance that touch most stakeholders). There is only one class with a sum of 4.4 which is information upstream, all stakeholders find this relevant because they have to (comply) or they like to (cooks informing the eaters). Policymakers are an exception, the ball stops there. Also other information related classes have high scores.

The average of scores of the interested parties in Table 6.3B2 are low for breeders and controllers as was seen in Table 6.3B1, but now the highest score is for the processors who find much relevance of many classes of subjects within the PESTEL elements. Where growers have no interest in the fabric of the clients of processors, product innovation and food waste, there are major concerns of processors. Yet growers and processors have most in common as is apparent from the two high sums of scores, so there must be much agreement among them, as is also evident from the dendrogram in Table 6.3C2

Table 6.3B2. Subclasses of PESTEL elements in alphabetical order (63) with 9 attributes the degree of relevance for stakeholders

Relevant for stakeholders			Irrelevant for stakeholders
	a	Breeder	
	b	Grower	
	c	Processor	
	d	Retailer	
	e	Food Service	
	f	Food Industry	
	g	Cook, consumer	
	h	Regulator, policymaker	
	i	Certifying, monitoring body	

Nr	Subclass	a	b	c	d	e	f	g	h	i	Average
1	Age restrictions										2.4
2	Appliances										2.0
3	Automation										3.0
4	Availability of labour										3.1
5	Availability of raw										2.0
6	Business climate										2.8
7	Buying power of consumers										3.4
8	Certification										3.8
9	Chemicals allowed										3.3
10	Circularity										2.8
11	Climate change										2.7
12	Cold chains										2.8
13	Competition										3.3
14	Compliance with food laws										4.1
15	Conservation of land, water										2.3
16	Convenience										2.9
17	Corruption										3.8
18	Credit										2.1
19	Decarbonization options										2.3
20	Decision support system										2.2
21	Diets										3.6
22	Distance from outlets										2.8
23	Efficiency: water, energy										3.2
24	Efficient uses of land										2.3
25	Emissions										3.7
26	Equipment										3.3
27	Fabric of outlets										2.6
28	Fluctuation of weather										2.4
29	Food additives										4.0
30	Food ethics										3.4
31	Food safety										4.3
32	Footprint of raw										2.4
33	Health										3.4
34	Importation										3.0
35	Information receiving										4.2
36	Information downstream										3.9
37	Information upstream										4.4
38	Innovation of techniques										2.7
39	Innovation products										3.1

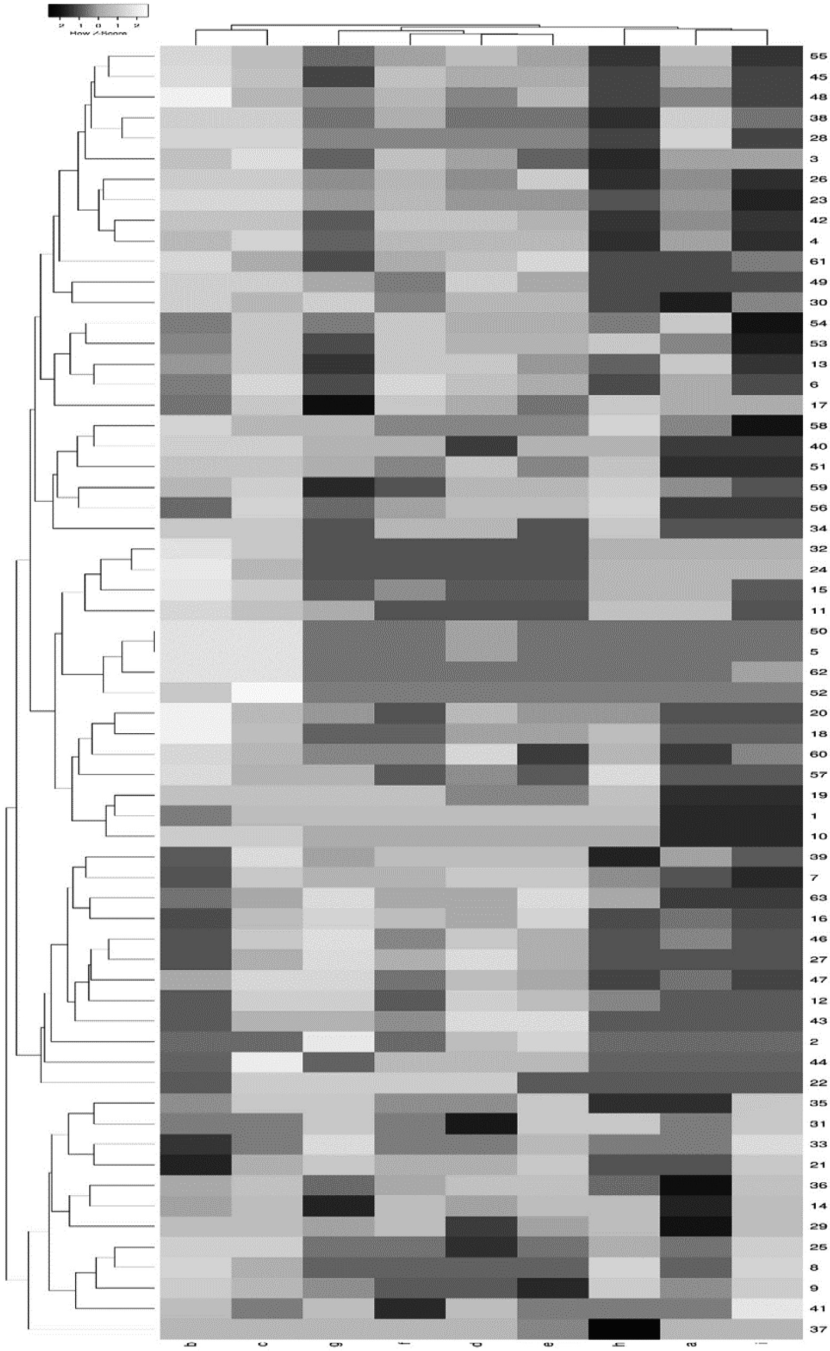
Relevant for stakeholders				Irrelevant for stakeholders
	a	Breeder		
	b	Grower		
	c	Processor		
	d	Retailer		
	e	Food Service		
	f	Food Industry		
	g	Cook, consumer		
	h	Regulator, policymaker		
	i	Certifying, monitoring body		

Nr	Subclass	a	b	c	d	e	f	g	h	i	Average
40	Input costs										3.6
41	Labelling (green, organic,..)										3.4
42	Labor costs										3.4
43	Market fabric of consumers										2.4
44	Market fabric of processors										2.1
45	Mechanization										2.8
46	Package disposal										2.6
47	Package, type, size										2.9
48	Precision techniques										2.4
49	Price fluctuations										2.9
50	Price of raw										2.0
51	Pricing of goods										3.6
52	Recovery of raw										1.7
53	Rights of workers										3.6
54	Safety at working place										3.7
55	Scale of operation										3.0
56	Sentiments (pandemic)										3.0
57	Subsidies on inputs										2.4
58	Sustainability aspirations										3.4
59	Tariffs										3.2
60	Urbanization										2.3
61	Vicinity of clients										2.7
62	Vicinity of raw										1.9
63	Wasting food										2.9
	Average	2.2	3.7	4.2	3.3	3.1	3.0	2.8	2.5	2.0	3.0

Clustering within PESTEL-Actor matters

This dendrogram (Table 6.3C2) shows a few clusters and twins that are expected and easy explained, other ones seem more coincidental. Obvious ones are automation, mechanization, information and precision in one cluster and certification, emissions and chemicals allowed and so are labor costs, labor availability and equipment grouped, close by workers' rights, salaries and business climate. Obvious twins are price and availability of raw (identical), decarbonization and circularity,

Table 6.3C2. Dendrogram of the subclasses of PESTEL elements (1-63 Table 6.3B2) with attributes the degree of relevance for stakeholders (a-i Table 6.3B2)



buying power and new products, food safety and wanting to receive information, diets and health, information up- and downstream, safety at the workplace and scale of operations. Less obvious at first sight are the fabric of outlets users have to look for and package disposal, apparently, they are mainly a consumer concern, hence the logic.

The stakeholders form three groups: the twins growers and processors are in one cluster, so are breeders, certifiers and regulators and the four users of products are clustered in the center. Clustering in Table 6.3C1 is slightly different, there breeders, albeit remotely, so rather stand alone, are in the same cluster as the users.

The PESTEL-Environment domain

Formulation of the domain

There are countries, notably those close to the equator devoid of mountains where it is too hot year round to grow potatoes. Yet potato products, dried and frozen are available such as mash powder in Paramaribo and frozen fries in Accra. There are no issues with respect to potato production and processing but high import duties when applied, act as a taxation and may protect local alternatives. With low buying power and small markets these are not focal points of the multinational processors. The same is the case in low income tropical countries where farmers grow potatoes in the hills, and where often no processing takes place because of lacking demand, unfamiliarity with the products, and absence of a cold chain in shops. Some import of chips and frozen French fries takes place for a supermarket chain and for hotels.

There are countries where potatoes grow but where the raw material cannot compete with imported tubers. Japan imports part of its raw material from Canada both for crisping and French fries. Potato chips producers in Manilla use German potatoes among others because the local tubers with low dry matter are not suitable. In Indonesia suitable tubers for chips production are not available year round and procure them from Australia and Argentina where also harvests take place six months later than in Europe. Usually only crisping tubers are imported as raw material for national production, French fries are imported processed and frozen. Issues for local farmers who supply part of the need, are quarantine measures to avoid the introduction of plant diseases, improvement of local raw material through variety introduction and crop management. Globally operating processors processing imported tubers in a new market have no other concerns than in their home country.

In several countries there is a local cottage industry of chips to cater for low income buyers at markets whereas well off customers purchase imported products in supermarkets (Kempenaar et al. 2017). The cottage industry procures from the local market where administrations often subsidize inputs such as chemicals, to stimulate the farming community. Farmers are at a disadvantage because of the low quality of the raw material that does not meet international standards coupled with a low efficient use of resources land, water, fertilizers and labor. Policies for processors and users in such markets usually are non-existent. Cottage level processors' concerns are increasing their scale of operations, consumers buy more when increasingly they have acquired a taste for the new snack.

Co-existence of large scale production of frozen fries and chips of domestic and multinational origin is found in large new markets of China and India. Policies affecting global processors are the need to establish joint ventures with national companies and high import tariffs for their imported produce. Their socio-economic concerns are copying and adapting technology and the increasing demand to reduce emissions of pollutants. They have to establish a grower base with adequate technology to deliver raw material of the right quality as instructed by their agronomists: right variety and directed land, water and soil fertility management. Users, consumers in these situations welcome the new food items, reason why the factories are scaling up. In saturated and export markets such as North America and Northern Europe farmers are subjected to trade wars, complying with agricultural policies including black listing of biocides, meeting contract obligations (quantity and specs) at competitive prices, continuous adaptations to new techniques, varieties and chemicals. Restricted use of irrigation water, salinity, erosion and climate change are increasingly a concern of growers. Processors keep a close eye on a level playing field with environmental and state aid interventions applying to all actors in the field, anticipating and complying more and more with legislation regarding renewable energy and water use whence also innovations in technology. Users demand adequate polices and laws regarding food and environmental safety, are keen on competitive pricing with a wealth of choice and price-quality combinations. Innovations in the kitchen consist of introduction of appliances such as microwaves and air fryers.

Condensation of the PESTEL-environment domain

Six production-consumption situations exist regarding processing potatoes. These are shown in Table 6.4A. together with a few of their most pressing PESTEL matters. Of each of the situations two cases are shown as examples representative of a number of such countries.

The introduction of potato processing at industrial scale into new markets takes place following a few different trajectories. Cottage industry level entrepreneurs start making chips in their

Table 6.4A. Most important issues for growers, processors exporting and/or producing) and consumers in various markets

	Actors	**Production and consumption environment**					
		No crop, no processing Some import	Crops present, processing not, some import	Crops there (not suitable or too expensive) still imports raw for local processing	Cottage processing industry from local raw	Start of large scale processing	Established large scale processing and still developing
Case		Surinam, Ghana	Guinea Conakry	Japan Philippines	Myanmar, Rwanda**	China, India, Ethiopia	USA, Netherlands
Policy	Farmers	NA	Exploration	Research and development	Subsidy for inputs	Subsidy for inputs	CAP, protection
	Proces-sors	Protectionism	Exploration	Stimulating local production	Usually none	Joint venture, taxation imports	Level playing field*
	Users	Use of local alternatives	Use of local alternatives	Food safety, price policy	Price	Food safety introduction	Food safety Environment friendly
Economy	Farmers	NA	Subsistence, hardly marketed	Import costs Only for high priced chips	Low contribution	Production costs, subsidy for imports	Continuity, contract conditions
	Proces-sors	low buying power, small market	low buying power, small market	Expensive raw material, sourcing area	Upscaling	Buying power, expansion	Competitiveness, export opportunities
	Users	Affordability	Affordability	Many local alternatives exist	Choice local or import	Choice local or import	Wide range of affordable products

	Actors	Production and consumption environment					
		No crop, no processing Some import	Crops present, processing not, some import	Crops there (not suitable or too expensive) still imports raw for local processing	Cottage processing industry from local raw	Start of large scale processing	Established large scale processing and still developing
Case		Surinam, Ghana	Guinea Conakry	Japan Philippines	Myanmar, Rwanda**	China, India, Ethiopia	USA, Netherlands
Society	Farmers	NA	Subsistence dominates	Pesticide use Green labels	Relieve from subsistence	Urbanization, opportunity to deliver	Needed scale (family, corporate)
	Proces-sors	Consumers do not know products	Consumers do not know products	Renewable energy water , labor rights	Low efficiency (energy, labor)	Copied from western industries	Renewable energy, water, new products for consumers
	Users	Unfamiliarity of ingredient	Unfamiliarity of ingredient	Safety, Demography Japan old Philipp young	Takes time to acquire taste	Rapid increase need, new food Safety, React upon calamity	QSR, image, health, diets, convenience
Technology	Farmers	NA	Varieties, seed, tubers	Development of local raw supply chain	Improving raw quality	New seed systems, raw supply system	New varieties, technologies, routine
	Proces-sors	NA	NA	Continuous equipment innovation High tech efficient	upscaling and mechanizati on	Take technology with them, improve raw	Continuous innovations in operations and products
	Users	Kitchen equipment	Introduction cold chain	New ways of preparing at home (airfry)	Introduction of cold chain	Expanding chilled and cold chain	New ways of preparing at home (airfry)
Environment	Farmers	NA	NA	Footprint import is opportunity	Erosion, water use, climate change	Water use, Energy use Climate change	Pesticides, CO_2, water Climate change
	Proces-sors	Footprint	Footprint	Waste avoidance and treatment	Not an issue	Increasing demands	Compliance with laws, climate change
	Users	No issues	No issues	Package, waste energy	Not an issue	Growing consciousness	Package, waste, energy concerns
Legislation	Farmers	NA	NA	NA	Usually none	Water extraction	Compliance with laws
	Proces-sors	NA	NA	Establishment laws	Usually none	Stricter labor laws, bureaucracy	Compliance with strict laws
	Users	No issues ***	No issues	No issues	No issues	No issues	Age restrictions
	Referen-ces	FAOSTAT, 2021	Fresh Plaza, 2016	Kurai, 2017 Gonzalezet et al, 2016	Kempenaar et al. 2013	Haverkort et al. 2012 Inouye 2018	Arici 2019 EUPPA 2021

• No state aid, compliance with laws environment, labour...
** Small scale industry
*** Imported than food safety, legislation etc. taken care of in exporting country
Potato climate suitability not tackled yet (lack of water, lack of highland,..

kitchen, packed in plastic bags, labelled with their mobile phone number and sold at nearby shops and markets. This then is scaled up to a small and gradually expanding factory with a local brand name and competes with the higher market segment of imported chips. When the foreign brand is large enough the global processor either buys the local brand or starts its own supply and demand chain. For a global player venturing into a new market without a take-over an about 10-year trajectory is needed to identify suitable varieties, organize growers for the production of seed and processing tubers before starting a production line. For frozen products it is also needed to establish a cold chain which takes time to develop, so in the mean time they supply the chips processors or start making flakes awaiting market development. Meanwhile the PESTEL matters in Table 6.4A apply.

