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On Processing Potato: 1. Survey of the Ontology, History and Participating Actors

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Abstract

The processing potato ontology includes the three domains of growers, processors and cooks producing tubers, products and dishes, respectively. Dishes consist of three subdomains: types of dishes prepared from products, kitchen operations and consumer preferences. 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 are 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.

Keywords Consumers · Cooks · History · Industry · Processes · Raw material · Specifications

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Introduction: Inception and Research Questions

After wheat and rice, potato is the third food crop in tonnage produced. The potato crop is propagated clonally with seed tubers that degenerate within a few generations. It can be harvested before crop maturity, containing 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 environmentally managed storage and for most products water has to be extracted. Tubers need to be heated to gelatinize starch that otherwise is not digestible for humans. Products are made in large centralised factories that in North America and North Europe use significantly more than half of the crop (in the USA, UK and the Netherlands over 70%) 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 decentrally in many bakeries, where water is added for processing into bread. This uniqueness of potato alone would be reason to write this paper, but it is at least as significant to elucidate the closely knit community of consumers, processors, growers and breeders of potato which is a unique social phenomenon in food production.

A four-tier analysis specifically developed for this series of surveys “On Processing Potato” is partly derived from ontology: (1) a domain is described and delimited and 2) classes and their siblings are pronounced and their attributes assigned. Beyond the ontology, (3) the attributes are awarded a value between 1 and 5 according to the degree they apply to the class, yielding a heatmap, and (4) the heatmap produces a dendrogram (heatmapper.ca, Babicki et al. 2016), with clusters of classes and attributes showing similarities. Such a dendrogram is shown for one domain as illustration only. Anyone interested can complete a heatmap in MS Excel and upload it into heatmapper.ca. The data presented are assembled through triangulation with observations (experience), scientific and professional literature and literature from the internet and through informal interviews as methods. The description of the domains, selection of classes and attributes and attribution of their values were carried out by the first author. Other persons in a different time and setting and applying a different way of data triangulation would possibly apply a different delimitation and awarding.

The cooperation domain describes classes and their attributes of growers, processors and cooks of tubers and products and dishes through relations, processes and operations. The intricate relationships between eaters of potato dishes, cooks, retailers, processors, growers of tubers for raw material, seed potato growers and breeders are a unique social phenomenon in food supply chains. In the scientific literature to date, this domain has not been formulated and delimited nor classes identified and properties attributed and supplied with values to allow a quantitative evaluation and grouping. This survey aims to elucidate the domain by focusing primarily on the three principal actors: growers of tubers, manufacturers of products and cooks of dishes. More specifically, research questions are about the processing potato ontology, about growing classes of tubers, manufacturing of products, about preparing dishes and consumer preferences.

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 products in mind. Are the specifications different when articulated by another party or in another environment?

Over time, the number of products available for consumers increased, so a completion of the domain manufacturing with class products to add societal attributes related to the origin of a product and the reason(s) it came to the market was needed. This gives rise to a possibility to enumerate classes of products and their relative social significance from a historical perspective. Are there reasons to give a different value to the degree an attribute applies to a class if society has an opinion about it?

The domain of processing potato needs to be divided into subdomains; is a division into growers, processors and users relevant and justified? Which level of detail is needed in order to adequately define the subdomains before entering them in detail in the following sections? Which other stakeholders are involved and what are their roles?

Starting with fresh tubers, purchased with the aim of a dish in mind, in kitchens they are washed, usually peeled, either or not cut and heated to end up amongst others as French fries or gratins. Historically, manufactured potato products were derived from kitchen preparations for several reasons and became available on markets. Is it justified and helpful to analyse what cooks do from simple to intricate operations as a starting point of listing manufacturing processes and resulting products accordingly, and as a logical sequence?

Classes of ready-made potato products that came to the market over the years vary in a number of requirements going from affordability to cooking skills needed to finish them in the kitchen. A description of this domain was not done in the past. What are the classes of products, the range of choices with a class and what relevant attributes apply for a meaningful four-tier analysis from the points of view of customers in a developed or in a developing setting?

Consumers are not just one group but are a diverse population with different interests depending on their attitude as determined by their economic status, taste, habits and on the purpose of buying: routine or for a special occasion varying from a snack between meals or preparing a dinner party. 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.

