Production yield analysis in food processing

Applications in the French-fries and the poultry-processing industries

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Abstract

Food processors face increasing demands to improve their raw material yield efficiency. To really understand the raw material yield efficiency of food processing, mass losses need to be divided in wanted (desired) and unwanted ones. The basic approach to increase the raw material yield efficiency is to minimise unwanted mass losses at source. Wasting raw materials should be avoided, because the largest proportion of the overall business costs is associated with the purchase of raw materials. This wasting will therefore put the company's profit under pressure. From a sustainability point of view, it is also important to transform raw materials efficiently into final products. There is an increasing interest to find appropriate measures to track the yield efficiency of food processes in order to guide organisational actions to reduce unwanted mass losses. Many unwanted mass losses are hidden and need to be explored to make the management fully aware of these losses and the corresponding economic impact. Poor practice, poor maintenance, outdated equipment and technologies must first be visualised before they can be corrected.

A new dimensionless number (called Yield Index) was developed to measure the true raw material yield efficiency of a transformation process. To measure the Yield Index, a food processor should measure the actual production yield and compare this with the maximum production yield. However, for many food processors the maximum production yield is unknown because of the lack of knowledge. With a systematic approach and considerable research effort it is possible to build a model that can predict the maximum production yield with respect to raw material parameters, additions and final product specifications. This model can then be used to pinpoint unwanted mass losses in the production process. The thesis describes in a comprehensive way the development of two models to estimate the maximum production yield of French-fries production and poultry-processing (transforming broilers chickens into meat parts). These models were used in practice, to pinpoint unwanted mass losses during processing and based on this knowledge, both processes were improved significantly. Based on these two practical case studies a general system approach was developed to implement production yield analysis (PYA) in other types of food processes.

It was found that often a significant lack of knowledge in the true efficiency of the production processes exists. A PYA makes it possible to calculate the true yield efficiency of the process. This information is needed to convince management about the necessity to reduce unwanted losses. Not only to improve economics but also to improve aspects of modern sustainable food processing.

Dit proefschrift draag ik op aan mijn vrouw Jacqueline en mijn kinderen Mart en Penny die mij tijdens de jaren van noeste arbeid uitzonderlijk goed hebben geholpen.

Voorwoord

Het was rond februari 2001 toen Ton Capelle mij vroeg te promoveren. Ton was destijds, behalve hoogleraar in Wageningen, eveneens directeur Onderzoek en Ontwikkeling van Cebeco. Aviko was in die tijd een dochterbedrijf van Cebeco, waardoor Ton en ik elkaar persoonlijk goed kenden. Ton was dan ook op de hoogte van de progressie die ik bij Aviko had geboekt met het structureel verbeteren van productierendementen, met name de theoretische diepgang intrigeerde hem. Gezien mijn jarenlange ervaring met dit onderwerp en mijn grote interesse in de wetenschappelijke basis van ontwikkelingen in de procestechnologie, zei ik dan ook al snel "ja" op vraag van Ton. In de eerste plaats wil ik dan ook Ton bedanken voor zijn initiatief en alles wat hij voor mij heeft gedaan.

Op zo'n vraag "ja" zeggen heeft nogal wat consequenties. Normaal komt een promovendus in dienst van de universiteit en kan "ongestoord en full time" werken aan de promotie. Bij mij was dat nogal anders. Ik heb als hoofd procestechnologie bij Aviko een drukke en verantwoordelijke baan en bovendien ook nog een gezin. Het was voor mij een inspiratiebron dat het verbeteren van productierendementen van groot maatschappelijk nut kan zijn. Dat motiveerde me sterk. U als lezer zult wellicht begrijpen dat het tropen jaren van noeste arbeid waren. Ook al moet ik zeggen dat we thuis alreeds vanaf den beginne een goed evenwicht vonden. Het hele gezin deed ook mee. De kinderen brachten me koffie op de studeerkamer en zorgden voor een goed evenwicht tussen werk en ontspanning. Mijn vrouw Jacqueline, typte één jaar lang elke dag 15 vellen met proefgegevens in de PC. Deze proefgegevens kwamen per fax aan vanuit de kippenslachterij van Plukon in Blokker. U wilt niet weten hoe hoog die stapel aan papieren in mijn studeerkamer is. Diep in mijn hart voel ik voldoening, jullie kwamen immers altijd op de eerste plaats. Jacqueline, Mart en Penny bedankt, jullie waren een enorme steun, elke huisvader kan daar trots op zijn. Het is dan ook daarom dat ik dit proefschrift aan jullie opdraag.