Quantification of the PESTEL-environment domain

The heatmap (Table 6.4B) resulting from the inventory of Table 6.4A gives the general impression that the more advanced the processing environment is, the more substantial elements of PESTEL matter to the three principle partners in the product supply chain. The optimal is at the large scale industry starting in upcoming markets. Here policymakers promulgate trade, tax and import measures that challenge processors, consumers lack knowledge and buying power, the raw material base needs to be built up and bureaucracy often is substantial. Some of these issues also play a role

Table 6.4B Heatmap of the 18 classes of actors (for growers, processors exporting and/or producing) and consumers) with 6 attributes the most important PESTEL element in various markets

PESTEL element matters much	a b c d e f	No crops nor processing Crops there, processing not Crops there, processing imported raw Local raw, cottage industry Local raw, start industrial processing Local raw, global corporate processing	PESTEL element hardly matters
White color = not applicable because of absence			

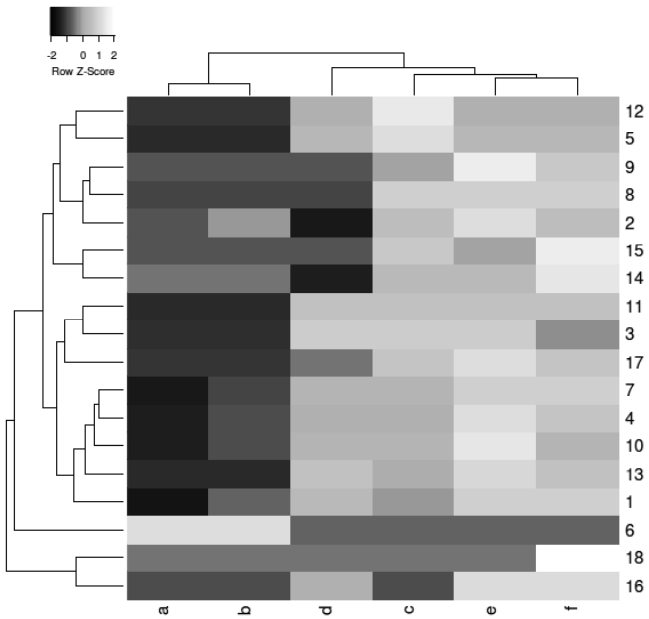
Classes of PESTEL x actor		c	a	b	c	D	e	f	Av.
Policy	Grower	1							3.8
	Processor	2							3.2
	User	3							2.2
Econo	Grower	4							3.2
	Processor	5							3.5
	User	6							3.3
Societ	Grower	7							3.0
	Processor	8							3.0
	User	9							3.0
Tech	Grower	10							3.0
	Processor	11							3.0
	User	12							2.8
Enviro	Grower	13							4.0
	Processor	14							2.5
	User	15							2.0
Legal	Grower	16							1.7
	Processor	17							3.0
	User	18							1.2
	Average		1.9	1.8	3.2	2.4	3.7	3.4	2.7

where processors use imported tubers only, but then raw material is less of a complication as procurement is through a trader. Legal issues score lowest for all classes of actors with an average of 1.2 for users of products and 1.7 for growers of tubers. The producers in developing markets are most affected by legal (administrative) procedures. The country's policies, economy and society produce the highest average score indicative of the great interest the actors attach to these PESTEL elements.

Clustering within the PESTEL-environment domain

The clustering of the classes of actor × element (Table 6.4C) shows a clear cluster of growers for all PESTEL elements except the legal aspects, there they form a separate cluster, a twin, with users. The economic and social matters show the largest agreement for growers. With policy matters at quite some distance. The economy is relevant for users in all market situations, an agreement not found so strongly that this class is a group in its own. Processors and consumers are not caught in separate clusters. Twins showing similarity of relevance attached to the same PESTEL elements are policy for users and technology for processors (having low scores in common), the two twins environment and society both for processors and users, and economy for processors and technology for users both are of highest relevance in markets where processing takes place with imported raw material.

Table 6.4C Dendrogram of the classes of actors (for growers, processors exporting and/or producing and consumers), (1-18, Table 6.4B) with attributes the most important PESTEL element in various markets (a-f, Table 6.4B)



The attributes, interest of markets in show two groups, the twins represent the two markets where no processing of tubers takes place. Of the other four markets the two with globally operating companies in upcoming and mature markets share most interests followed by the same group of companies processing in countries with imported tubers with cottage industry with locally produced tubers at quite some distance.

Deliberations and conclusions

This chapter focuses on the societal aspects of processing potato: 1) benefits for society, 2) sustainability issues from various perspectives through Theoretical triangulation and 3) the surroundings (the PESTEL elements) of the three key participants in different production and sales environments. The research questions asked are addresses in the three paragraphs below.

Research question about benefits of processing potato

Processing potato is a well-established trade in the major potato producing countries so the advantages must be apparent. The inventory and analysis of the rewards of the industry (Tables 6.2ABC) shows benefits for the three participants in the supply chain. The joint driving forces of growers, processors realize the benefits they all look for. Mapping 21 products with 15 attributes showed that the highest sum of scores was about twice that of the lowest, indicative of a general strong variation in perceived benefits by parties for different products. Users of potato products, notably cooks and consumers especially appreciate convenience they are used to when preparing other meal components such as those from cereals. Shops, depending on social setting, offer a wide array of products some of them are too difficult to make at home for many cooks especially the breaded fried mash based ones or takes so much time that it only rarely is done such as the preparation of chips. The introduction of new products such as pellet based expended snacks or vegetable mixes in baby food have benefits for consumers, a widened choice, and for processors, a widened market. Beside product innovation processors find benefits in adding value by increasing recovery through optimization of operations, use of side-flows and improving the raw material base by guiding growers. Especially for growers, but the other two parties, processors and users, benefit from the scale of production of tubers that is enhanced or maintained by the industry and by the somewhat regulating effect processing tubers into frozen French fries, chips and flakes has on supply of raw and the reduction of fluctuation of supply and prices of raw. This because tubers can only be stored less than a year but products for years and tubers not meeting specifications for one products (e.g. chips) are then processed into a lower value product such as flakes.

Research question about sustainability

Sustainability is a major social issue, how to optimally use and re-use resources and reduce emissions relate to the environment. Processing companies also reckon food quality aspects and benefits for society as part of the sustainability domain which is justified from their business perspective: safe for the environment, consumer and community. In the Four-Tier Analysis the classes of sustainability

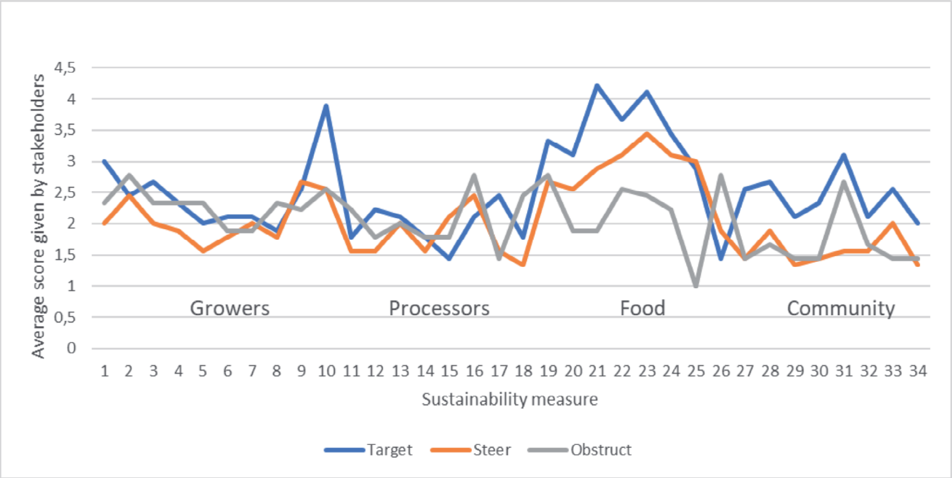


Figure 6.1. Average value of the scores of sustainability measures pertaining to growers, processors, food health and safety and community services in the three scenarios given by the nine stakeholders (breeders, growers, processors.......cooks, policymakers) when they are targeted, steering or obstructing the measures.

issues are expressed as measures to be taken by growers on their farms (9 measures) and processors in operations (7) , on food quality (8) and for communities (8). Retail, food service, food industry and users/consumers are not dealt with by the industry, nor treated here as they are of too a generic nature to merit scrutiny here. The attributes in the Tables 6.2B1, 2, 3 are successively 1) the degree nine stakeholders are targeted and need to carry out the measures or monitor them, 2) how much are able to steer the measures in a way they become more effective and 3) how much they are able to ignore them if they feel opportunistic. Of the attributes consumers are least targeted and processors in their operations most, more than twice; of the classes profits score least and food safety highest also more than twice. Important measures are tracing for growers, distances for processors, food safety and mitigating effects of calamities in the community such as a pandemic. The sum of all scores in this scenario is 777. The dendrogram discloses a class of measures about food safety, one about innovation and a few twins like profits and recovery. The sum of scores in the heatmap where stakeholders steer is 630, so in general participants are more subjected than in control. Breeders receive lower scores than when subjected but regulators, evidently more. Being able to obstruct also has a total sum of 630. Processors score more than three times that of breeders. Most difficult to obstruct is gluten-free batter as it would be disclosed easily and most simply innovation of new products by producers shops and consumer refusing to produce, distribute or use them. Figure 1. makes it clear that growers and processors are not very distinct in the three scenarios except for growers being targeted for information streaming. Food quality is most targeted, best given direction and least sensible to obstruction.

Research question about social surroundings

The same nine stakeholders involved in sustainability issues and measures, show interest in and are subjected to national policies, the economy, the social setting, technological developments, the environment and legal matters embodied in the PESTEL approach Table 6.3B. But they can also exert an influence. Growers are most influenced because of societal demands regarding biodiversity, use of land, water chemicals and subsidies but also have quite some influence through numbers (not routinely) and political actions and by illustrating which rules work and which ones do not. A clear demonstration of interaction. Breeders on the other hand are influenced by 4 out of 6 PESTEL elements but have no say so there. Processors and restaurants are much influenced by surroundings but have less power than growers and consumers, two numerous groups. Focusing on each PESTEL matters was done by switching PESTEL matters and stakeholders of the relevant tables and dividing the resulting classes of PESTEL element in 3 –4 subclasses totaling 63 subclasses. The stakeholders were made their attributes by giving them scores for the relative relevance of the PESTEL elements for them. The average of scores for the processors was twice as high as for the monitors. The order of the stakeholders in Table 6.3B2 looks most like stakeholders affected by PESTEL elements and less like the order of mastering the elements. In both situations processors and growers take the lead and breeders and monitors are at the tail end. Clusters of PESTEL matter receiving the same degree of attention are 1) those around technology, precision and automation, 2) price, availability and quality of raw and 3) food safety, health and diets.

Research question about the degree of market development

Involvement of the degree of market development while analyzing is a typical example of environmental triangulation. Three parties (growers, processors and users) in six environments (stages of market development) produces eighteen classes with the six PESTEL matters of relevance for them as attributes. The sums of the scores for attributes are 18 for countries where no potato is grown nor processed and moves up to 65 with increasing processing taking place with local tubers by nationally and internationally operating companies to decrease to 60 when produced in mature markets. In these markets, compared to the developing ones, policy is of less relevance for processors since policies are stable, growers are less delivered to the whims of economy, users still have to get more used to new products and growers are still in greater need of mechanization . All six economies have users of potato products where they find legal, policy and environmental matters less pertinent than growers and processors but the economy is of importance for them. The highest score (three times more than users-legal) is for economy and processors. They only export to, enter economies or start operations when the economic situation looks promising.

Chapter 7.