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 organise data in a systematic way 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” (fertiliser, 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) and 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, fertilisation, crop protection) and its potato crop with properties such as variety, yield and quality. Decision support systems (DSS) and crop observations assist growers in intervening. 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 fertilisation and biocides used. They add their own observations which are shared with the grower such as yield, tare, size, dry matter and reducing sugar 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 (exemplified in Fig. 1) concepts of the potato ontology are shown: tubers, processes outside the farm and nutriments made of potato products. Raw material Processing_tubers and its siblings Table_tubers and Seed_tubers have a superclass tubers with sibling stems, leaves and root members of the super-superclass Plant_parts and have subclasses itself: Rejected_tubers and Accepted_tubers with one of the sub-subclasses being Fried_tubers with sub-sub-subclass French_fries_tubers. Similarly, the superclass Production_processes has siblings, amongst them the class Potato_products_production_processes with three subclasses amongst 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 and quality characteristics of the raw material (variety, size, defects, tare, dry matter concentration, fry colour and origin). The origin goes back to the field where grown with all data recorded. Details of production, growing, costs, conventional and organic, sustainability and climate change issues for Northwest Europe are given by Gofart et al. (2022).

The umbrella-domain “Processing Potato” consists of three sibling domains. The first one is “Production of processing potato tubers” up to delivery of the raw material at the processing plant; this is the domain of growers. It is followed by “Processing potato tubers into intermediate and finished products” which is in the domain of processors and is concluded by the Dishes Domain with three related sibling domains, that of “Kitchen, domain of cooks”, “Products made into dishes” and “Consumer Preferences”.

Domain of Growers: Cultivating Tubers

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 under crop management (low and high