Aviko in zijn geheel, maar met name Martin Keijbets mijn baas en Jan Kelderman de adjunct directeur Productie, wil ik tevens bij deze in het heel bijzonder bedanken. Zij zagen mijn potentieel en hebben me dan ook de kans gegeven om mijn promotieonderzoek te beginnen. Jan heeft daar een grote rol in gespeeld. Martin heeft het nodige weekendwerk in dit proefschrift zitten, hem bood ik als eerste elk artikel aan ter controle. Tevens maakt hij onderdeel uit van de promotiecommissie, een betere deskundige op dit onderwerp is niet te vinden.

Dank ook aan de Plukon Royale groep. Peter Poortinga de CEO en Jaap Obdam de R&D-manager wilden direct meewerken aan het onderzoek. Met Michiel Klopstra, Sietse Kuiper en John Logeman heb ik bij Vleesch du Bois (onderdeel van Plukon) vele zinvolle discussies gehad. We hebben theorie en praktijk kunnen vereenzelvigen en een goed resultaat kunnen neerzetten. Ik wil special John Logeman bedanken, die alle slachtproeven met enorme precisie heeft uitgevoerd. Heren ook bedankt voor alles wat ik van jullie heb mogen leren, voorafgaande aan dit onderzoek at ik alleen kip nu weet ik er ook het fijne van. Het maakt mij na ervaringen in de zuivel en aardappelverwerkende industrie veel meer allround.

Reeds vanaf het begin heb ik de luxe gehad om te mogen werken met twee promotoren. Samenwerken met Ton Capelle en Hans Tramper was erg plezierig en ik moet zeggen dat ik twee promotoren een meerwaarde vind. Het vermogen van Hans tot het kritisch beoordelen van mijn manuscripten was van een enorme meerwaarde, een aantal van zijn tips heb ik me tegenwoordig eigen gemaakt en verkondig ik nu binnen mijn eigen groep. Wat te denken van "een verhaal moet logisch en niet chronologisch". Vandaar dat ik dit nawoord voorwoord heb genoemd! De discussies tussen Ton, Hans en mij waren altijd van een goede diepgang, we waren een echt team, hetgeen heeft geresulteerd in het proefschrift wat nu voor u ligt. Ton en Hans, bedankt voor het meedenken en kritisch beoordelen van mijn manuscripten, ik heb het nodige van jullie mogen leren.

Sandra Kroonenberg heeft de finale controle van mijn manuscripten gedaan, daar hadden Ton en Hans ook geen zeggenschap meer over. Sandra is een wereldreiziger, heeft zich menig buitenlandse taal eigen gemaakt en heeft een werkkring met veel affiniteit tot wetenschap. Sandra ik ken je al ruim 25 jaar, mag ik je hartelijk bedanken voor je inbreng en inzet. Het was veel weekendwerk voor je.

Veel experimenteel werk heb ik zelf gedaan maar ook veel niet. Collegae van de groep Procestechnologie van Aviko R&D ook hartelijk bedankt voor jullie inbreng. Gert Joling, Maaike Nahuis, Caspar Maan en tal van stagiaires hebben allemaal direct dan wel indirect een bijdrage geleverd aan dit onderzoek.

Ik hoop dat dit voorwoord voor menigeen niet het enige leesbare deel vormt van dit proefschrift. De rest is namelijk veel interessanter.

Derk

Contents

Publications of the author

All chapters of this thesis have been or are accepted to be published in well-known independent peer reviewed international scientific journals.

Part 1

Somsen, D., & Capelle, A. (2002). Introduction to production yield analysis - a new tool for improvement of raw material yield. *Trends in Food Science and Technology*, *13(4)*, 136-145.