General discussion

Illustrated synopsis

Potato products are derived from plants that form dry matter produced in photosynthesis from water and carbon dioxide with solar radiation as energy source. Nutrients, among them nitrogen, potassium and phosphorous, are taken up to make the building of tissue for organs, tubers one of them, possible. The quantity of tubers formed depends on the amount of resources and the

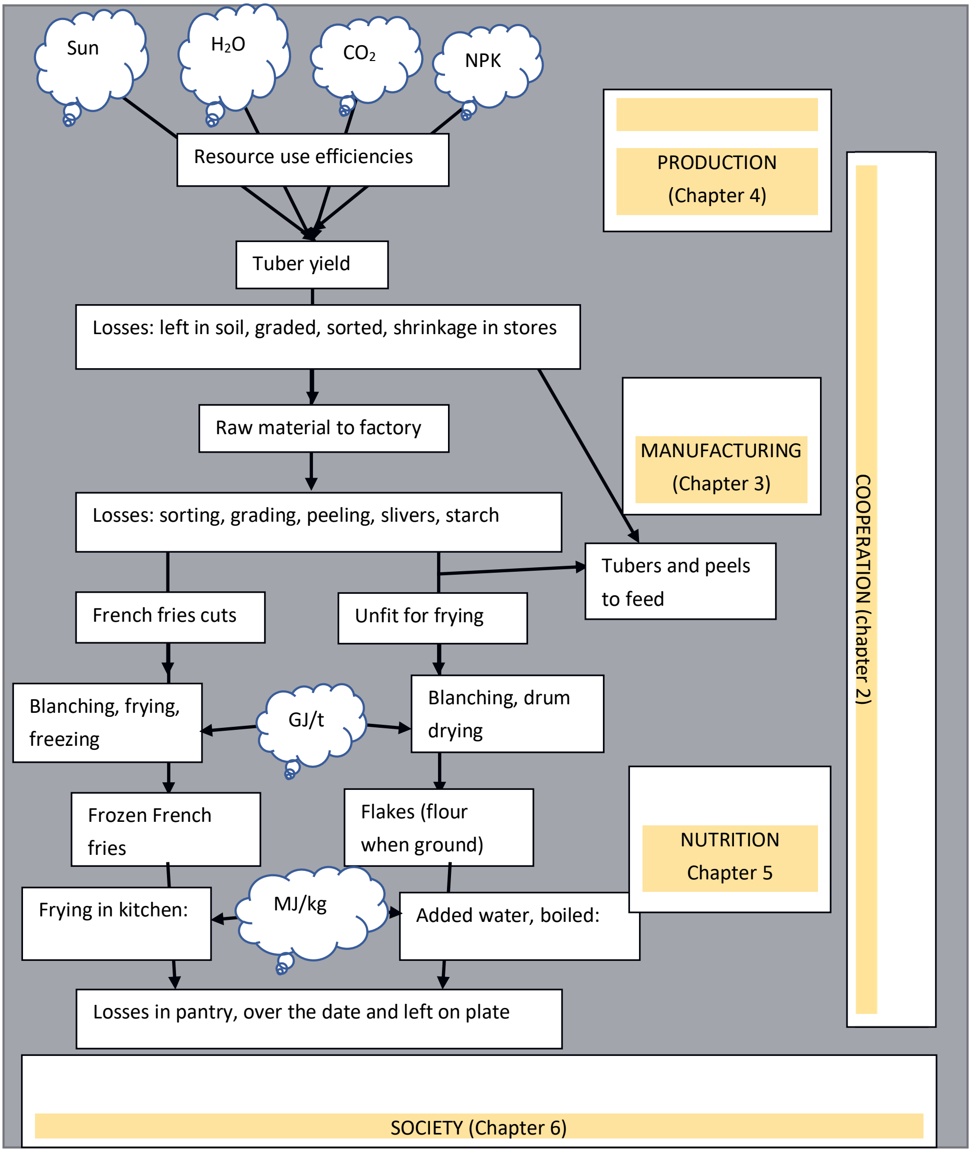


Figure 7.1. Schematic representation of capturing resource, production, losses and interwoven chapters

Table 7.1. Super-domains with their domains with their classes and their subclasses (three examples only) with their attributes (2 examples per subclass only)

Nr	Super-domain	Domains	Examples of three classes	Examples of attributes
1	Cooperation	Tubers (grown by growers)	Starch tubers	Starch concentration Storage duration
			Flour tubers	Specifications need Few storage requirements
			Chips tubers	Dry matter concentration Size
		Products (made by processors)	Starch	Native Degree of modification
			Flour	Color Granular size
			Chips	Tuber origin Pellet origin
		Kitchen operations (by cooks)	Moist dishes	Thickened (soup) Baked (gratin)
			Fried dishes	French fried Sauteed
			Formed dishes	Mashed Shredded
		Preferences (of consumers)	Traditional	Preferring: chips French fries
			Price conscious	Canned Baked
			Health seekers	Vegetable mix Gratin
2	Manufacturing	Products (in shops and for food industry)	Dehydrated	Freeze dried Drum dried
			Conversed	Formed Extruded
			Baked	Baked skin-on (jacket) Toasted (chunks)
		Processes (of tubers)	Dehydration	Starch extraction Ambient air drying
			Blanching	Par boiling Canning
			Frying	Chips making Expanding pellets
		Operations (by processors)	Grading	Optical Mechanical
			Heating	Frying Boiling
			Cooling	Chilling Freezing
3	Productivity	Supply chain (of actors)	Cooks	Meeting expectations Need for convenience
			Processors	Price of raw Future products needed
			Growers	Meeting specs Storability
		Performance (of fields and factories)	Tuber yield	Productivity per unit area Quality (meeting specs)
			Product yield	Efficiency at handling Efficiency at processing
			Nutrient yield	Losses of nutrients

Nr	Super-domain	Domains	Examples of three classes	Examples of attributes
				Nutrient concentration
		Efficiency (resource use and losses)	Recovery Energy Water	Losses of dry matter Losses of water Decarbonization Re-use heat Use efficiency (farm) Recirculate (factory)
4	Nutrition	Dishes (on tables)	Boiled Fried Formed	Mashed Stewed Chipped Pan fired From mash From shreds
		Senses (of consumers)	Sight Taste Feel	Size Shape Salty Umami Finger Mouth
		Nutrients (in tubers, products and dishes	Energy Building tissue Health	Starch Fat Protein Fiber Vitamins Minerals
		Perspectives (of industry following consumer wishes)	Biofortification Home delivery Small footprint	Attainability Opportunity Newness Competition Market share Global vs local
5	Society	Benefits (of making and using products)	Kitchen Farm Economy	Convenience Water, energy efficiency Prolongation of storage Reduction price fluctuation Adding value to tubers Employment
		Stewardship (sustainable production)	Resource conservation Food quality Public	Reduction of emissions Improved water use Health of offerings Nutritional information Develop markets Adapt to climate change
		Surroundings (PESTEL matters for actors and in different environments)	Policy Economy Technology	Trade barriers Subsidies Buying power consumers Price of raw material Mechanization Innovation

efficiencies of their use. Before tubers arrive at the factory they incur losses in the soil, through grading and sorting and shrinkage in the store. Also productivity in the factory, expressed as recovery, is at the cost of resources, water and energy (GJ/t) and suffers losses as is shown in Figure 1, similar to processes in kitchens (MJ/kg). The chapters connect well to these subjects but do not follow the line from capture of solar radiation to serving a dish but start with a description of the super-domain and the three principle participants followed by a central theme of the thesis: manufacturing. Efficiencies on farms and in factories and losses are found under the heading production, followed by the nutritive value of potato products. Production and consumption take place in society, which also imposes the policy, economy, social, technology, environment and legislation related boundary conditions, as treated in the last chapter.

Table 7.1 zooms in on this material and details by showing an overview of the five super domains (chapters), each with three distinctly formulated domains. Each domain has multiple classes of which Table 7.1 provides three examples and all classes within a domain share attributes that to a lesser or greater degree apply to a class, thus enabling the establishment of heatmaps, value allocation and hierarchical clustering. Some domains were easy to delimit and complete exhaustively with classes and their attributes the 'Tubers Domain' for instance. Others, 'Consumer Preferences' as an example, meet more difficulty and a choice had to be made to limit the effort and space dedicated to such domain. The focus is 'on processing' potato with tubers from growers, products from factories and users making dishes. Where appropriate, through theoretical triangulation a comparison of geographically situated developed (northern focus) and developing (southern focus) is made. In-depth comparison of geographic situation including examples of countries is carried out in Chapter 6.

Concerns and challenges of the industry

At the onset of composing the thesis, five captains of globally operating potato processing companies were interviewed about pressing matters in their industry. Not in order of urgency, they mentioned saturating markets, pandemics, overcoming bureaucracy when establishing plants in new markets, blue market strategies such as making and selling potato-based fufu in Africa and a new snack with accompanying sauce for pubs. Red ocean strategies mentioned are promoting hash browns for breakfast and another 'iconic' shape of chips or French fries, short-term re-use of heat from steam peeling, frying and freezing for drying and long-term and complete decarbonization by using electricity from renewable sources only. For the raw material, basic concerns are climate change, lack of suitable land and irrigation water and more and more crop protection agents being banned. Also, some worry that shipping frozen products over the globe is less justifiable than producing locally. Expectations are that the demand for products will still increase strongly in unsaturated markets underpinned by population and income growth, breeding and genetics will overcome pests and diseases, and automation, robotization and precision farming will strongly gain importance. Capturing these early will provide a competitive advantage.

Most of these subjects were touched upon in the five chapters but no concrete answer is supplied about these specific concerns that call for a company-location-timing specific approach. Yet the Four-Tier Analysis, as introduced in this thesis, proofed its usefulness. The concerns-challenges domain is formulated as a need to act to prepare the company for future environmental changes and autonomous growth. A strategy to sell the company is not to be addressed (delimitation). Condensation of the domain is outlined above, the classes being the concerns and challenges, and it is up to the company to expand or condense. Examples of their attributes, among others, are short or long-term, expensive or inexpensive, complex or simple. The resulting Table 7.2A demonstrates 10 examples of concerns/challenges and 10 examples of their attributes and Table 7.2B their quantification in a heatmap and 7.3C the hierarchical clustering.

The heatmap clarifies that most values of attributes across the classes cross out (all value 3) as a rounded figure except the term to accomplish (value 4): in general, solving and achieving takes much time. Across concerns and challenges, the attributes new factories in developing markets and genetic techniques have high average scores because intricate, with much national policy involvement and both needing genetics. Raw material procurement, bureaucracy and market saturation have low scores not needing external assistance, technology or breeding.

Table 7.2A Condensation of the concerns and challenges domain

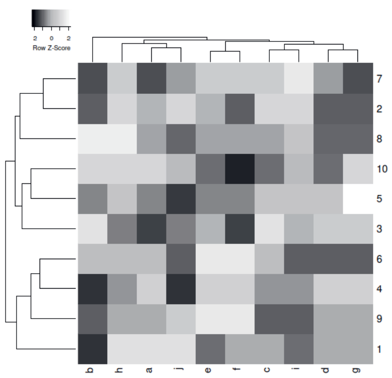
Code	Limited list of 10 classes of concerns and challenges	Code	Limited list of 10 attributes with values from high (5) to low (1)
1	Adapting to climate change	a	Breeder involvement needed
2	Assuring raw material base	b	Consumer involvement needed
3	Blue market strategies (cases)	c	Expected rate of return
4	Capitalizing on genetic breakthroughs	d	External assistance needed
5	Decarbonization (short and long-term)	e	Intricacy
6	Establishing factories in developing markets	f	National policy-related
7	Overcoming bureaucracy	g	Technology issue
8	Overcoming saturating (home) markets	h	Term needed to accomplish
9	Preparing for calamities	i	Urgency
10	Red ocean strategies (cases)	j	Use of ecological principles

The dendrogram in Table 7.2C makes three clusters of classes visible showing some consistency. Assuring and overcoming are the three members of the top cluster, red and blue ocean strategies and decarbonization are in the middle and the bottom cluster with four members consists of challenges and entrepreneurial risks. The attributes demonstrate a dimmer order but clearly display three obvious twins: technology is associated with seeking assistance outside the company, urgency with the rate of return and a third with the same mutual distance: dealing with national and intricacy (complexity).

Table 7.2B. Ten classes of concerns and challenges and ten attributes (codes in Table 7.2A)

	a	b	c	d	e	f	g	h	i	j	x̄
1											3
2											2
3											3
4											4
5											3
6											4
7											2
8											2
9											3
10											3
x̄	3	3	3	3	3	3	3	4	3	3	3

Table 7.2C. Dendrogram (Codes in Table 7.2A)



Meeting the aims

In the introduction of the thesis, the objectives of the series of five reviews were articulated. They concerned the fitness of the Four-Tier Analysis for answering the research questions and more specifically addressed the five themes: participation, manufacturing, production, nutrition and society.

Table 7.3A Condensation of the research questions domain

Code	Instances of the class of responses to the research questions	Code	List of attributes with values from high (5) to low (1)
1	Ontology and concepts are defined	a	Openness of question
2	Domains are distinguished and formulated	b	Detail of question
3	Domains are condensed to classes and attributes	c	Effort gone into answering
4	Attributes are quantified	d	Detail of answer
5	Classes and attributes are clustered	e	Adequacy of answer
6	Methodological triangulation worked out	f	Novelty of finding
7	Environmental triangulation worked out	g	Relative input from science
8	Theoretical triangulation worked out	h	Relative input from observations (experience)
9	Kitchen operations are suitable starting point	i	Further research recommended
10	Each product requires specific tubers	j	Proposals for practice possible
11	The history of products is tracked down	k	Interesting for society
12	Advantages of use of products are evident	l	Growers find this of interest
13	The variety of products in supermarkets is known	m	Processors find this of interest
14	Products are classified by process undergone	n	Cooks find this of interest
15	Factory operations per process are known		List of answers (continued
16	Supply chain exchanges are known	21	Sensory perception of products recognized
17	Factors determining tuber yield are known	22	Nutrient composition of products assessed
18	Recovery and losses in factories are known	23	Benefits of processing evaluated
19	Resource use (farm, plant, kitchen) is known	24	Sustainability on farm, factory an plate judged
20	Potato dishes are listed and classified	25	PESTEL matters evaluated
		26	Perspectives are weighed

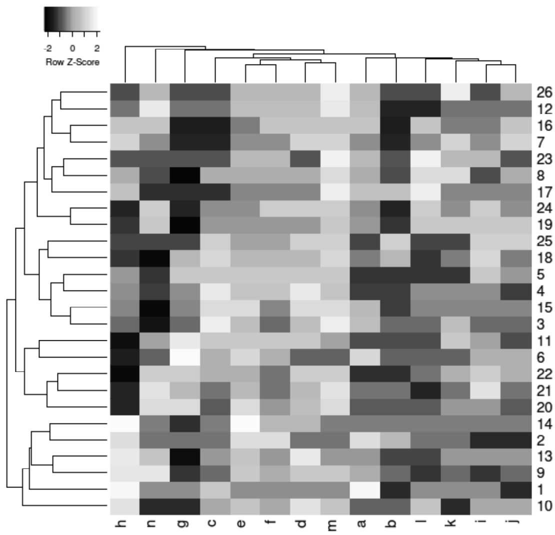
Table 7.3B. Heatmap of 26 responses to the research questions and their 14 attributes. Codes in Table 7.3A

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	Average
1															3.2
2															2.5
3															3.5
4															3.2
5															3.1
6															2.7
7															3.1
8															3.9
9															2.8
10															2.9
11															3.1
12															3.4
13															3.1
14															2.5
15															3.4
16															3.4
17															3.3
18															3.5
19															4.1
20															3.1
21															3.5
22															3.7
23															3.6
24															4.2
25															4.0
26															3.7
Average	3.2	2.6	3.4	4.0	4.0	3.5	2.9	3.2	3.4	3.0	3.1	3.0	4.2	3.1	3.3

Twenty-six research questions are distinguished, so here it is possible to judge if they were answered satisfactorily in the chapters. The research questions are not recapitulated as such in Table 7.3A but their answers are. They have been provided with 14 attributes, the first two concern the articulation of the question itself, whether the question is open (for example, provide an ontology) or closed (list the variety of products in a supermarket) and whether the question is straightforward or dressed up with arguments. There is considerable variation in effort in researching, finding and constructing evidence among subjects and input from science (published sources) or observations (experience) are communicating vessels. A detailed answer is not identical to an adequate or satisfactory one as the latter possibly becomes more passable if more effort is put into it. The chapters have not provided in detail suggestions for further research nor for exploring avenues for application in practice by growers, processors and cooks but in Table 7.3A their potential is indicated. The value of the attributes is supplied by the author. It is very much plausible that a reader with a different angle of view has other opinions resulting in quite different heatmaps, clustering and considerations. After all, this clearly is the most biased heatmap of this thesis.