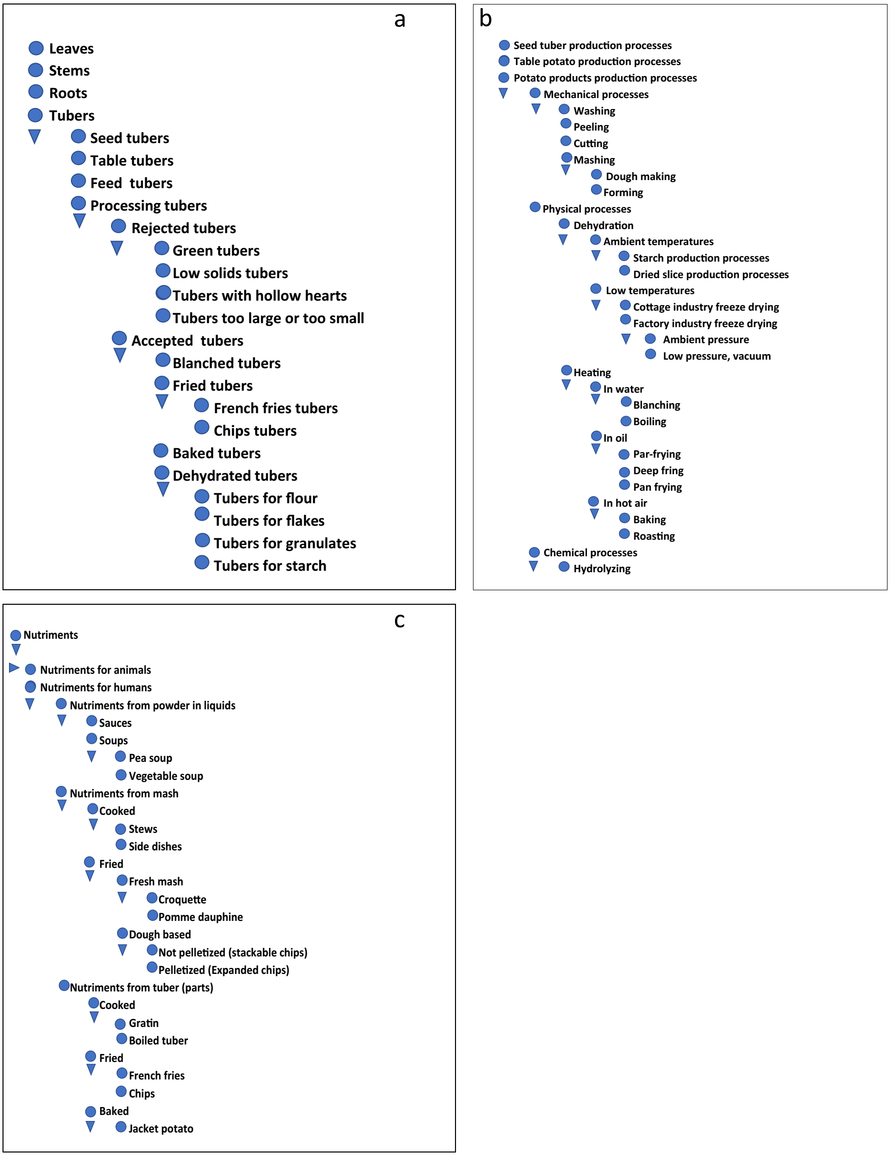

Fig. 1 Part of the potato ontology with classes of tubers of raw material made by growers (**a**), of operations by processors (**b**) and dishes made of potato products by cooks (**c**)

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, amongst others, depends on mealiness, structure, size and shape, to a great extent depend on the genetic make-up of the planted material. 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 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 and 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", $P = G \times E \times M$ 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 and 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 1 distinguishes the various subclasses of tubers for processing (and as illustration, also for seed and fresh market) purpose after harvest and handling: tare removal, sorting of tubers with defects and sorting. The sub-subclass has accumulated a few more attributes, those regarding storage regime.

The specifications (Table 1) of the tubers of the harvested crops, stipulated by the manufactures, 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 2021a, 2021b). 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, so absence of specifications other than a high starch concentration and low transport costs, less than 100 km because the starch factory is in the production area, makes this possible. In some countries, the crop is grown on peaty soils which do not favour the taste of table and processing potatoes. Potato flour production 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. Some factories, or lines, specialise in producing flour and require specific varieties with desired colour and taste. Here, a wide range of sizes is acceptable and not many other specifications are required. Tubers destined for French fries production need to have flesh with a creamy colour in most parts of the world, but are white fleshed in the USA and UK and some of the 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

Table 1 Description of the class of tuber domain, its subclass tubers before storage and subclass tubers after storage (raw material delivered to the factory (seed and fresh exempted))

Attribute of subclass	Subclass	Attribute of sub-subclass	Sub-subclass
Specifications (known pre-planting)	Pre-storage tuber	Storage regime	Raw material tuber
Tare, small tubers, glycoalkaloids, starch	Ungraded, no sprout control	Hardly stored, ambient for few months only	Starch tuber
No small tubers, defects, reducing sugars	Ungraded, sprout control	Rather low temperature (6 °C)	Flour tuber
Size, shape, defects, fry colour	Graded, sprout control	Rather low temperature (6 °C)	French fries tuber
Firm skin, size, nutty taste, buttery texture	Graded, sprout control	Rather low temperature (6 °C)	Baking tuber
Meeting many specifications, very low in reducing sugars	Graded, sprout control, washed upon delivery	Not too low temperature (10 °C) to avoid formation of reducing sugars	Crisping tuber
As for flour tubers, no odour, no greening	Graded, sprout control	Rather low temperature (6 °C)	Chilled tuber
Small sized, waxy	Graded, sprout control (washed upon delivery)	Rather low temperature (6 °C)	Baby tuber
Without skin blemish	Graded, sprout control	Rather low temperature (6 °C)	Fresh market
Disease-free (according to class)	Graded	Low temperature (3 °C)	Seed tuber

restrictions lead to a high cost of production to which storage and transport costs up to a few hundred kilometres 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 centres where their products are consumed so tubers are often transported for many hundreds of kilometres up to over 1000 km. Baby tubers for canning and chilled, if not scooped with a melon baller from large tubers, are either graded but also often specifically grown from early harvested densely planted crops, and crops with a variety that produce many small tubers with a firm waxy structure. In Table 1, 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.

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. Recovery is the proportion of raw ending up as processed finished product.

The heatmap in Table 2 indicates that in general size should be average with the exception of tubers for baking that need to be very large and baby tubers that 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 6 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 fibre is recovered at higher than feed value. A very high average of scores is for chipping tubers, twice that of starch tubers.

Cluster analysis showed that the classes of starch and seed tubers are apart from the other ones. 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, are rather similar. With attributes, year round delivery stands alone with two clusters remaining, one with value addition assured at high recovery from tubers with the right size and dry matter concentration, and one that concerns farm matters with variety specificity.