This article was also published in Dutch: Somsen, D., & Capelle, A. (2003). Nieuw instrument voor verbetering grondstofrendement. *Voedingsmiddelen industrie, 3(4),* 35-44.

Part 2

Chapter 2
Somsen, D., Capelle, A., & Tramper, J. (2004). Manufacturing of par-fried French-fries. Part 1: Production yield as a function of number of tubers per kilogram. *Journal of Food Engineering, 61(2),* 191-198.

Chapter 3
Somsen, D., Capelle, A., & Tramper, J. (2004). Manufacturing of par-fried French-fries. Part 2: Modelling yield efficiency of peeling. *Journal of Food Engineering, 61(2),* 199-207.

Chapter 4
Somsen, D., Capelle, A., & Tramper, J. (2004). Manufacturing of par-fried French-fries. Part 3: A blueprint to predict the maximum production yield. *Journal of Food Engineering, 61(2),* 209-219.

Part 3

Somsen, D., Capelle, A., & Tramper, J. (2004). Production yield analysis in the poultry-processing industry. *Journal of Food Engineering. (in press).*

Part 4

Somsen, D., Capelle, A., & Tramper, J. (2004). Production yield analysis - a new systematic method for improvement of raw material yield. *Trends in Food Science and Technology. (in press).*

For this thesis the text of published or accepted articles was integrally adopted. Editorial changes were made for reasons of uniform presentation.

Reference should be made to the original article(s) as mentioned above.

Objectives and outline of the thesis

The conditions under which food processors are operating are becoming more and more complex. Production processes are extremely complex and contain so many important variables that it is hard to know if the transformation from raw material(s) into final product(s) is (are) carried out efficiently. The basic aim of the research study described in this thesis is therefore, to provide food processing companies a structured system approach for the optimisation of raw material yield based on predictive maximum yield efficiency models. For many food processes the true raw material yield efficiency is completely unknown. This lack of knowledge is a poor foundation for systematic yield improvements!

This thesis explores two different food processes and shows how the true yield efficiency can be calculated and significantly improves results based on a structured systematic approach. This approach is primarily directed to minimise unwanted mass losses at source.

There are some food processes in which the true yield efficiency can be calculated relative simply. These are transformation processes in which the maximum production yield is solely influenced by the chemical composition of the raw material. For a company that produces sugar from sugar beets for example, the maximum production yield can be easily calculated based on the average sugar content of the beets and the desired sugar content of the final product. For the dairy industry this is often the same situation. The maximum production yield of several dairy products can be calculated when the average protein, carbohydrates and fat content of the milk are known. The research reported in this thesis however, discusses more complex food processes that are currently very opaque from a raw material yield perspective.

In the first part of the thesis the general introduction is given and all mass losses which may arise during food processing are categorised and extensively discussed. Detailed knowledge of all of these mass losses is a first key condition to realise a thorough understanding of the transformation process. In the existing literature no references were found which provided an overall overview of these mass losses. Therefore an overview is given in chapter 1. In paragraph 1.4 the generic yield model is developed. However to measure the true raw material yield efficiency (as expressed by the Yield Index [Eq. (1.10)]) some mathematical functions of this generic model must be solved for each transformation process individually. In part 2 and 3 of this thesis two totally different food processes are investigated and the corresponding yield models are developed. Part 2 will explain the transformation of potatoes into par-fried French-fries en part 3 explains the transformation of broiler chickens into meat parts. The major arguments to select these two processes are:

- Both are complicated food processes, meaning that the maximum yield cannot be simply estimated based on their chemical composition.
- Both processes are executed world-wide at a large scale of operation.
- The processes are completely different.

In part 4 a general system approach is given to execute a PYA in a food processing company based on the experiences that were gathered in part 2 and 3 of this research. Additionally the results of both projects (French-fries and poultry-processing) are summarised and the general discussion and conclusions are given.