The scientific novelties in the thesis are about the choice and comprehensiveness of the subject, The Four-Tier Analysis (domain-classes-awarded attributes-clustering) research approach with results discussed internally. Table 7.3A shows which research questions and answers are of interest respectively for society, growers, processors and cooks. These stakeholders will read the relevant parts (domains) of the thesis with more interest than other parts. There they find information for instance, about factors that determine choices of consumers, avoidance of losses in fields, factories and kitchens, opportunities for electrification, energy and water use in fields, factories and kitchen, societal issues when establishing a factory in a developing market, et cetera. There they may draw their own conclusion. So intentionally no recommendations are supplied.

Table 7.3C. Dendrogram showing the hierarchical clustering of responses (1-26, Table 3B) and their attributes (a-n, Table 7.3B)



The average value of all attributes is the lowest (2.5) for the formulation of the domains with only high scores for introducing the question and drawing on experience. Other low scores (<3) are for specs of raw and processes per product, both relatively straightforward enumerations. The highest score (4.2) is for extensively addressed sustainability, followed by related resource use and comparable to the evaluation of PESTEL matters. Theoretical triangulation is carried out in chapter 6 by comparing the values given to attributes by processors, governing bodies and recalcitrant actors.

The lowest average score (2.6) of an attribute over all responses is for detailing the question that was only done extensively for the evaluation of PESTEL matters and yields in fields and factories. Input from science scored just below average (2.9) and from observations just above average (3.2). Detail and adequacy of the answers both have high average values of 4.0, only surpassed by the interest of processors (4.2), who are only marginally interested in the formulation of the domains and classification of products.

The responses (Table 7.3C) are grouped in 4 main clusters but coherence within them is not discernible. Apparently, the combination of responses and attributes varies too widely to be able to detect any consistency in the set. The attributes show a few meaningful twins such as suggestions for research and practice, novelties are associated with the adequacy of the answer and the more detail there is in the answer, the more processors find it of interest.

The Four-Tier Analysis

The Four-Tier Analysis described in the Introduction consists of a brief formulation of a domain which is a more or less anecdotal description and delimitation. A summary of the domain by introducing classes and their attributes is found in the condensation Table A. Both classes (plotted in

Table 7.4. Key elements of domains, non-exhaustive , serve as illustration

	Domains		
Four-Tier Analysis	**Tubers of growers**	**Products of processors**	**Dishes of cooks**
Formulation and delimitation of the domain	Made by growers following specifications. Feed excluded.	Derived from recipes over the ages. Must contain potato	Made by cooks, contain products, eaten by consumers only
Condensation into classes (not instances)	Classes of raw material underwent handling and storage regimes	Timeline of appearance of classes of products and why	Classes of products are prepared to become classes of dishes
Quantification of attributes (heatmap)	Farm, factory value, delivery (time, distance), specificity	Impacting markets economies and resource use, complexities	Price, availability, complexity, esteem, fanciness, appliances
Clustering (dendrogram)	Tubers fried are in other groups than tubers making starch and flour	Fried products and powdery products are distinct	Fried dishes differ from boiled dishes
Theoretical and environmental triangulation	Attributes very much class own, so no other triangulation options exist	Theoretical triangulation with inverted values for attributes: classes hierarchy unchanged but altered for attributes	Environmental triangulation reiteration from a developing market perspective; cluster and attributes hierarchy change

rows) and attributes (plotted in columns) are refined and the attributes are given weight, heatmapping, as to the degree they apply, in the quantification Table B. Transforming the data into a dendrogram results in the clustering of both classes and attributes, Table C. For the kitchen domain and the subdomains tubers, products and dishes, the approach is summarized and illustrated with a few keywords for the right understanding in Table 7.4.

Not describing a domain but just hinting at how it came into existence, and making it assumable that there are divisions and distinctions (classes) possible that can be assigned properties and characteristics (attributes) makes a complete description redundant. The subsequent tabling of the classes and their description in some logical order (from peeling to baking, appearance in time) narrows down the elements of the domain and the resulting class-attribute table represents the core of the analysis. The heatmap per se is still qualitative although it offers a quick glance, but when given values it allows a quantitative evaluation of classes and attributes with mutual impact. Clustering offers the possibility for future focus, to approach identical and close twins in a single fashion.

Theoretical or environmental triangulation is only possible with classes in which the value of attributes varies with the environment or with the social position. As a rule, attributes were given a high score irrespective of concerns. Then very convenient and requiring very much water both receive a value 5. If however, water use is a concern, it should receive a low score of 1. With this different question in mind, theoretical triangulation, heat mapping and clustering were carried out in a reiteration (Chapter 2, Table 2.3B). It revealed that the hierarchical clustering of the classes, if the values of the attributes were mirrored from the average, did not change. That of the attributes did and showed a more distinct grouping, less uniformity assists in distinguishing attributes one wants to be altered, into a desired direction. The sums of scores also become more meaningful because a high sum is indicative of favorable attributes for a class or over all classes. Starch has the highest unconcerned score but when concerns are taken into consideration, it is for chips. Other theoretical triangulations in the thesis are looking at products with attributes that receive different appreciations (scores) from processors than from consumers such as such as ranges of different products, prices and sizes. Similarly, actors undergoing PESTEL matters weigh them differently from those influencing them. The most extensive triangulation was with 34 classes of sustainability measures with the degree of involvement of 9 stakeholders as attributes seen through the eyes of processors, advocating their performance, policymakers steering sustainable development and thirdly obstructors trying to hinder a quick win and not interested in the long term. Giving values to attributes of cooking dishes in Nairobi or New York (an environmental triangulation, Chapter 2, Table 2.4B) changes both the hierarchy of classes and clusters; this exercise is only carried out once. Data triangulation, obtaining the same set from different places, times and persons, has not been carried out. Any interested researcher, however, in any domain at any time and any place can alter the composition of classes and attributes and values of the latter resulting in data triangulation.

The total number of heatmaps in the thesis is 29 and the number of times a class is inserted into them is 585 (sum of all classes) and for attributes the figure is 324 (sum of all attributes). The relationship between the number of classes and of attributes and the number of clusters with two members (twins) observed in hierarchical clustering is shown in Figure 7.2. On average 31 % of the classes belong to a twin versus 39 % of the attributes as the slopes of the lines are 0.31 and 0.39 respectively. Dr E.J.Bakker of Biometris at Wageningen University and Research ran 1000 simulations with 50 classes and 30 attributes credited randomly with scores ranging from 1 to 5 according to uniform and normal distributions. The number of twins ranged from 37 % for a normal distribution with 5 attributes to 39 % for a uniform distribution. Based on this, it is assumed that the attributes in this thesis are close to a random selection. Many unrelated clusters produce many twins. The classes on average have fewer so larger clusters, since every cluster has only one twin, classes also have fewer twins. This phenomenon is explained by assuming that classes of products, processes, dishes and actors for example in general have clusters distinguished by an attribute: fried or not, cold or hot, producers or users. Attributes apparently lack common denominators so their clustering is closer to that of a random population. In other words, larger clusters are indicative of a bias towards more relations within a population. The twins and clusters based on the heatmaps of this thesis are not meaningless as the numerical approach does predict the relatively large numbers of clusters and twins but the composition is determined by the scores awarded and similar scores yield similar clustering for each run.

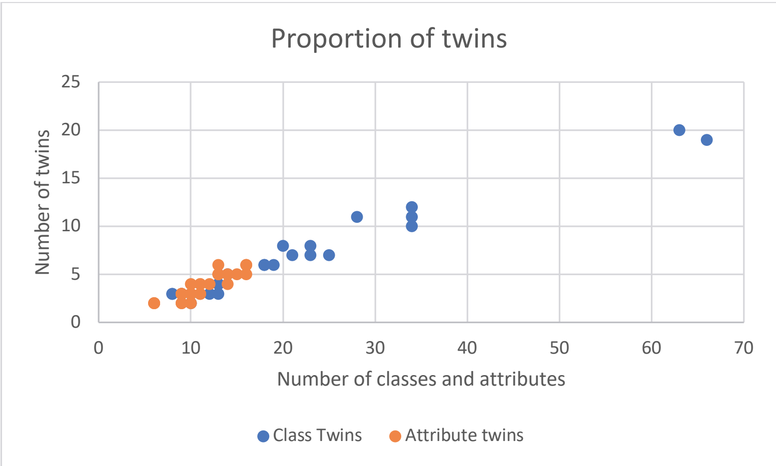


Figure 7.2. Relationship between the number of classes and attributes and the number of clusters with two members (twins) observed in hierarchical clustering Classes: y=0.31+0.1882; R^2 = 0.9674, Attributes: y=0.39-0.6276; R^2= 0.7889

In conclusion, this thesis is an interdisciplinary study of an aspect of society describing the public relationships of farmers, manufacturers and consumers through flows of substances and information for mutual satisfaction. This is the first time that the Four-Tier Analysis has been applied in such a study. In descending numbers of sources and increased involvement of the author, triangular collection of data was from scientific articles, websites, potato projects' procedures and results, professional journals and own lifetime observations. The research is partly descriptive (who makes tubers, how are French fries made, what is the cottage industry?), partly explanative (why are products chosen?) and partially action-oriented: obtaining practical results through systematic analysis. There are several illustrations in the thesis where the uniqueness of the potato chain, compared to that of wheat for instance, is highlighted. The "Condensation" section of each domain contains many references that underpin the classes and their attributes. This way the 17 domains are embedded in the existing literature. The distinctiveness of the overall subject "On Processing Potato" is such that it transcends existing literature and as such is an exceptional addition to existing literature. This uniqueness of the study (subject and approach) makes it not readily comparable to other research on a food supply chain. The comprehensiveness of the study with a super-domain containing seventeen domains with great numbers of classes and attributes with over six thousand times a score awarded to date has not been produced for any other crop. The current exclusive study essentially benefited from a lifelong career, international experience and expertise in the potato realm. The Four-Tier Analysis is easily applicable to other crops or other commodities because of its representativeness, reliability and validity but also has its draw-backs.

The representativeness of the research is maximal in the thesis as virtually all classes, for instance, of all tuber types as raw material, of all products and of all major classes of dishes were included and not just samples. In this thesis the gathering of data per domain is done at the level of classes and their attributes. Classes, however, have instances. A class of dishes available in supermarkets Table 3.2A1 has instances of different brands (Jumbo, Aviko), and instances of tastes (Burgundian, Greek) and there are more instances because there is more than one supermarket and each has the same or similar instances. Some of the attributes of the classes (Table 3.2B) apply to all instances, others (price range) vary among shops. So to base the findings on instances rather than classes (in case data gathering were based on instances rather than classes) sampling is necessary. As illustration, a result of such sampling would be: one thousand times a score between 1 and 5 for preference would be given to: ten types of frozen French fries in ten different countries by ten types of consumers. Another example: of how the Four-Tier Analysis, applies at the level of instances and their attributes: "convenience experienced by a policeman (instance of the class of salaried workers) with crinkle-cut French fries (instance of the class of fried products) in Kenya (instance of the class of developing markets)". Such studies are of importance to learn more about consumer preferences and situation specificity but only marginally contribute to the current scope of the study that focuses 'on processing potato'. Moreover the Four-Tier Analysis here would not be a proper instrument for such research questions.

The Four-Tier Analysis developed specifically for this this is reliable as it can be repeated easily. There are no other actors, growers of potato, for instance, who would produce other classes of tubers than the ones mentioned, nor processors making something (completely) else. The focus here, however is on large scale production with involvement of all possible stakeholders. There are other situations, the cottage industry where chips are made in a kitchen in the hills of Myanmar, and a chips factory starting in Rwanda from locally grown potatoes with foreign aid, or a factory in Ethiopia started by an investor where a complete different domains exists. The helicopter view of the Four-Tier Analysis yielding information for interested parties condensed in Table 7.3A would hardly apply there. The research questions there are about reliability of supply of raw due to weather and growers opting for other outlets, about changing food habits of consumers not exposed to potato products to date. Research there would not give priority to the Four-Tier Analysis but rather on case specific fact finding. Also, as the example of theoretical triangulation on sustainability measures has shown, a strong bias is possible where opinions matters. The Four-Tier Analysis then is not a reliable instrument.

The results of the Four-Tier Analysis are valid and values, albeit initially (Tables A) of a qualitative nature, once quantified (Tables B) are always in a range. For temperatures it is obvious: freezing takes place at one end of the scale, baking at the other, and each operation in between has its own unambiguous temperature. Cooking skills to produce a gratin are at one end of the scale and peeling at the other. Shredding and mashing have the same skill level but are easier than boiling as the cook needs to decide when to stop it. Even if in a heatmap another researcher would here and there swap neighboring values, this would not affect conclusions as to the importance of an attribute to a range of classes. The approach would, however, improve if scores are not only awarded by a single person but by a team, preferably consisting of a representative of all stakeholders. Also to make it more location specific by geographic focusing on Russia for instance, or Brazil. Then more solid location relevant information would emerge.

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Summary

Potato is special

The overall aim of this thesis is to capture the domain of processing potatoes in society in a coherent manner allowing qualitative and quantitative evaluation of the findings. It contains a scientific study of an aspect of human society where the public relationships are described of farmers, manufacturers and consumers. These partners in the supply chain exchange flows of potato substances and of information for mutual satisfaction. Potato on fresh weight basis is the third staple food crop after wheat and rice. Corn is grown to a wider extent but the bulk of this crop is used for feed and biofuel. Contrary to wheat as staple that is purchased by consumers as bread or paste and (almost) ready to eat, potato is often purchased as fresh tubers washed, peeled, cut and heated through boiling, baking or frying. Cereals can be consumed raw, but raw potato tubers are indigestible for humans and need to be heated to gelatinize its starch thus making it bio-available. A considerable proportion of tubers, however, more than half in Europe and North America, is processed into food products mainly. To process cereals water must be added, most potato products entail removal of water. Wheat flour is a bulk product, a mixture of variety and origin delivered by different growers a central collection point. It is milled centrally from where it goes to processors (bakeries) which make specific products. For potato, however there is a strong link between the quality of the raw material as determined by the variety of the crop its environment, cultivation practices and post-harvest handling and storage. There are strong links between breeders who constantly need to overcome new pests and diseases, adaptation to new environments and new specs of tubers for new products. Growers of tubers need to buy seed tubers from specialized seed growers because clonally multiplied potato, contrary to cereals, degenerate within a few generation because of an accumulation of pests and diseases. Cereals contain about 80 % dry matter, a potato tubers contain some 80% water which allows respiration and makes them vulnerable to losses, unless stored under refrigerated conditions and even then for a limited period as they shrink, loose quality and start to sprout, whereas cereals need no cooling and are storable for a prolonged period. Even many potato products need cooling, freezing or chilling, because of their low dry matter concentration and active respiration.

Five super-domains

The thesis is organized in seven chapters covering fives super-domains. The second chapter addresses the participating actors: growers of tubers used as raw material for products, processors making products and cooks using them to make dishes. Chapter 3 reports the manufacturing of the range of products found in the market, the processes operations to make them. Chapter 4 on productivity addresses production in supply chains, expressed in performance of farms and factories and their efficiencies. Potato products are nutritious as pronounced in Chapter 5 where they are deployed in dishes, excite the senses and provide nutrients. In Chapter 6 the benefits of processing for society is described, stewardship, so care of the resources, consumers and communities and taking into account the matters related to national policies, economy, society, technology, environment and legislation for established and new processing companies in a range of environments that differ in degree of market development.