Domain of Processors: Making Products

Domain Description

Potato products appear in dry (flour, chips), and liquid (beer, vodka) form and more or less as moist as the fresh tuber used as raw material (baked, blanched and chilled) or semi-dehydrated (French fries and formed products such as croquettes). Some products are easily prepared in a cottage industry setting, and others need complex equipment, to make popped chips for instance. Some products are ready to eat

Table 2 Heatmap of 9 classes of tubers and 11 attributes awarded a higher score the more they apply to a class

		Standard		
High value	a	Losses in handling		Low value
	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	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

(biscuits and snacks), and others only need to 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, a Spanish chronicler, in 1538 according to Burton (1966) citing Penrose (1864), and Laufer (1938), 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 (1893) 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 2 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 1 week. The product is dry, dark coloured, 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 2 months, the colour becomes white and the glycoalkaloid 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 (1893): "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 flake-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 summarised in Table 3. One group of products not part of the processing subdomain described here is that of Potato Peeling and Packing Companies (PPPC (2021)) where heating or dehydration is not one of the processes deployed.

History of Potato Processing

The first mention of a processed potato product (Table 3) 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 these served as an antiscorbutic to avoid scurvy and they occupied less space than tubers and when reconstituted and boiled, produced 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 mentioned 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.

Table 3 First time mention of a manufactured potato product (block) and mentioned in descriptions of recipes *(italics)*

Time	Product/*dish*	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*	*Flavoured potato dough with crust, fried*	*Side dish*
1853	*Chips/crisps*	*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, flavoured formed and fried or baked patties*	*Household kitchen preparation*
1901	Flour	Cooking, drying, grinding	Storable, multi-purpose use

Table 3 (continued)

Time	Product/*dish*	Process(es)	Social satisfaction
1908/1910	Chips/crisps	Thin slices fries till all water is evaporated	Snack
1917	Flakes	Cooking, drum drying	Improved processing techniques
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	Pelletising 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

Industrial freeze drying takes place since early last century (Fellows 2017). Upon reconstitution, these products still need to be heated to permit starch to gelatinize. When dried in hot air, whereby the tubers lose 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 the USA in 1887. 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 commercialised.

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 an 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 New Hampshire, USA, in 1831 (Brautlecht 1940) and in 1833 one opened 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, it had several uses and in Europe for a long time it was the raw material for vodka production. Modification of wheat and corn starch took place already 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 UK) are thin slices of tuber fried in oil until the sizzling stops when all water is evaporated. They are loosely packed in aluminium-coated polyethene bags with controlled atmosphere to avoid the oil to deteriorate, salted or with a wide array of flavours 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 Daily News 2010), both claimed to be the oldest chip 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, brought 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…." (Anonymous 1830). Croquettes as a savoury meat-based snack were described amongst 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-twentieth century along with 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 (Bredase Courant 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 2021a, 2021b). 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 airplane passengers in 1945 (Tressler and Evers 1957) and the military contain a variety of possible potato products, amongst them boiled tubers, French fries and puffs. Distributed through supermarkets, 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 have a more grainy texture than flour and make a distinct mash, were produced first in Idaho by the RT French Company in 1952 by boiling cooled blanched tubers, mixing them 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 are 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 since 1967. 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 summarises "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 maize 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 commercialised 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, and upon release of pressure they puff. The company Popchips produces them since 2007.

Protein extraction is not mentioned in this survey but will be treated in a sequel that describes processes amongst the food grade protein extraction. Starch factories in most countries dumped fruit water until around 1970. By then they were forced by legislation to heat the fruit water and extract feed grade protein. As of late last century, food grade extraction takes place at some factories using chromatography.

The products listed in order of historic appearance in time in Table 3 are grouped into products with similar properties in Table 5.

Intermediate and Finished Products

Native potato starch is a subclass of the class products (with attributes rasping, sieving, washing and drying (BeMillet and Whistler 2009)) and so are blanched tubers that subsequently undergo one or more processes (with one attribute in common: blanching). Finished products (sub-sub or sub-sub-subclasses) are modified starches (with attribute modification), tuber parts (with attribute blanching), when sterilised storable as canned (PSU 2021), when mashed and dried emerge as flakes (Cui et al. 2018) and French fries (par frying) and formed products (mashing and forming (PotatoPro 2021)) are crisps (frying (Van Loon 2005)), dried (drying (Doymaz 2012)) and baked (AHDB 2021) products. Hydrolyzing, fermentation and distillation yield vodka (Xu et al. 2016).