PART 1

General introduction

CHAPTER 1

General introduction

Abstract
Mass losses during processing will result in a decrease of production yield. Losses can be separated in wanted and unwanted losses. Wanted losses are necessary to transform raw material into desired final product(s). Unwanted losses will result in additional raw material usage and generate additional waste and will therefore put the company's profit under pressure. The paper categorises mass losses that effect production yield and describes a generic model that can be used to calculate production efficiency. Increasing production efficiency is the basis for improvement and cost-cutting.

Nomenclature

A	*Addition (w/w %)*
Crm	*Cost of additional raw material ($)*
MA	*Additions (kg)*
MA_max	*Additions at optimum process {YI=1} (kg)*
Mfp	*Mass of final product (kg)*
Mfp_max	*Maximum possible amount of final product {YI=1} (kg)*
ML	*Overall mass loss (kg)*
Mrec	*Mass of received raw material including tare (kg)*
Mrm	*Mass of clean raw material (kg)*
MT	*Tare, contamination and foreign bodies (kg)*
Prm	*Price of the raw material ($ kg^{-1})*
PY	*Production yield (w/w %)*
PY_max	*Maximum possible production yield (w/w %)*
RM	*Raw material variables that influence production yield*
TPR	*Variables of the current transformation process that influence production yield*
QS	*Specifications of final product that influence production yield*
R	*Direct reused component (w/w %)*
YI	*Yield Index (-)*
v	*Number of raw material parameters that influence production yield*
w	*Number of added ingredients*
x	*Number of reused components*
y	*Number of process parameters that influence production yield*
z	*Number of specifications that influence production yield*

Subscripts:

Wanted	*Indicates a wanted or unavoidable mass loss*
Unwanted	*Indicates an unwanted mass loss*

1.1. Introduction

A food processing plant consists of a series of unit operations, each of which has a specific function, such as:

- Washing and cleaning
- Removal of outer part
- Size reduction and enlargement
- Sorting and separation
- Mixing
- Smoking
- Drying
- Heat treatment
- Fermentation
- Transportation
- Weighing and Packaging

Each of these unit operations is designed using physical and chemical principles. Food industry has developed out of an artisanal activity. Historically, this industry has not designed its processes in an engineering sense, mainly because food processing started once in the kitchen and current processes are scaled up from that. Secondly, food industry has to deal with complex raw materials. Quality is often not constant and will change from season to season. Another obstacle is that many quality parameters are very hard to measure, particularly real time and some important characteristics are only measurable in a subjective way, like: crispiness, texture, taste and smell. Other quality parameters such as moisture, fat, protein and sugar content are objective characteristics but in practice it is often hard to measure them rapidly and reliable. It is therefore hard to know exactly if the raw material is transformed into the most efficient way into end products.

In the past processes were carried out batch wise at low capacity, highly labour intensive and many industries worked on a seasonal basis. Nowadays, most processes are continuous at high capacity and plants receive raw material all year round. This makes processing much more efficient than a few decades ago. But still there is room for improvement by implementing smart monitoring techniques. Especially looking more closely into the basics of the transformation process (raw material into end product) will enable a lot of improvement.

The costs of raw material are the major part of the overall business costs. The overall business costs are defined as the total of all running and capital costs including marketing, sales and overhead costs. The figures in Table 1.1 present some typical examples of raw material costs. They are based on interviews with specialists of several food processing companies in The Netherlands and on literature research.

Production yield can be seen as a transformation coefficient that can be calculated out of produced quantity of end product and amount of basic raw material needed [Eq. 1.1]. Other material input (ingredients and other additions) and other output (waste, animal feed etc.) are not included. For processes with multiple end products or valuable co-products the production yield per type of product should be calculated. Overall production yield can be calculated by summation of individual yield values.

In practice it is often possible to calculate the production yield of the factory, because it is a simple and straightforward factor to calculate. Table 1.2 presents production yield figures for several products.