Findings per super-domain

Cooperation domain

Preparing meals with potato as ingredients dates from the time of the domestication of the crop in the Andes region. It systematically involves washing, peeling, partitioning in smaller sections and heating to gelatinize the otherwise for non-ruminants indigestible starch. Since the Columbian Exchange both the crop and potato processing expanded globally. The history of potato processing starts with the pre-historic pre-Columbian era when drying as a means to preserve and render the tuber less bulky and making flour and alcoholic drinks were common practice. Once the crop was a global food crop, processing established, initially into an array of nourishments for seafaring and military purposes and later for convenience and to satisfy hedonistic needs. The cooperation super-domain consists of three domains: production of the tubers serving as raw material, processing in manufacturing units and utilization of products, preparation of dishes, by cooks in kitchens. These and classes of consumers distinguished by their food preferences are listed. Kitchen operations from washing to baking a gratin serve as a suitable starting point to approach processes and operations in modern manufacturing. Growers producing tubers for varying finished product need to meet different specs from long to round tubers with high and low starch concentrations to name a few. Some cooks are after convenience and buy products that need few preparations whereas adventurous cooks need basic products, if purchased at all.

Manufacturing domain

When similar products but from a different producer and in varying weights are summed a regular supermarket in the Netherlands arrives at close to 200 products that are boiled down to less than ten classes for simplicity sake. A considerable proportion of tubers grown is processed whereby in most cases water is extracted (except for blanched and chilled products) at ambient (starch production) or elevated (boiling, frying) temperatures and in many products the original tuber structure is still present. The range of products for consumers and for the food industry stored at ambient conditions, chilled or frozen is listed and categorized. The basic processes underlying their production for instance dehydration, heating, forming, modifying, granulating, fermenting are explained. Finally, all factory operations, numbering 66, that regulate the processes from arrival at the plant to packing are described. It is also demonstrated for each class of specific processes which processes of the 66 they undergo.

Productivity domain

Breeders, growers, processors, retailers and users in the potato products supply chain, and the information and material they convey, are introduced and especially issues regarding growers and processors are addressed. The influence of genotype, environment and crop management and the efficient use of resources of the production of raw material, tubers harvested for processing purposes, are delineated. Climate change is briefly touched upon: elevated CO_2 and higher temperatures positively affect yields in summer crops, less so in winter crops. Performance of the crop is expressed as tuber yield and quality: high dry matter, low sugars and a high proportion of product specific tuber size tuber are associated with high recovery. Post-harvest operations consist of on-farm handling and storage, and in-factory processing determine efficiencies of the use of energy and water and of recovering finished products from the tubers. The amount of energy as fuel, steam and electricity, of water used and water lost from the tubers during various production steps in making French fries and flour is compared and options for decarbonization reviewed, where especially replacing fuel by electricity from renewable sources offer perspectives. Performance on farms and in factories to a large extent, depends on the successful reduction of losses and wastes. The Four-Tier Analysis of the continuum of the two production systems allows drawing of conclusions on increased productivity of resources and reduction of losses.

Nutrition domain

Worldwide hundreds of potato dishes exists, firstly made up by cooks in kitchens. Gradually cooks applied processed products as ingredients to save time and to widen their range of dishes. The products are classified according to their features ranging from thickener in soups to snacks ready to eat. Beside cooks, also the food industry makes ample use of (modified) potato starches, flakes, flour and granulates. Before users prepare meals from purchased ingredients they only have had visual perceptions of the products as displayed on shelves and freezers of shops. The organoleptic properties, taste smell and structure of tubers and products are perceived in the kitchen and at the table only. Sensory appreciation is a function of the types of additives in dipping and batter during processing and their role to improve products and flavoring. The nutritional value of tubers, of other staple foods and of potato products and dishes is analyzed and their enhancement and losses in production of the raw material and in processing discussed. The density of constituents in general is negatively correlated with the water content of the product. It is observed that beneficial compounds for human health such as resistant starch and fiber are adequately present in products, vitamins, anti-oxidants and minerals of products are partly lost at processing.

Society domain

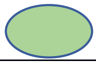
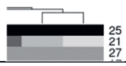
Wheat, the most important food crop can be stored for a much longer time than potato. It is ground and made into flour or pasta that turned into bread or a dish any time. Potato is only storable for a limited period so floods the market at harvest. Major benefits of processing for growers include regulating availability of markets and price through contracts, Moreover, the decrease of consumers buying fresh tubers is compensated by processors buying raw material. Processors add value and employment and consumers are offered a wide array of affordable and convenient products to select from. Large potato processing companies produce annual sustainability reports advocating measures for growers to spare the habitat, more efficient processes in factories, newer and healthier products and assisting communities. These are recorded and viewed in a theoretical triangulation from angles of processors, policymakers and from those trying to bend the rules. Growers are targeted strongly by processors to give information, food quality is mainly targeted by processors, regulators exert some influence by setting norms for maximum levels around nitrate for instance and around food safety. Obstruction of sustainability measures is possible except for food safety as it is easily found out. The industry, especially when expanding to new (developing) markets face political, economic, social, technological, environmental and legal (PESTEL) issues that depend on the presence of a raw material base, competition and buying power and culture of the consumers.

Research approach

Four-Tier Analysis

The analysis (Table 1) especially developed for this research, the overarching domain of "On Processing Potato" consists of four tiers. In the first tier a domain is distinguished, *formulated* and delimited. A domain has things that are organized in classes that have the same attribute (property). In the second tier the classes and attributes are described and *condensed* into one or more tables. In the third tier the attributes are weighed as to the degree they apply to the class resulting in a *heatmap*. In the fourth tier a dendrogram is derived from the heatmap allowing a hierarchical *clustering* of the classes and attributes.

Table 1. Aspects of the Four-Tier Analysis

Tier	Tier	Acts	Example: factory	Result
1	Formulation	Ontological description and delimitation	Factory: all operations between arrival of the tubers and departure products so from washing to packing	Domain 
2	Condensation	Triangulation, listing classes and attributes	Classes: washing, cutting, frying cooling. Attributes: temperature, duration, use of water, energy	List / Class / Attr
3	Quantification	Assigning a 1-5 value (color code) to the attributes	Water use = 5 (for washing), 1 (frying) Duration = 1 (cutting), 4 (cooling) Temperature = 5 (frying), 1 (cooling)	Heatmap 1 3 4 5
4	Clustering	Hierarchical groups of classes and attributes	Clusters (twins) of classes with many attributes in common: peeling and cutting and, temperature and energy	Dendrogram 

Throughout the thesis the Four-Tier Analysis is applied rigorously, Table 2 summarizes the 28 heatmaps produced, the subjects and their attributes and an illustration of both.

Table 2. Number of classes, subjects and one example per heatmap and their number of attributes, what they are aimed at and one example thereof. They total 6136 class × attribute combinations in this thesis.

In italics: after environmental or theoretical triangulation.

Ch	Classes			Attributes		
	Nr	**Subject**	**Example**	**Nr**	**Regarding**	**Example**
2	18	Kitchen operations	Mashing	9	Kitchen matters	Cooking skills
	9	Tubers to make	Chips	11	Affecting class	Size
	23	Products history	Frozen fries	16	Socio-technical	Availability
	23	*Products history*	*Frozen fries*	*16*	*Socio-technical*	*Availability*
	13	Dishes from products	Hash brown	13	Cook related	Convenience
	13	*Dishes from products*	*Hash brown*	*13*	*Cook related*	*Convenience*
	12	Consumer types	Adventurers	16	Preferred product	Hasselback
3	8	Products in shops	Snacks	11	Consumer view	Price
	8	*Products in shops*	*Snacks*	*11*	*Consumer view*	*Price*

Ch	Classes			Attributes		
	20	Process-Product	Drum dried flour	13	Technology	Oil use in factory
	66	Factory operations	Forming	10	Technology	Water use in factory
4	9	Actors	Cook	14	Relevance	Storability
	19	Performances	Tuber size	11	Affecting class	Grading
	10	Operations in chain	Heating	9	Impacting habitat	Eco-toxicity
	28	Losses in chain	Brine separation	9	Loss reduction	Altering specs
5	13	Dishes from products	Gratin	10	Technical	Cooking temperature
	13	Dishes from products	French fries	12	Sensory related	Crunchiness
	14	Products	Flour	11	Nutrient content	Vitamin C
	21	Perspectives	Home delivery	11	Opportunity	For start-ups
6	21	Products	Freeze dried	15	Social benefits	Energy reduction
	34	Sustainability actions	Renewed energy	9	Stakeholder target	Processor
	34	*Sustainability actions*	*Renewed energy*	*9*	*Stakeholder target*	*Processor*
	34	*Sustainability actions*	*Renewed energy*	*9*	*Stakeholder target*	*Processor*
	9	Stakeholders	Regulator	6	PESTEL affected	Legislation
	9	*Stakeholders*	*Regulator*	*6*	*PESTEL affected*	*Legislation*
	63	PESTEL elements	Competition	9	Parties affected	Food industry
	18	Actors-PESTEL	User-Technology	6	Development stage	Global industry
7	10	Concerns-challenges	Climate change	10	Characteristic	Urgency
	20	Questions answered	Recovery factors?	14	Answer relevance	Answer adequacy
∑a	471times a class appears in 23 heatmaps			255 times an attribute appears in these maps		
∑b	583 times a class appears in 29 heatmaps			313 times an attribute appears in these maps		
a: original triangulation, *b: environmental or theoretical triangulation*						

Data collection and perception

Information collected and expressed in this series of five reviews rests on two pillars: practical experience and scientific literature. Further information was gathered through interviews, consulting the internet and reading (professional) journals. At the onset of the analysis, five captains of the global potato industry have been asked about their worries and challenges to assure relevance of the findings for businesses. All information, classes, attributes and values expressed in scores from 1 to 5, needed for the assemblage of the twenty-two heatmaps listed in Table 2 was gathered through this process of Methodological Triangulation. In a some cases it was assumed that value ascription to attributes was done by an entity with a different position (undergoing measures rather than directing for instance) resulting in Theoretical Triangulation.

Table 3. Triangulation in social sciences: types, description and examples

Type	Description	Example
Methodological	Data set assembled from different sources	Throughout the thesis, all domains: experience, scientific literature, professional journals, interviews, the internet
Theoretical	Data set appreciated from various points of view	Sustainability measures valued by processors, policymakers and obstructing parties differ (Chapter 6), subjected or steering

Type	Description	Example
Environmental	Data set that takes setting or location into account	Poor or affluent market affect attributes of products: price, storability, appliances needed (Chapter 2) as illustration
Data	Data set assembled by different persons, different times and at different places	Potentially any interested party, anywhere and anytime can restructure and re-evaluate any domain in this thesis, thus realizing data triangulation

When assuming another site, as illustration a developing market (India) versus a developed one (USA) conditions and opportunities differ. This is a case of environmental triangulation. Theoretical and environmental triangulation lead to heatmaps with different color layout and different hierarchical clustering of classes and attributes.

In all heatmaps a score of 5 was given to a high value, so an operation at the expense of high resource input (much water) receives a score of 5. Viewing from a different angle (theoretical triangulation), considering water use as a loss, a score of 1 is justified. A score of 3 remains 3 in both triangulations, a 4 becomes a 2 and a 2 becomes a 4. So the values are flipped around the mean score of 3. This exercise does change the clustering of the attributes, but interestingly, not that of the classes. When another researcher comes with other boundaries of a domain, with altered sets of classes and attributes and different values (Data Triangulation, Table 3) it will yield new heatmaps, new dendrograms and possibly new conclusions.

Samenvatting

Aardappel is bijzonder

Het overkoepelende doel van dit proefschrift is het domein van de aardappelverwerking in de maatschappij op een samenhangende wijze vast te leggen en om het kwantitatief en kwalitatief op waarde te schatten. Het bevat daartoe een wetenschappelijke studie van een aspect van de menselijke samenleving namelijk de open relaties van boeren, fabrikanten en consumenten. Tot tevredenheid van deze partners stroomt er aardappelmateriaal en informatie door de voedselketen. Aardappel is op basis van vers gewicht het derde basisvoedselgewas op de wereld na tarwe en rijst. Er wordt meer maïs geteeld, maar het grootste deel van dit gewas gaat naar veevoer en biobrandstof. In tegenstelling tot tarwe waarvan consumenten het hoofdbestanddeel kopen als brood of pasta en dat (bijna) klaar is om te eten, worden aardappelen vaak gekocht als verse knollen, gewassen, geschild, gesneden en verhit door koken, bakken of frituren. Granen kunnen rauw worden gegeten, maar rauwe aardappelknollen zijn onverteerbaar voor mensen en moeten worden verhit om het zetmeel te gelatiniseren en beschikbaar te maken. Een aanzienlijk deel van de knollen, echter, meer dan de helft in Europa en Noord-Amerika, wordt voornamelijk verwerkt tot voedingsmiddelen. Om granen te verwerken moet water worden toegevoegd, voor de meeste aardappelproducten moeten verwerkers water verwijderen. Tarwebloem is een bulkproduct, een mengsel van tarwerassen en herkomst, aangeleverd door verschillende telers op een centraal verzamelpunt. Het wordt centraal gemalen van waaruit het naar verwerkers (bakkerijen) gaat die er specifieke producten van maken. Voor aardappel is er echter een sterk verband tussen de kwaliteit van de grondstof zoals bepaald door het ras van het gewas, de omgeving, teelthandelingen en behandeling en opslag na de oogst. Er zijn sterke banden tussen kwekers die voortdurend nieuwe plagen en ziekten moeten overwinnen, en het ras moeten aanpassen aan nieuwe omgevingen en nieuwe specificaties van knollen die horen bij nieuwe producten. Telers van knollen moeten poters kopen van gespecialiseerde pootgoedtelers omdat de klonaal vermeerderde aardappel, in tegenstelling tot granen, binnen enkele generaties degenereert door een opeenstapeling van plagen en ziekten. Granen bevatten meer dan 80 % droge stof, aardappelknollen bevatten ongeveer 80 % water, waardoor ze ademhalen, gevoelig zijn voor verrotting, tenzij ze onder gekoelde omstandigheden worden opgeslagen en zelfs dan voor een beperkte periode omdat ze krimpen, kwaliteit verliezen en beginnen te ontkiemen, terwijl granen geen koeling nodig hebben en gedurende een langere periode kunnen worden opgeslagen. Zelfs veel aardappelproducten hebben koeling of bevriezing nodig, vanwege hun laag drogestofgehalte en hun ademhaling.