A summary of the products and their processes and or operations as attributes is presented in Table 4. This table includes the principle processes 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 flavour. This is expanded in the sequel of this article on processes between delivery of tubers at the factory up to leaving it as packed finished product.

The temperature (Table 5) at which processes take place is highest for fried products, about 170 °C, and lowest, ambient, for manufacturing native starch and some (not all) modified starches. Boiling and distillation are 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 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.

Table 4 Description of the domain "Processing of Intermediate and finished potato products"

Product level			
Intermediate		Finished	
Class	With attributes	Subclass	With attributes
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, sterilisation

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 polythene 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 the cottage industry such as powdered ones and their derivatives, formed products. Chips and French fries are most common and in some developing market 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, and crisps 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.

Quantification of the Attributes of the Product Classes

Table 5 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 and need of equipment and skills increase with time. Dehydration through natural means is an old technique and so are brewing and distillation, but

Table 5 Heatmap of 23 manufactured products and 16 attributes. Bold underlined attributes following theoretical triangulation received a high score in the first run. As such a high score is considered unfavourable for these attributes, they were given a low score 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	x̄	**x̄**
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/crisps	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	2.9	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**

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 aluminium-coated plastic in controlled, nitrogen only atmosphere. All potato products bought save 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. Column d 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 and so do products that need much water and energy. Table 5, however, in bold and underlined also offers the possibility to allocate low scores to attributes considered unfavourable. In a theoretical triangulation, iteration colours, 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 7 are chuño air-dried 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, and lowest for water use in the kitchen as most products, chuño excepted, need no washing, some a little added before cooking and many fried products or snacks need none.

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 in both evaluations. Where 'low water use' received a low score in the first evaluation it became an asset in the second one and its average score 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.

The products in both scenarios are clustered with a group of powders, of dried products, of frozen products and more loosely of snacks and drinks.

The Kitchen Domain

Cooks in 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 (cold) 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), amongst 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 discolours, turns yellow, golden or brown. At home, i.e., in a non-industrial setting, unprocessed tubers, when not harvested at own farm, garden or allotment, are purchased, washed or unwashed, packed or in bulk at the market, greengrocer or supermarket.

When making an inventory of all operations taking place in kitchens, a distinction is made between mechanical operations where the tuber material or a substance thereof derived change shape but during which the physical and chemical properties are not altered. The physical treatment the tuber and its parts undergo is heating which is done in hot water (boiling), hot oil (frying) or hot air (baking). The array of mechanical and heat-involved operations is summarised in Table 6. The table also shows where the operations lead to.

When on sale unwashed, usually brushed on the farm or the packing station, before preparation, tubers are washed in kitchens and peeled unless a skin-on dish is desired such as wedges, baked whole tubers and 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 summarised and quantified through rating of the degree an attribute applies to the class.

Table 6 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 in cold water in a pan, heated till boiling for 15 to 30 min 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 min; 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 min 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	

Table 6 (continued)

Attribute	Operation	Description	Meal ingredient
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 min 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/crisps)	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

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 discolour 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 min. 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 boiling in hot water and takes about the same time. Tubers subjected to hot air are baked in the oven for 30 min 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 colouring and flavour development (Cerny 2008) takes place in the Maillard reaction, a non-enzymatic browning when heating carbohydrates with specific amino acids forms pigment. Also at high temperatures during frying, the reducing sugars glucose and fructose with the amino acid asparagine form acrylamide which is considered an unfavourable 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 done with a piping bag which is not readily available in 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 min on an electric stove (Korzeniowska-Ginter 2019) and baking in the oven for 45 min 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. Labour 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.

The number of classes of kitchen operations has been condensed to 18 in Table 7 and supplied with 9 attributes and valued.

The lowest average for all classes has the attribute water need. Only the class of washing operations (with a few of its instances, soaking, brushing by hand, washing machine) uses a considerable amount of water. In the food serve, abrasive peeling in a water-fed peeler uses water. 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 labour requirement with only boiling in water and microwaving taking the least labour. The opposite of labour intensity is convenience when the product is bought in a shop. This is well possible in developing markets but many products need to be transported and shelved, chilled or frozen so are not

Table 7 Heatmap of 18 classes of kitchen operations of potato with 9 attributes

High, much			Low, little
	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	

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
	x̄	3.8	1.9	3.4	3.3	4.2	3.3	4.0	3.7	2.6	

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 labour 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 all in need of energy, skills and equipment.