Table 1.1. Raw material costs in percentage of overall business costs for several types of factories in the food processing and drink industry

Type of industry	Raw material costs (%)	Remarks	Reference
Beer	10-11%	Raw material cost represents the costs of malted barley and hop. 10.5-12% if costs of water and yeast are also included. 26-30% for all raw materials including packaging costs.	De Groen and Termijtelen, 2001
Cheese	50-80%	Depending on type of cheese	Muller and Wolfpassing, 1992
Cheese	80-90%	Production of Gouda and Edam cheese. Business costs are exclusive selling, marketing and overhead costs.	Menting, 2001
Dairy	52%	Overall milk costs of Campina.	Campina Melkunie, 2000
French-fries	30-45%	Depending on crop, market prices and scale of operation.	Aviko information
Poultry	68-70%	Poultry-slaughtering plant that produces deep frozen products (wings, drumsticks, breast meat etc.).	Poortinga, 2001
Fructose	45-55%	Production of fructose from chicory roots.	Poiesz and Van Nispen, 2001
Sugar	85-95%	Production of sugar from sugar beets.	Poiesz and Van Nispen, 2001

$$PY = 100Mfp / Mrm \qquad (1.1)$$

Because raw material costs are high in comparison to other costs, a logical question is: what is the maximum possible production yield with respect to the raw material quality and the end product specifications? This question is often hard to answer and needs further research and development of a computer model. Most processors do not have a computer model to predict the maximum possible production yield as appeared from the interviews.

In this paper we will introduce the Yield Index of a process. It is a dimensionless figure to monitor the efficiency of the transformation process [Eq. 1.2]. It can be used to predict the amount of unwanted mass loss and the equivalent of raw material that is needed additionally.

$$YI = PY / PY\_max \qquad (1.2)$$

Example: suppose a factory transforms 80 tons/h of potatoes into deep-frozen French-fries during 7000 h a year. The raw material costs are \$0.08/kg and the average production yield is 50%. Research showed that 60% yield is maximum possible. That means that the Yield Index is 50/60=0.83. This indicates that 17% additional raw material is needed, which cost in this example: 80,000*7000*(1-0.83)*0.08 = \$ 7,616,000.- per year!

Table 1.2. Typical production yield values for several products

Type of industry	Raw material	Final product	Production yield(%)	Remarks	Reference
Beer	Raw barley	Grolsch pilsner	About 1280%	Is above 100% because of additions (water, hop and yeast)	De Groen and Termijtelen, 2001
Dairy	Cow's milk	Gouda cheese	About 10%		Menting, 2001
French-fries	Potatoes	Deep frozen fries	45-65%	Strongly depending on variety, raw material quality and final product specifications	Aviko information
Poultry	Broiler chicken	Chilled carcass	68-72%	Depending on variety, size breed, and equipment adjustments	Klopstra, 2001
Sugar	Chicory roots	Fructose syrup	20-22%	Fructose syrup of 76% solids. Average inuline content of roots is 16%.	Poiesz and Van Nispen, 2001
Sugar	Sugar beets	Sugar	14-15%	Average sugar content of the beets is 16%. Final product >99.9% sugar	Poiesz and Van Nispen, 2001

The advantage of the Yield Index is that it is independent of the quality of raw material used, because the Yield Index is a dimensionless figure. If the quality of the raw material is better, the actual yield will be higher but also the maximum possible yield.

The performance of the production process often is not visible enough in the factory and difficult to measure on a unit operation basis. Operators and shift managers are too busy with solving their daily troubles and maintaining the line capacity. To solve this problem the efficiency of the process must be made as visible as possible for the managers in the factory to urge them to smarter actions, illustrated by the statement "if you cannot measure it, you cannot manage it".

To enable fact-based management, organisations need to know how they are doing. They need a suitable indicator to visualise the efficiency of the transformation process. They need to know the various mass losses and need a method to make a good distinction between wanted (or unavoidable) and unwanted losses. This will be discussed in this paper.

1.2. Methodology

Interviewed companies were selected based on following criteria:

- Company must be a major player in the food industry, international oriented, with a turn over of at least $ 100,000,000 annually.
- Company must have several production plants.
- Willingness to share specific production yield information with a confidential nature.
- Type of industry: dairy, meat, vegetables or beverage.