Vijf superdomeinen waar vijftien domeinen onder vallen

Het proefschrift is ingedeeld in zeven hoofdstukken waarbij de hoofdstukken 2 tot 6 gaan over vijf superdomeinen. Hoofdstuk 2 richt zich op de deelnemende actoren: telers van knollen die worden gebruikt als grondstof voor producten, verwerkers die producten maken en koks die ze gebruiken om er gerechten van te maken. Hoofdstuk 3 rapporteert de productie van het assortiment producten op de markt, de processen die er achter schuilen om ze te maken en daarachter hun bewerkingen. Hoofdstuk 4 gaat over productie in toeleveringsketens, uitgedrukt in de prestaties van boerderijen en fabrieken en hun doelmatigheid. Aardappelproducten zijn voedzaam zoals besproken in Hoofdstuk 5, waar ze worden ingezet in gerechten, de zintuigen prikkelen en voedingsstoffen leveren. In Hoofdstuk

6 komen de voordelen van verwerking voor de samenleving aan de orde, rentmeesterschap, dus zorg voor hulpbronnen, consumenten en gemeenschappen en daarbij rekening houdend met de zaken als nationaal beleid, economie, samenleving, technologie, omgeving en wetgeving en dat voor gevestigde en te vestigen verwerkende bedrijven in een reeks omgevingen in verschillende mate van marktontwikkeling.

Vindingen per superdomein

Samenwerkingsdomein

Het bereiden van maaltijden met aardappel als ingrediënten dateert uit de tijd van de domesticatie van het gewas in de Andes-regio. Het omvat systematisch het wassen, schillen, aan stukken snijden en verhitten om voor niet-herkauwers onverteerbare zetmeel te gelatiniseren. Sinds de Columbian Exchange breidde zowel het gewas als het maken van producten zich wereldwijd uit. De geschiedenis van aardappelverwerking begint in het prehistorische precolumbiaanse tijdperk met het vriesdrogen om de knol in te dikken en bewaarbaar te maken. Ook aardappelmeel en alcoholische dranken waren toen al gebruikelijk. Toen de aardappel een wereldwijd voedselgewas werd, vestigde de verwerking zich, aanvankelijk in een reeks voedingsmiddelen voor zeevaart en militaire doeleinden en later om het gemak te dienen en om hedonistische behoeften te bevredigen. De ontologie van aardappelproducten bestaat uit drie domeinen: productie van de knollen die als grondstof dienen, verwerking in productie-eenheden en gebruik van producten, bereiding van gerechten, door koks in keukens. Deze en klassen van consumenten die zich onderscheiden door hun voedselvoorkeuren zijn vermeld. Het is duidelijk dat bewerkingen in de keuken van wassen tot het bakken van een ovenschotel tot geschikte uitgangspunten voor de verwerking dienen. Knollen die telers produceren voor verschillende eindproducten moeten voldoen aan verschillende specificaties, van lange tot ronde knollen, met hoge en lage zetmeelconcentraties, om er maar een paar te noemen. Sommige koks zijn op zoek naar gemak en kopen producten die weinig bereidingen nodig hebben, terwijl avontuurlijke koks basisproducten zoeken, als ze al worden gekocht.

Productiedomein

Wanneer vergelijkbare producten van diverse merken en in wisselende gewichten worden opgeteld, komt een reguliere supermarkt in Nederland uit op bijna 200 aardappelproducten, die voor het gemak worden teruggebracht tot minder dan tien klassen. Een aanzienlijk deel van de geteelde knollen wordt verwerkt waarbij in de meeste gevallen water wordt onttrokken (behalve voor geblancheerd koelverse producten) bij omgevingstemperatuur (zetmeelproductie) of bij verhoogde temperaturen (koken, frituren) en in veel producten is de oorspronkelijke knolstructuur nog aanwezig. Het assortiment producten voor consumenten en voor de voedingsindustrie, gekoeld of bevroren, is gerangschikt en gecategoriseerd. De basisprocessen die ten grondslag liggen aan hun productie, zoals droging, verhitting, vorming, modificeren, granuleren en fermenteren worden toegelicht. Ten slotte worden alle fabrieksactiviteiten, 66 in totaal, die de processen tot stand brengen, van aankomst in de fabriek tot verpakking beschreven en worden de productklassen vermeld met welke van de 66 de processen die eraan ten grondslag liggen.

Productiviteitsdomein

Veredelaars, telers, verwerkers, detailhandel en gebruikers in de aardappelproductieketen evenals informatie en het materiaal dat ze doorgeven komen aan bod, met nadruk op zaken die van belang zijn voor telers en verwerkers. De invloed van genotype, milieu, teelt en het efficiënte gebruik van hulpbronnen voor de productie van de grondstof, knollen geoogst voor verwerkingsdoeleinden zijn besproken. Eveneens hoe verhoogde CO_2 en temperatuur de opbrengsten en het gebruik van hulpbronnen in een veranderd klimaat positief kunnen beïnvloeden, vooral in zomergewassen en in beperkte mate in wintergewassen. Prestaties van het gewas worden beschreven in termen van opbrengst en kwaliteit: een hoger drogestofgehalte, minder suikers, meer knollen in de voor het product gewenste maat leiden tot een hogere opbrengst in de fabriek. Naoogst activiteiten op de boerderij bestaan uit behandelingen en opslag en in fabrieken uit processen die efficiënt gebruik van energie en water bepalen en de winning van eindproducten uit knollen. De hoeveelheid energie in de vorm van brandstof, stoom en elektriciteit, van het gebruikte water en het water dat verloren gaat uit de knollen tijdens verschillende productiestappen bij het maken van frites en bloem zijn vergeleken en opties voor decarbonisatie beoordeeld. Vooral het vervangen van fossiele brandstoffen door elektriciteit uit hernieuwbare bronnen biedt perspectief. Prestaties op boerderijen en in fabrieken zijn voor een groot deel afhankelijk van de succesvolle vermindering van verliezen en verspillingen. De vierledige analyse van het continuüm van de twee productiesystemen maakt het mogelijk conclusies te trekken over een verhoogde productiviteit van hulpbronnen en afname van verliezen.

Voedingsdomein

Wereldwijd bestaan er honderden aardappelgerechten, in de eerste plaats verzonnen door koks in keukens. Geleidelijk aan pasten koks verwerkte producten toe als ingrediënten om tijd te besparen en hun assortiment gerechten uit te breiden. De producten zijn geclassificeerd op basis van hun kenmerken, variërend van verdikkingsmiddel in soepen tot snacks die klaar zijn om te eten. Naast koks maakt ook de voedingsindustrie ruim gebruik van (gemodificeerd) aardappelzetmeel, vlokken, meel en granulaten. Voordat gebruikers maaltijden bereiden van gekochte ingrediënten, hebben ze alleen visuele percepties van de producten gehad zoals weergegeven in schappen en diepvriezers van winkels. De organoleptische eigenschappen, smaak, geur en structuur van knollen en producten worden alleen in de keuken en aan tafel waargenomen. Sensorische waardering is afhankelijk van de soorten additieven in dippen en beslag tijdens de verwerking en hun rol om producten en smaakstoffen te verbeteren. De voedingswaarde van knollen, van andere voedingsgewassen en van aardappelproducten en -gerechten is geanalyseerd evenals hun winst en verlies in de productie van de grondstof en in de verwerking. De dichtheid van bestanddelen is in het algemeen negatief gecorreleerd met het watergehalte van het product. Het blijkt dat gunstige bestanddelen zoals resistent zetmeel en vezels voldoende aanwezig zijn in producten maar dat vitamines, antioxidanten en mineralen deels teloor gaan bij de verwerking.

Maatschappijdomein

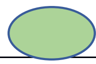
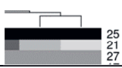
Tarwe, het belangrijkste voedselgewas, kan veel langer worden bewaard dan aardappel. Het wordt gemalen tot bloem of pasta die op elk moment kunnen worden omgezet in brood of een gerecht. Aardappel is slechts voor een beperkte periode bewaarbaar, dus overspoelt het de markt bij de oogst. Belangrijke voordelen van verwerking voor telers zijn onder meer het reguleren van de beschikbaarheid voor markten en van prijzen door middel van contracten. Daarnaast wordt de afname van consumenten die verse knollen kopen, gecompenseerd door verwerkers die grondstoffen kopen. Verwerkers voegen waarde en werkgelegenheid toe en consumenten krijgen een breed scala aan betaalbare en tijdbesparende producten aangeboden om uit te kiezen. Grote aardappelverwerkende bedrijven produceren jaarlijkse duurzaamheidsrapporten waarin wordt gepleit voor maatregelen voor telers om het milieu te sparen, voor efficiëntere processen in fabrieken, nieuwere en gezondere producten en voor het helpen van gemeenschappen. Deze zijn vastgelegd en bekeken in een theoretische triangulatie vanuit de ooghoek van verwerkers, beleidsmakers en vanuit degenen die de regels proberen bij te buigen. Telers zijn door de verwerkers het meest gehouden aan de duurzaamheidsmaatrelen en vooral om registratiegegevens door te geven. Vooral verwerkers bepalen de kwaliteit van de producten. Regelgeving oefent enige invloed uit op duurzaamheid door normen te stellen voor nitraat bijvoorbeeld en rond voedselveiligheid. Partijen kunnen maatregelen tegenwerken behalve bij voedselveiligheid omdat ze dan snel tegen de lamp lopen. De industrie, vooral bij uitbreiding naar nieuwe (opkomende) markten, wordt geconfronteerd met politieke, economische, sociale, technologische, ecologische en juridische (*legal*) (PESTEL) zaken afhankelijk van de aanwezigheid van een grondstoffenbasis, knollen dus, concurrentie en koopkracht en cultuur van de consumenten.

Onderzoeksaanpak

Vierledige Analyse

De analyse (Tabel 1) die speciaal voor dit onderzoek is ontwikkeld, voor het superdomein van "Over Aardappelverwerking" bestaat uit vier lagen. De eerste laag onderscheidt een domein dat wordt *geformuleerd* en afgebakend. Een domein heeft dingen die zijn georganiseerd in klassen met hetzelfde kenmerk (eigenschap). De tweede laag beschrijft de klassen en kenmerken en die zijn *gecondenseeerd* in een of meer tabellen. De derde laag weegt de kenmerken (*kwantificering*) naar de mate waarin ze van toepassing zijn op de klasse, wat resulteert in een *heatmap*. In de vierde laag wordt een dendrogram afgeleid van de heatmap die een hiërarchische *clustering* van de klassen en attributen mogelijk maakt.

Tabel 1. Aspecten van de vierledige analyse

Laag	Rang	Handelingen	Voorbeeld: fabriek	Resultaat
1	Formulering	Ontologische beschrijving en afbakening	Fabriek: alle handelingen tussen aankomst van de knollen en vertrekproducten dus van wassen tot verpakken	Domein 
2	Condensatie	Triangulatie, opsom-ming van klassen en kenmerken	Klassen: wassen, snijden, frituren koelen. Kenmerken: temperatuur, duur, gebruik van water, energie	Lijst Klasse Ke
3	Kwantificering	Een waarde van 1-5 (kleurcode) toewijzen aan de kenmerken	Waterverbruik = 5 (voor wassen), 1 (frituren). Duur = 1 (snijden), 4 (afkoelen) Temperatuur = 5 (frituren), 1 (afkoelen)	Heatmap 1 3 4 5
4	Clustering	Hiërarchische groepen van klassen en kenmerken	Clusters (tweelingen) van klassen met veel gemeenschappelijke kenmerken: schillen en snijden en temperatuur en energie	Dendrogram 

Door het hele proefschrift heen is de Vierledige Analyse stelselmatig toegepast. Tabel 2 vat de 29 geproduceerde heatmaps, de onderwerpen van de klassen en hun kenmerken samen met een voorbeeld van beide.

Tabel 2. Aantal klassen, onderwerpen en één voorbeeld per heatmap en hun aantal kenmerken, waar ze zich op richten met een voorbeeld daarvan. In totaal zijn het 6136 klasse × kenmerk combinaties in dit proefschrift

Schuin: na omgevings- of theoretische triangulatie

C	**Klassen**			**Kenmerken**		
	Tal	**Onderwerp**	**Voorbeeld**	**Tal**	**Betreffende**	**Voorbeeld**
2	18	Keuken operaties	Pureren	9	Keukenzaken	Kookkunst
	9	Knollen voor	Chips	11	Beïnvloedt klasse	Grootte
	23	Productgeschiedenis	Diepvries friet	16	Sociaal-technisch	Beschikbaarheid
	23	*Productgeschiedenis*	*Diepvries friet*	*16*	*Sociaal-technisch*	*Beschikbaarheid*
	13	Gerecht van product	Rösti	13	Kok gerelateerd	Gemak
	13	*Gerecht van product*	*Rösti*	*13*	*Kok gerelateerd*	*Gemak*
	12	Soorten consumenten	Avonturiers	16	Voorkeursproduct	Hasselback
3	8	Producten in winkels	Snacks	11	Consumentenbeeld	Prijs
	8	*Producten in winkels*	*Snacks*	*11*	*Consumentenbeeld*	*Prijs*
	20	Proces-Product	Trommel gedroogd	13	Technologie	Oliegebruik in de fabriek
	66	Fabrieksactiviteiten	Vormen	10	Technologie	Waterverbruik in fabriek
4	9	Acteurs	Koken	14	Relevantie	Bewaarbaarheid
	19	Voorstellingen	Knolgrootte	11	Beïnvloedt klasse	Sorteren
	10	Handelingen in keten	Verhitten	9	Impact op habitat	Ecotoxiciteit
	28	Verliezen in keten	Pekelscheiding	9	Vermindert verlies	Specificaties wijzigen
5	13	Gerecht van product	Gratin	10	Technisch	Kooktemperatuur
	13	Gerecht van product	Patat	12	Zintuigelijk	Knapperigheid
	14	Producten	Bloem	11	Nutriëntengehalte	Ascorbinezuur
	21	Vooruitzichten	Thuisbezorging	11	Kansen	Start-ups
6	21	Producten	Gevriesdroogd	15	Sociale voordelen	Energiebesparing
	34	Duurzaamheidsacties	Decarbonisatie	9	Actor is doel	Processor
	34	*Duurzaamheidsacties*	*Decarbonisatie*	*9*	*Actor is doel*	*Processor*
	34	*Duurzaamheidsacties*	*Decarbonisatie*	*9*	*Actor is doel*	*Processor*
	9	*Belanghebbenden*	*Overheid*	*6*	*PESTEL getroffene*	*Wetgeving*
	63	PESTEL elementen	Concurrentie	9	Betrokken partijen	Voedingsmiddelenindustrie
	18	Actoren-PESTEL	Gebruiker-Tech	6	Ontwikkelingsfase	Opkomende markt
	10	Zorgen-uitdagingen	Klimaatverandering	10	Karakteristiek	Urgentie
	20	Vragen beantwoord	Herstelfactoren?	14	Relevantie van het antwoord	Adequaatheid van het antwoord
$\sum^a$	471keer verschijnen klassen in 22 heatmaps			255 keer worden attributen weergegeven in deze maps		
$\sum^b$	583 keer verschijnen klassen in 29 heatmaps			313 keer worden attributen weergegeven in deze maps		
a: originele triangulatie, *b: omgevings- of theoretische triangulatie*						

Gegevensverzameling en -perceptie

De informatie die in deze serie van vijf overzichten is verzameld en tot uitdrukking gebracht, berust op twee pijlers: praktijkervaring en wetenschappelijke literatuur. Verdere informatie is verzameld door middel van interviews, het raadplegen van het internet en het lezen van (vak)tijdschriften. Aan het begin van het schrijven is vijf captains van de wereldwijde aardappelindustrie gevraagd naar hun zorgen en uitdagingen om de relevantie van de bevindingen voor bedrijven te waarborgen. Alle informatie, klassen, kenmerken en waarden uitgedrukt in scores van 1 tot 5, die nodig zijn voor hetsamenstellen van de tweeëntwintig heatmaps in Tabel 2, is verzameld via dit proces van Methodologische Triangulatie. In sommige gevallen werd aangenomen dat waarde-toekenning aan kenmerken is gedaan door een entiteit met een andere positie (bijvoorbeeld die maatregelen onderging in plaats van uitvaardigde), wat resulteerde in Theoretische Triangulatie.