The dendrogram in Fig. 2 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, and 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.

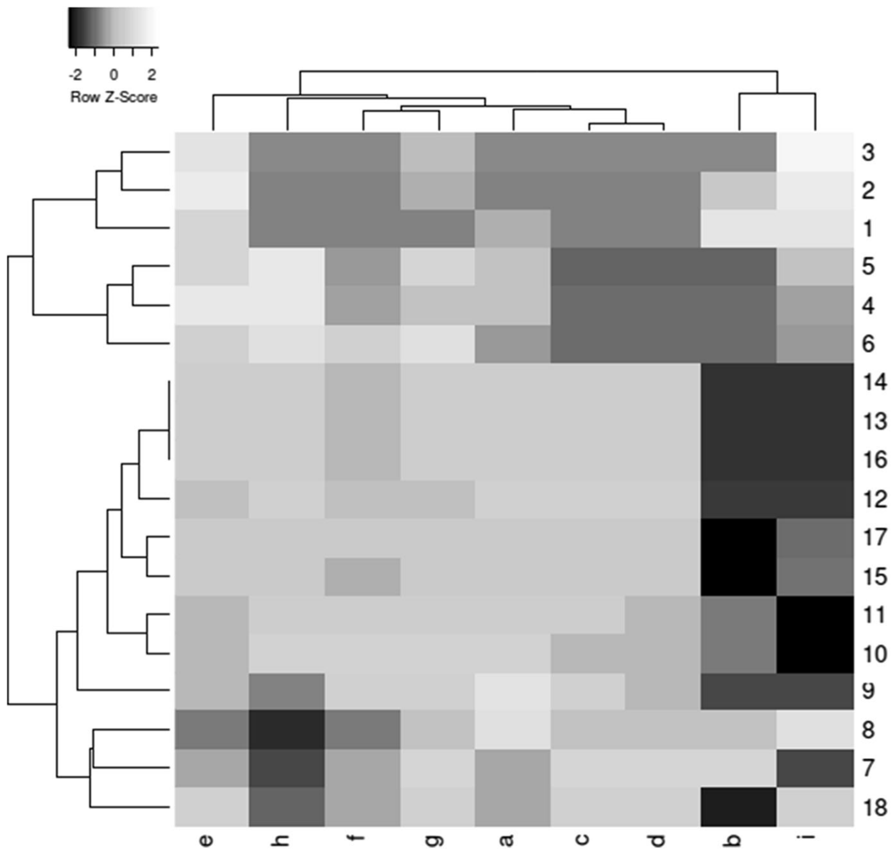

Fig. 2 Dendrogram of processes in kitchens (codes a–i and 1–18 in Table 7)

The attributes show two clusters. The rather distant twins, high water need and suitability for developing markets have some logic behind them: 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.

Cooks Making Dishes

The second aspect of the kitchen domain is the sphere around consumers that buy and use processed potato products and 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. Hashbrowns are made of julienned blanched tubers and French fries from par-boiled cut tubers frozen or chilled. Jacket potato (but for the topping) and gratins are complete dishes themselves 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 and guests. Classes of products are many, the next survey presents 200 products found in one supermarket on a particular day and the following 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 the cook to approach the original. Those surveys also demonstrate how ingredients such as minerals, vitamins and antioxidants increase or decrease during processing and how much time is saved in the kitchen if a product is bought rather than starting with fresh tubers. The subject of the domain cooks making dishes from products 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.

The major classes of dishes prepared from purchased products are listed in Table 8, with attributes of the products and of preparation. These attributes do not vary amongst 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-off 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 more fancy to eat in restaurants or with guests than where consumers have a wider array of tastes and preferences. In developing markets, especially when traditionally for the cook, often the lady of the house, time dedicated to cooking is more amply available, the disposal 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 among and within societies.