Tabel 3. Triangulatie in sociale wetenschappen: soorten, beschrijving en voorbeelden

Soort	**Beschrijving**	**Voorbeeld**
Methodologische	Dataset samengesteld vanuit verschillende bronnen	Door het hele proefschrift heen, alle domeinen: ervaring, wetenschappelijke literatuur, vaktijdschriften, interviews, internet
Theoretische	Dataset gewaardeerd vanuit verschillende gezichtspunten	Duurzaamheidsmaatregelen zijn verschillend gewaardeerd door verwerkers, beleidsmakers en dwarsliggende partijen (hoofdstuk 6), of ze onderworpen of sturend zijn maakt uit
Omgevings	Dataset die rekening houdt met setting of locatie	Arme of welvarende markt beïnvloedt kenmerken van producten: prijs, bewaarbaarheid, benodigde apparaten (Hoofdstuk 2) ter illustratie
Gegevens	Dataset samengesteld door verschillende personen, verschillende tijden en verschillende plaatsen	Potentieel kan elke geïnteresseerde partij, overal en altijd, elk domein in dit proefschrift herstructureren en herwaarderen om deze triangulatie uit te voeren

Bij het aannemen van een andere locatie, ter illustratie een zich ontwikkelende markt (India) versus een ontwikkelde (VS), verschillen de omstandigheden en kansen. Dit is een geval van omgevingstriangulatie. Theoretische en omgevingstriangulatie leiden tot heatmaps met verschillende kleurlay-out en verschillende hiërarchische clustering van klassen en eigenschappen.

In alle heatmaps werd een score van 5 gegeven aan een hoge waarde, dus een operatie ten koste van een hoge resource input (veel water) krijgt een score van 5. Vanuit een perspectief bezien (theoretische triangulatie), watergebruik als verlies beschouwend, is een score van 1 gerechtvaardigd. Een score van 3 blijft 3 in beide triangulaties, een 4 wordt een 2 en een 2 wordt een 4. Dus de waarden worden omgedraaid rond de gemiddelde score van 3. Deze oefening verandert wel de clustering van de kenmerken, maar interessant genoeg niet die van de klassen. Wanneer een andere onderzoeker met andere grenzen van een domein komt, met gewijzigde sets van klassen en kenmerken en verschillende waarden (data triangulatie, Tabel 3) zal dit nieuwe heatmaps, nieuwe dendrogrammen en mogelijk nieuwe conclusies opleveren.

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Most photographs were taken by the author, a few that were not, are copied from the Handbook Potato and accredited there (Adobe, Avebe, Kiremko, M. Elemans).

About the author

Dr. *ir*. Anton J. Haverkort (1951) took his MSc degree (*cum laude*) at Wageningen University in 1978 and his PhD of Reading University in 1986, based on his research on potato in tropical highlands. Until 1987 he worked in Peru (internship), Turkey (assistant expert), Rwanda (science coordinator) and Tunisia (regional director) employed by the International Potato Center (CIP). Thereafter he worked at Wageningen University and Research as research leader in numerical, molecular and systems oriented potato projects in the Netherlands and dozens of countries at all continents. He productively wrote numerous columns, scientific and professional articles and books. He served as extraordinary professor at the University of Pretoria (South Africa) and visiting professor at Hokkaido University (Sapporo, Japan) and currently is still serving at Niğde Ömer Halisdemir University (Turkey). Upon retirement in 2016 he completed the Handbook Potato published in several languages and headed a task force climate change of a globally operating potato processing company. He is recipient of awards and honorary member of the European Association of Potato Research. As of 2020 he dedicated most of his time to On Processing Potato.

Glossary

Potato production and processing specific definitions and explanations of terms and acronyms

Abrasive peeling	Tubers with running water placed in carborundum (flint crystals) lined rotating drum
ACD	After cooking darkening, grey coloring of cooked tubers due to oxidizing ferri-chlorogenic acid
Acrylamide	C_3H_5NO, arises in the Maillard reaction from reducing sugars and asparagine heated above 170°C
Additives	Substances added to blanched products before chilling, among them the anti-oxidant ascorbic acid structure maintaining $CaCl_2$. In French fries and batter also structure and flavor enhancing matter are included.
After cooking	darkening: see ACD
Air frying	Heating oiled raw or par fried tuber chips in a hot air fryer at about 180°C
Ambient drying	Cottage industry in tropical countries: drying slices of raw tuber by exposure to sun and wind. Upon reconstitution with water the slices still need to be cooked
Ambient storing	Without cooling, refrigeration
Amylopectin	Dominant starch component: long chains of glucose molecules with many branches
Amylose	Starch component: long chains of glucose molecules without branches
Annealing	Stabilizing starch by withholding sufficiently high temperatures at above gelatinizing moisture content
Anthocyanin	Chemical with anti-oxidant properties responsible for the red and purple color of the flesh
Anti-oxidants	Health promoting flavonoids, terpenoids, Vitamin C and other compounds absorbing free radicals in the human body
Attribute	Descriptor (of properties) of a class
Baby tubers	Small tubers less than 25 mm graded form mature crop or purposely grown from densely planted early harvested crop. Scooping balls with melon baller from large tubers yields similar product
Bakeries	Bread making facilities using dehydrated tuber products to improve performance of wheat flour
Baking	Dry heating of tubers in the oven or in the ashes of fire
Batter	Slurry of wheat (or potato, cassava, corn, rice and dextrins). flour enveloping tuber sticks or formed products before frying to obtain a crunchy crust
Battered fries	Battered fries first pass a hot oil bath to settle the batter than a second cooler to cook the product to the desired degree
Belt blanching	Chips slices sprinkled with hot water over a conveyor belt
Belt drying	Blanched tuber parts are dried by hot air (flow of 70°C) over a belt before par-frying the parts in oil
Binder	Starch that keeps particles of food (meat, bread) together to prevent it from disintegration
Bio-availability	Fraction of consumed nutrient that is available for digestion by the intestines
Bio-accessibility	Fraction of consumed nutrient actually absorbed by the guts
Blanching	Subjecting tuber parts to water of 70°C for some minutes to stop the activity of enzymes removes sugars and adhering starch. For potato starch it also means it becomes digestible for humans
Bleaching	Treating native starch with peroxide or hypochloride
Blue market strategies:	Venturing into a new not yet existing market. Example: making and selling potato-based fufu in Africa
Breading	Successively applying flour, milk or water or egg wash and bread crumps to a product before frying to retain moisture and create a crispy crust
Boiling	Heating tuber (parts) in boiling water at 100°C at sea level, less at higher altitudes
Bread	When only made of potato ingredients, it assures absence of gluten

Breading	Addition of bread crumps to batter to enhance the thickness and crispiness of the crust
Brine separating	Destoned washed tubers contain light elements such as plant parts and low dry matter tubers. when passing a brine bath of 6% NaCl equivalent to a specific gravity of 1.07 of tubers of 18% dry matter) the floaters are removed.
Brushing	Removal of the remaining steam peels from the tubers with rotating brushes
Bulking	Increasing the amount of processing tubers of a desired variety by multiplying them for a few seasons in the field
CA	See Controlled atmosphere
CAP	Common Agricultural Policy assuring level playing field in the EU
Canning	Packing and preserving boiled tubers in sealed tins or jars
Carotenoids	Compounds responsible for creamy and yellow fleshed tubers, positive health aspect
Casserole	Dish mostly made of glass placed in the oven
Chakta	Distilled chicha (Andean region)
Class	Group of instances (of entities such as products, parties, processes) with similar attributes
Chicha	Beer from fermented mashed raw tubers (Andean region)
Chilling	Cooling boiled of par fried tuber (parts) to a few degrees above 0°C after packing and shelved and sold in a cold chain (refrigerated)
Chips	Thin tuber slices fried in oil a 175°C until all water is gone (French fries in the UK and some Commonwealth countries,
Chlorogenic acid	see ACD
Climate change	Increase of carbon dioxide, temperature and of temperature and rainfall related erratic events
Clustering	Grouping classes with most similar attributes (dendrogram assisted)
Chopping	Cutting cooked tubers before freezing arbitrarily into parts less than 30 mm
Chuño	Tubers freeze dried by exposure on rocks at high altitude (Andean)
CODEX	Alimentarius Commission. Food Safety UN organization under aegis of FAO and WHO
Columbian exchange:	crops from the new world (Americas) spreading globally such as potato, tomato. corn
Color enhancer	Potato flour enhances the color and thickness of baked products as bread and cakes
Concentrating starch:	with hydro-cyclones starch is concentrated in crude starch milk
Consistency	Firmness, part of texture of tubers or products ranges from very soft to very firm
Controlled	atmosphere, loosely stacked products ambient air replaced with air devoid of oxygen (nitrogen usually)
CDRF	Controlled Dynamic Radiant Frying (CDRF) technique which combines evaporation of water with formation of a brown crust, similar processes as frying but with no fat uptake
Consumer	Person eating potato products (snacks) or potato product based food prepared by the cook (the user)
Convenience	Advantage and satisfaction from 1) time saving through buying a potato product rather than making it in the kitchen from tubers, 2) less need of cooking skills and 3) less intricate kitchen appliances
Cookie	Chips produced from dough, well known trade name *Pringles*®
Cooking	Heating tuber (parts) or reconstituted products in water, oven, oil, fire in various ways
Cooling	Lowering the temperature of products 1) after heating at processing,2) reading finished product for sale as chilled product
Corporate farming:	operating large farms by a company with many employees, occasionally processing company owned out of necessity to ensure a regular flow of raw material
Cottage industry	Making potato products in kitchens at home and/or at very small scale using simple equipment and packing
Crisps	See chips
Croquette	Battered, deep-fried, salted, spiced potato dough formed oblong
Cube	Squared tuber parts with sides of 1-2 cm

Curry	Indian spicy sauce containing tuber cubes
Decarbonization	Reducing CO_2 emission of the factory from transport, heating and cooling
Decoration	Artistically draped strings of potato mash with a pastry tube on e.g. a casserole
Deep frying	Frying sticks, cubes of slices of tubers in oil of about 175°C
Defects	Unmarketable a) tubers sorted because of shape or rot b) products because of abnormalities, usually too dark color after frying
Dehydration	Removal of water from ground tubers resulting in settled and dried starch in cold processes and in flour or flakes when heated before drying and grinding
Dendrogram	Clustering of products, processes and operation in hierarchies and their descriptors with similar properties
Deoxidizing	Removal of oxygen through vacuum with chilled products of nitrogen atmosphere only with chips
Destoning	Removal of stones in a) a stony field before planting a crop and b) from harvested tubers, usually by soaking in water whereby the stones sink to the bottom
Dewatering	In a starch plant the starch suspension is dewatered first by vacuum filtering followed by spreading the result in hot air of 160°C for 2 seconds, just short enough to avoid gelatinization
Dextrin	produced from starch by heating (pyroconversion) facilitated by first acidifying it. It has many non-food applications and is used as a batter ingredient as it produces crispier products when deep frying.
Dextrose	The dipping solution of French fries 1% dextrose (a reducing sugar, oleoresin of turmeric) to give fries a golden color at frying
Dicing	Cutting cooked tubers before freezing into 1 cm cubes
Dish (potato-)	Part of a meal with potato as ingredient. Main dish: several ingredient, side dish: prepared potato only
Dipping	Submerging an intermediate product to water with additives such as SAPP and/or dextrose
Dietary fiber	Roughage, cell walls and parts of peels not complete digestible by human intestines
Dipping	After blanching the product is dipped in a 1.5% SAPP (disodium acid pyrophospate) solution to prevent after cooking darkening (ACD)
Disintegration	Loss of original texture
Drum dying	Potato mash applied to a drum with a screw conveyer dried with steam is scraped off yielding flakes, flour when ground
Drying	Freese (see there) Ambient wind sun in cottage industry Hot air, flash drying Drum (see there)
Dry matter	All tuber matter (starch, protein, minerals, fiber, compounds) except water
Dry matter	Concentration: proportion of dry matter in a tuber, usually expressed as percentage, derived from specific gravity assessed through under water weight measurement
Dryness	Taste of water in a boiled tuber or product, ranges from very humid to very dry
DSS	Decision support system assisting growers on timing and dose of inputs
Dumpling	Boiled potato dough either or nor wrapped around a filling
Earliness	Time between planting and crop maturity (also called lateness)
Electrification	Replacing steam and fuel driven processes by ones with electricity, aimed at reducing CO_2 emission
Emulsifier	Modified starch that stabilizes an emulsion such as a batter
Energy	In factories provided by fuel (gas petrol, diesel), electricity and (fuel heated) steam
Enhancer	Potato flakes and granules that enhance flavor (potato taste) or texture (mouth feel) in baked
Environment	1) Conditions were crops are grown (weather and soil) that differ in summer and winter, lowland and highland, rainfed and irrigated