Table 8 Description of aspects of the domain cooking dishes from products

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
Sauce	Starch	Ambient	Paper, carton	Yes	Boil	No	Somehow
	Flour	Ambient					
Soup	Starch	Ambient					
	Dehydrated tuber	Ambient					
Mash	Flour	Ambient					A bit
	Granulate	Ambient					
Side dish	Par-boiled tuber (chilled, canned)	Chilled or canned	Plastic, CA*		Many***		Quite
Hash brown	Julienned and formed tuber	Chilled	Plastic CA	No	Fry		Quite
		Frozen	Plastic				
Croquettes, balls	Formed products	Frozen	Plastic				
French fries	Par-fried French fries	Chilled	Plastic, CA				
		Frozen	Plastic				
Pommes sautéed	Roasted tuber pieces	Chilled	Plastic, CA				
		Frozen	Plastic				
Jacket potato	Baked tuber	Frozen	Plastic		Bake		
Gratin	Gratin	Frozen	Tray		None		
Snacks	Chips	Ambient	Plastic, CA**			Yes	Not
	Stackable chips	Ambient	Carton tube				
	Expanded chips	Ambient	Plastic, CA**				
Drinks	Beer	Ambient					
	Vodka	Ambient					

*Controlled atmosphere (vacuum), **controlled atmosphere (nitrogen only). ***Baking, frying, cooking, microwaving, roasting, mashing, forming

The results of heatmapping the dishes made from potato products and their attributes are represented in Table 9. Of the products, the average of scores is lowest for soups (2.0) with the highest score for eating Potage Parmentier, potato soup, in a restaurant. Gratin has the highest average of scores (3.1) because of its fanciness and because 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.

The situation in less well-off markets varies (average of averages 2.5) from that in affluent societies as is made clear in Table 9, bottom (2.9), showing that more points of attention matter. Fried and baked products (snacks excepted) differ much in the two markets because cold chains and appliances often lack in developing countries. The averages of scores for 13 attributes are highest for fanciness (4.5), treating guests with an exotic dish and, obviously, the costs of food are 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.

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, cold chain, appliances) is one with low scores for the privileged.

Consumer Preferences

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 experienced 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 and small or large cities and old or young both directing their behaviour from traditional to innovative. They vary from low to high income and are increasingly influenced by health conscientiousness and less pandering to indulgence. Interest in price, product information and

Table 9 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 origin of the tubers also segregates the class of consumers in the various classes uninvolved, careless, conservative, rational and adventurous consumers.

Diverse types of consumers attach varying importance to the three aspects and their underlying characteristics. Amongst other, 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 plays a role with for instance hash brown having a place in a cooked breakfast not enjoyed by all cultural groups and certain flavours on chips have preference, such as paprika in Europe and barbeque in North America. Zarantonello and Schmitt (2010) and Deseret (2021) differentiate groups of consumers including holistic, inner-directed and utilitarian and Deseret (2021) enumerates eight groups, some of them do (principle oriented) or do not (achievers) coincide with the ones mentioned in Table 10. When it comes to segregating consumers into recognisable classes with comparable characteristics for, for instance, targeted new food product development, it is important to realise that the classification of a consumer in a particular group can vary with varying circumstances. Suppose a normally price-conscious consumer organises a festive dinner party, in that case, he may decide to buy more expensive products than he would normally buy.

Condensation of the preference domain (Table 10) produces 12 classes of consumers presented in Table 11 ranging from convenience seekers to culture-driven ones. Attributes in the heatmap in Table 11 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, buying baked tubers yields least convenience and the more sophisticated the product, the more time is saved if bought. Low-priced products are favoured and so are many products by different cultural groups. Pan-fried potatoes are popular in Germany, baked in the UK and expanded snacks are supplied with flavourings that target a variety of ethnicities and cultures.

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, 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 shows the closest association between seekers of information and worriers about the environment together with consumers concerned about their health. Consumers after taste and convenience have much in common and so

Table 10 Sub-domain Consumers, description of classes with attributes and their preferences and attitudes

Consumer class	Properties expressed in key words re preference and social situation	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-fulfilment, 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	Flavour is the main property of interest	
Health 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	Allrecepies 2021
Culture driven	Consumers with a targeted ethnic or cultural background preferring specific products occasionally at specific (festive times)	Ethnic foods 2021

Table 11 Twelve classes of consumers with 16 attributes, their degree to which they prefer the product

						Standard											
		Much preferred			a-p	Preference							Not much preferred				
		Consumer preference for dishes from products and snacks															
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
	Sum	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

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 amongst wedges and hash browns (fried formed shreds). Other twins are preferences for croquettes 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.

Discussion and Conclusions

The number of classes and attributes in this survey about the super-domain cooperation between growers, processors, cooks and consumers is given in Table 12. In the four-tier analysis, the domains are described and delimited and the classes and attributes listed in the formulation and the latter awarded a score from one to five. This was done for in total 75 classes and 65 attributes. Including two heatmaps for processors in a theoretical triangulation and also two heatmaps for the kitchen in an environmental triangulation, 1527 times a score was given.

Table 12 Overview of the five domains figuring in this survey

Domain	Classes	Nr	Example of class	Attributes	Nr	Example of attribute
Growers	Tubers	9	Tubers for chips	Requirements	11	Size
Processors	Products	23	French fries	Particularities	16	Storage temperature
Cooks	Operations	18	Peeling	Necessities	9	Energy
Kitchen	Dishes	13	Rösti	Description	13	Availability
Preferences	Consumers	12	Traditionalist	Preferred product	16	Liking chips
Total		75			65	

Insights Gained

In the "Introduction: Inception and Research Questions" section of this survey, research questions were asked about the ontology and description of the domain "on processing potato". Subsequently, after the ontological description of the domain and its elements, of tubers serving as raw material, of products manufactured classes of operations in kitchens, and finally their use by cooks, they were enumerated and supplied with attributes. Below, the newness of the findings per domain is put forward.

Nine classes of tubers are distinguished of which two are not intended 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. Chipping tubers need to be round and for making French fries tubers need to be oblong as illustration. The average of scores for potatoes destined for chip production is twice that of starch but no social consequence can be attached. The classes of tubers only have own attributes or specifications: 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 is possible and specifications 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.

Some products were made well before the tuber spread to Europe and the rest of the world in the sixteenth century, freeze dried chuño, flour and drinks. Industrial scale starch production started in the ninteenth century, and chips were introduced early twentieth century but a real boom of new products started in the second world war until some 10 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 are new and tasty products (snacks), convenience (time saving) and prolonging the storage period (frozen products) of the produce. Theoretical triangulation is 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 smaller and more 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.

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 operation in kitchens needs more water or energy than another, cooks have fewer opportunities than processors have to fine-tune operations. Of all operations, there are only two that require water, washing and boiling, and none of all the others; so, logically this attribute receives a low average of scores summarised 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.

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.

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.

The Four-Tier Analysis

The four-tier analysis described in the "Introduction: Inception and Research Questions" section 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 tables. In the quantification tables, both classes (plotted in rows) and attributes (plotted in columns) are refined and the attributes given weight, awarded a score, as to the degree they apply to a class. Transforming the data into a dendrogram (Fig. 2) results in the clustering of both classes and attributes. For the kitchen domain and the subdomain tubers, products and dishes, the approach is summarised and illustrated with a few key words for the right understanding in Table 13.

It suffices not to extensively describe a domain, but just hinting at its existence and its limits, while assuming that there are divisions and distinctions (classes) that can be assigned properties and characteristic (attributes). The subsequent tabling of the classes and their description in some logical order (from peeling to baking for instance, or 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 still is qualitative, although it offers a quick glance. When given values, it allows a quantitative evaluation of classes and attributes. 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 of which the value of attributes varies with the social position or with the environment. As a rule, attributes were given a high score irrespective of concerns. Then very convenient and requiring very much water both received a value 5. If however water use is a concern, it should receive a low score of 1. With this different question in mind, theorical triangulation, heat mapping and clustering were carried out in a reiteration (Table 7). 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, however, did and showed a more distinct grouping, less uniformity assists in distinguishing attributes one wants altered, into a desired direction. The average of scores also becomes more meaningful because a high average is indicative of a favourable attributes for a class or overall classes. Starch has the highest unconcerned score but when concerns are taken into consideration, it is chips. Other theoretical triangulations in the survey are looking at products with amongst other attributes of different products such as ranges of prices, variety and sizes that receive different appreciations (scores) from processors than from consumers. Giving values to attributes of cooking dishes in Nairobi or New York (an environmental triangulation, Table 9) changes both the hierarchy of classes and of 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 but any interested researcher in any domain at any time and any place can alter the composition of classes and attributes and values of the latter and data triangulation is a fact.

Table 13 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 market economies and resource use, complexities	Price, availability, complexity, esteem, fanciness, appliances
Clustering (dendrogram)	Tubers fried are in other group than tubers making starch and flour	Fried products and powdery product 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: class hierarchy unchanged but altered for attributes	Environmental triangulation reiteration from developing market perspective; cluster and attribute hierarchy change

Declarations

Competing Interests P C Struik is editor in chief of Potato Research.

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