	2) Setting of the industry in the physical and social world
Evaporation	Disappearance of water from tubers through the skin in stores or though boiling in water or oil
Ex-field	Tubers lifted reaching their off-farm destination directly from the field
Expanded snack	Pellets after expansion seasoned with salt and spices supplied with colorants and packed
Expansion	Exposing pellets to temperatures well above boiling, so deep frying or air frying expands them as the inside water forms steam which takes more space
Expansion	Increase in size by absorption of air following popping due to heating of pellets whereby water entrapped in gelatinized starch boils, evaporates so takes more space.
Extender	To use less meat in hamburgers potato flour is mixed with it
Extrusion	Pressing dough through a shaped opening and the resulting string cut at regular intervals producing pellets
Fabric	Location of outlets (for users and consumers) and of markets (for processors)
Feed	Food for animal, a) heated suitable for non-ruminants, b) unheated suitable for ruminants only
Fiber	Carbohydrates resistant to digestion by humans, derived from skin and cell walls, resistant starch included
Finished product	Products from a processing unit ready to be cooled, frozen, packed and sold
Flakes	Heated, ground and drum dried potato paste scraped from the drum, soluble in cold water
Flakes	Mash pressed to a drum and dried, then scraped off and broken
Flash drying	Spread julienned tuber parts subjected to a stream of hot air cooks and dries them and avoid conglomeration
Flavoring	Adding flavor, seasoning to: 1) Chips and expanded products through a dispenser and tossing the product gently in a drum 2) Batter of French fries 3) Chilled products by supplying the seasoning in a separate sachet
Flesh	All tuber substances within the peel, latter exempted
Floaters	Tubers unfit for processing into fried products floating in a salt bath with 9% NaCl corresponding with a specific density of 1.07 which corresponds with 18% dry matter
Flour	Flakes ground to a powder
Food industry	Bakeries and factories using potato products for their final products such as pastries and Soups
Food service	Restaurants, caterings and institutions (hospitals, prisons) with kitchens deploying products
Flouriness	Degree of floury tubers showing flour in the cooked flesh upon breaking , taste: powdery, soft
Forced ventilation:	Air pumped through tubers with electrical ventilators top remove heat, moisture and CO_2
Forced refrigeration:	tubers cooled mechanically to lower than ambient temperatures
Forming	Making shapes of potato dough such as patties, balls, croquettes before coating and frying
Four-Tier Analysis:	1st delimit domain, its classes and their attributes, 2nd assembling and condensing data in a summary table, 3rd mapping and quantifying data in a heatmaps and 4th clustering data with the aid of a diagram
Freeze drying	Drying tuber (parts) by exposing them to below freezing temperatures and dry air with low relative humidity. Chuño is one of the results but also modern packed cubes exist. Upon reconstitution, the product needs to be heated before human consumption
Freezing	Lowering the temperature of fried finished products to -18 degrees Celsius so they can be stored at that temperature for a few years
French fries	Twice fried tuber sticks, first at 160 ºC for 8 minutes to cook, then at 180 ºC for 4 minutes to form a crispy crust. Factories perform the first process (par-frying) and freeze the product that is subjected to the second process (deep frying) in the kitchen of the consumer
Fresh matter	Mass of tubers before processing not having lost any water and dry matter from peeling, cutting and heating
Frietkot	Belgian small French fries outlet, not unlike a diner

Fritter Small strings of tuber resulting from coarse grating as ingredient in hash browns
Frozen Frozen products
Fruit water Liquid remaining after settling of the starch the bottom of the vessel upon grinding of the tubers
Frying Of French fries: Mostly continuous over belt with steam cover over oil to prevent oxidation
Gelatination Dissolving starch in water at (near) boiling temperatures
Genotype Variety of a species, wider sense, the planted see tuber with its properties
Gluten-free ingredient: Potato does not contain gluten so fits in the diet for coeliac patients
GlobalGap Good Agricultural Practices https://www.globalgap.org/uk_en/
Glycemic Index: measure (GI) of increase of the glucose level in blood after eating starchy or sugary food (Venn and Green 2007)
Glycoalkaloids Bitter tasting poisonous compounds found in plants of the nightshade family, including potato
Gnocchi See dumpling
Grading Sizing, tubers pass a grid for proper sizing. For crisping 30 – 50 mm and for chipping 45-90 mm size grades are desired.
Granules Powder with grainy structure containing complete cells and cell groups produced by blanching and cooling of peeled and cut tubers, subsequently boiled, gently mashed and flash dried (sprayed and briefly exposed to hot air). Granules are only soluble in hot water
Gratin Oven baked slices topped with a crust with grated cheese and/or butter and bread crumps
Grating Grating tubers into fine particles for starch extraction (cold process)
Greening Tubers exposed to light turn green due to chlorophyll formation, they also form more glycoalkaloids
Grilling Cooking tuber (parts) by exposing them to radiant heat over fire or in grill oven
Grinding Ground flakes become flour
Heatmap A matrix with instances of potato related subjects or objects in rows and their attributes in columns. A greener color shows that the attribute applies to a greater degree, a redder color shows the opposite
HACCP Hazard Analysis at Critical Control points. Food safety system of among othersFAO, CODEX
Halving and quartering: Oversized tubers are cut in halves or quarters to arrive at dimensions suitable for handling by the equipment and for specific end products
Handling On-farm grading and sorting
Hash brown Fried patty shaped cakes (fritter) of salted and spiced grated strings of raw or of riced cooked potato
Hasselback Tuber with incisions about 75% deep a few mm apart, doused with oily substance, baked
Hilling Covering the base of potato plants with soil (earthing up) to protect tubers from exposure to rain and light
Hot air Super-heated steam (well above 100°C) on raw potato slices cooks and dries them
Humectant Shelf life extender: a low proportion of potato flour used in bakeries to slow down staling of their products (humidifying agent)
Hybrid seed Seed produced from a cross of two parent potato plants, particularly for inbred parents (hybrid true potato seed, HTPS)
Hydrolysis Treating starch whereby long chains are broken down to smaller ones to make native starch suitable as ingredient in the baking industry.
Instant mash Flour only needing a liquid (water or milk) to create a ready to eat mash
IQF Individually Quick Frozen of frozen products loosely packed in polyethene bags to avoid clumping
Jacket potato Baked skin-on tuber
Julienning Cutting tubers in thin strips of their length
Kettle frying Frying unwashed, uncooked and thicker chips than in the continuous process in batches in an oil bath (kettle)
Kitchen Place at home, in restaurants, institutions and other outlets where meals are prepared

Knife block Water and tubers are piped at 42 km/hr through a knife block producing chips and wedges of various sizes as directed by the maze of the knifes
LP/LL Low peel low leach fine white flour
MacFry Specifications for French fries served at MacDonalds: 6 mm x 6 mm x 70 mm
Maillard Non-enzymatic browning of tubers at high temperature, a chemical reaction reducing sugars and protein gives, color, taste and smell to fried tubers (see also Acrylamide)
Management Planning and applying operations and material (water, fertilizer biocides) in field and stores
Marketable Part of the tubers of the lifted crop of value in supply chain
Mash Crushed tubers for brewing or starch making, when whipped reconstituted flakes: puree
Meal component Main dish or side dish
Mealiness See flouriness
Microwave Freeze drying under vacuum and/or with microwave application speeds up the sublimation process
Modification of starch: subjecting native starch to physical or chemical treatments to alter its properties for a wider range of uses in the food industry
Moray White colored washed chuño (Andean)
MRL Maximum Residue Level legally allowed in a food product
Native starch, protein: extracted and purified from tubers before any further modification
Oil removal After (par) frying excess oil is removed by vibrating the belt on which they leave the oil bath
Ontology The ontology of the processing potato domain, describes classes and their attribute of growers, processors and cooks of tubers, products and dishes throughrelations, processes and operations
Operation Action carried out by a processor (such as peeling, heating, packing)
Packing Packaging, wrapping finished products. Chips loosely packed in aluminum coated plastic bags in 100% nitrogen; powdery products in carton boxes and frozen products loosely packed in plastic bags; chilled in plastic bags often in vacuum
Panfrying Frying potato (parts) sprinkled with oil in a pan. With deep frying potato is submerged in oil
Papa seca Boiled and dried tubers (Andean)
Parfry See French fries
Parts Tuber cuts (chunks, dices, cubes, slices, sticks, balls)
Par-frying Frying tuber parts at near cooking temperatures for less time than required for completing cooking (deep frying) which takes place when preparing the meal ingredient in the kitchen
Pasteurizing/sterilization: Heating the vacuum packed product to (near) boiling temperatures so it can be stored at 4°C for a few months. When steam heated at above 100°C, the shelf life is longer still
Patatin Storage protein in potato
Pattie Deep-fried mashed potato forms with batter crust
Peeling and packing companies: they sell fresh peeled uncooked tubers to kitchens and processors. This is outside the potato processing domain
Peeling by knife Cutting, skin removal with a knife by hand (cottage industry)
Pelleting Slightly moisturized flour is pressed through a mold and the string cut at regular intervals. The process yields pellets of exactly the same shape and size, ready to be fried and expand.
Pellets Pellets expand manifold with some 10 seconds so are kept in the oil by a submerged conveyer belt
Performance of a crop: Its yield and quality
PESTEL Analysis tool to identify Political, Economic, Social, Technological, Environmental and Legal elements affecting the stakeholders of the potato processing industry
Phenolic compounds: chlorogenic acid, flavonoids and anthocyanins. The latter give potato flesh a red color
Pie Meat and Potato: a) casserole with meat covered with mash oven baked, b) filling of these two ingredients baked in a wrap of wheat dough
Poaching Cooking tubers in water of 75°C

Polyethene Plastic used in packing frozen and chilled products
Polythene See polyethene
Pomme Dauphine: Deep-fried somewhat puffed puree of mash and watery wheat dough with egg and spices (sold frozen)
Pomme Duchesse: Puree of spiced mash and egg squeezed though a pastry bag in small heaps baked in the oven at a very high temperature for crispy crust (sold frozen)
Pommes sauteed = pommes rissole (resoled): pan fried tuber pieces
Popchips Thin slices of dough processed (puffed) at high temperature and pressure
Process What occurs with(in) the tuber when subjected to an operation
Precision farming Sensing of crop and soil based timing and dosing of inputs (tillage, seed, chemicals)
Processing industry: Businesses (large to small, global to cottage) where potatoes are processed beyond washing and peeling
Protein See patatin
Puffed chips Slices dough of potato and cereal flours, baked at high pressure,
Pre-heating Disrupting cells for easier cutting and less shear: exposure to warm 55°C water for 40 minutes. Pulse electric fields (PEF) have same purpose
QSR Quick Service restaurants (formerly known as fast food restaurants)
Raw Raw material: tubers entering the factory for processing purpose
Reconstitution Adding water to dehydrated tuber parts or flour
Recovery Proportion of raw material that ends up in the finished product(s)
Red ocean strategies: Competing in existing markets such as promoting hash browns for breakfast and another 'iconic' shape of chips or French fries
Reducing sugars Glucose and fructose
Refining starch Washing of the crude starch milk to remove juice
Rehydration See reconstitution
Resistant starch Portion of starch that is not digested
Respiration Loss of dry matter during storage where oxygen and starch are used up to produce energy (part as heat).
Retrogradation Restructure of amylose and amylopectin molecules in a crystalline structure after dissolving starch at which the molecules separate. First boiling or blanching followed by cooling slowly retrogrades gelatinized starch that takes up water leading to stronger fritters in hash browns
Ricing Pressing cooked tubers before forming through a ricer (sheet with small holes)
Rissole Pastry with savory filling
Roast potato Pre-boiled or pre-fried baby potato or chunks oiled and baked at a high temperature
Root crop Crops with vegetative parts, botanically their roots, harvested for food (example sweet potatoes)
Rösti See hash browns, but also pan cake shaped
SAI Sustainable Agriculture Initiative https://saiplatform.org/
SAPP After blanching the product is dipped in a 1.5% SAPP (disodium acid pyrophosphate) solution to prevent after cooking darkening (ACD)
Sautee See pan frying
Scalloped potatoes: Very thin slices baked in milk
Seed tubers Tubers not used for consumption but as propagation material
Senescence sweetening: Accumulation of sugars in old tubers that have been stored for many months
SFA Sustainable Farm Assessment of SAI Platform with bronze, silver and gold levels https://saiplatform.org/fsa/
Shaping Making shapes of potato dough such as patties, balls, croquettes (forming)
Shredding Cutting tubers with a mandolin slicer with julienne attachment yielding long thin strips, ingredient of hash browns
Sieving pulp Separating pulp from starch and juice wit extraction sieves

Slice Tuber cut with a slicer, 2 mm for frying chips, 6-10 mm for cooking purposes
Slicer Tubers are spinning in water, a stationary knife to produce slices of varying thickness, 1.5 mm thin for chips, 5 mm thick for chilled products
Skin Botanical: epidermis, industry: peel, kitchen: half shells of baked scooped out tubers
Skin-on Unpeeled (potato products of unpeeled tubers)
Snack Portion of crispy potato product eaten between meals
Solids Dry matter of tubers determined by weighing them under water yielding their specific gravity
Sorting Optical (automated or visual) technique to remove blemished peeled potatoes (with defects)
Sorting Removal of tubers or parts or finished products not fit for the markets after visual observation. In modern factories often fully automated
Specialties Formed products are delicate and cannot be tossed like French fries so require special care to even color when led through the hot oil
Specific gravity Density of the tuber, indicative of its dry matter concentration because starch is heavier than water
Specs Specifications of raw material for the factory (such as tuber size, dry matter concentration) and of finished products for customers (such as size, fat concentration)
Stackable chips Chips made from rolled, punched and fried of baked dough, all with same shape
Staple Food as main source of energy (and protein) in a diet
Starch Amylose and amylopectin, long chains of glucose
Steam peeler Perforated container with tubers subjected to steam of 200°C at 18 bar for 8 seconds, upon withdrawing pressure the skin pops off.
Steam peeling Subjecting tubers for a very short period to hot steam at high pressure. With sudden release of pressure the skin releases
Steaming Heating tuber (parts) over boiling water
Stew Tuber (parts) boiled with meat and other vegetables
Structure Feel of particles upon consumption (chewing) ranges from very fine to very coarse
Structurer Potato starch giving desired structure to potato and other food products
Tare Non tuber substances accompanying harvested tubers (earth, stones , plant parts) temperatures during the day and freezing during the night
Texture enhancer: Dehydrated potato added to non-potato foods result into more moisture mouth feel in baked products and add crispiness to fried ones
Texture Mouth feel of potato products, crispiness among others mainly related to wateriness of the product
TGA Total glycoalkaloids concentration
Thickening agent: thickener Potato flour (as flakes or granules) thickens sauces and similar meal ingredients
TPS True Potato Seed, see hybrid seed
Thickener Starch, flakes or flour added to a liquid enhancing their viscosity.
Triangulation Methodological collecting and assembling data from different sources including : experience, scientific literature, professional journals, interviews, the internet
Environmental: taking the setting or location into account: developing or developed market
Data set assembled by different persons, different times and different places
Theoretical: addressing data with different questions (for instance, are parties subjected or steering?)
Trimming Removal with a knife by hand, of undesired surface spots after mechanical peeling (cottage industry)
Tuber crop Crops with vegetative parts, their tubers(botanically their stems) , harvested for food (example potatoes)
Tunta See moray
UPOV The International Union for the Protection of New Varieties of Plants (HQ Geneva, non-UN)

User — Person subjecting potato products to further preparations (cooks making dishes) or processing or modification (food industry)
Washing starch — Washing the starch granules out of the cells
Washing — Submerging and rinsing tubers after harvest to remove adhering soil, especially clay caps
Water holding capacity of the soil: mm of water contained in 1 m of soil, optimal in intermediate soil types rich in organic matter
Water jet — A water jet cuts tubers in slices or strips
Waxy — 1) A waxy tuber does not disintegrate upon cooking, 2) Waxy starch consists of amylopectin only
Waxy potato — Its tubers only contain amylopectin, no amylose
Yield improvement: Hydration of flour and starch (derivatives) lead to a reduction of the need of wheat based dough for bakery