The following companies were selected: Aviko B.V. (French-fries industry), Campina B.V. and Frico Cheese (both dairy-industry), Plukon Royale Group B.V. (poulty-industry), Royal Cosun (sugar-industry) and Royal Grolsch N.V. (beverage-industry).

A comprehensive questionnaire was sent to each company. Evaluation of the answers was done orally at company location. All information presented in this paper was reviewed by all interviewees.

1.3. Overview of factors that influence production yield

A general overview is given about the factors that influence production yield. Examples are given for each of these factors in different sectors of the food and drink industry.

1.3.1. Raw material

Raw material will influence the production yield as shown in Table 1.3. The basic raw materials for the food industry can be separated into two categories:

- Solid materials such as animals, eggs, nuts, cereals, vegetables, fruits etc.
- Liquids such as milk and water.

Solid materials may differ in shape, size, structure, composition, defects etc., which will influence the production yield. In liquids the composition is the key factor. Diseases and infections of the raw material will also effect the production yield (Klopstra, 2001; Lankveld, 2001; Menting, 2001; Poiesz & Van Nispen, 2001).

1.3.2. Transport and storage losses prior to processing

During loading, transport from the supplier to the factory and during storage at the factory unwanted losses can occur due to climatic circumstances (frost, rainfall etc.), damages, biological reactions and time.

Table 1.3. Raw material parameters that influence production yield

Raw material	Final product	Parameters	Reference
Potato	French-fries	Dry matter content, tuber length, shape, defect load, average diameter of the cells, peelability and reducing sugar content	Aviko
Milk	Cheese	Fat- and protein content	Lankveld, 2001; Menting, 2001
Broiler chicken	Meat parts (wing, leg, breast)	Live weight, uniform flock size, weight of DOA's (dead on arrival), weight of condemned carcasses and parts, weight of intestines and giblets, high meat percentage (wing, legs and breast) and empty intestines	Klopstra, 2001
Chicory	Fructose	Inulin content, size and shape and the firmness of the roots	Poiesz and Van Nispen, 2001
Malt	Beer	Extract content of the malt, size of the granules and protein content	De Groen and Termijtelen, 2001

Examples:
- French-fries: impact forces during handling and pressure during storage can lead to tissue discoloration (Molema, 1999), which will lead to additional sorting loss later on in the process. This loss can amount up to 10%.
- Dairy: during weekends the milk is buffered for 2-3 days at the factory. Because of this delay, the yield of the cheese production is about 0.2% (absolute) lower than normal (Menting, 2001).
- Poultry: weight loss prior to slaughtering results in yield loss of all meat parts (Moran & Bilgili, 1995). The weight loss ranges from 0.06-0.51%/h of initial weight (Veerkamp, 1986).
- Sugar: during 6 weeks storage of the roots at factory location 10-20% of the initial inulin content is lost (Poiesz & Van Nispen, 2001).
- Beer: transport from silo to silo and from silo to the production line can damage the malt and can result in major yield drops (De Groen & Termijtelen, 2001).

1.3.3. Tare, contaminants and foreign bodies
Other materials than raw material itself can be part of the delivery and can influence the production yield negatively. The percentage of tare that is received must be measured, because more tare means less raw material. Most common is a no-claim bonus system to correct for tare received.

Examples:
- French-fries: sand, clay, stones, wood, foliage, metals and other foreign materials are to a certain extent always part of the potato delivery. The amount of tare can differ considerably, but is mostly between 0.1 and 1.5%. Stones, wood particles and foliage may damage or block the cutting system, which results in additional unwanted cutting loss and more broken strips.
- Dairy: occasionally milk can be contaminated with antibiotics, this milk is not suitable for cheese production. The complete production batch can be lost if contaminated milk is used. About 0.01% of the milk batches that arrive at the factory is contaminated with antibiotics (Menting, 2001).
- Poultry: faeces can be part of the delivery (Klopstra, 2001).
- Sugar: about 17% of the delivery is tare (Poiesz & Van Nispen, 2001).

1.3.4. Surface losses
Many raw materials contain a surface (peel, skin, feathers, rind, shell, bran of cereals etc.) that must be removed during processing. The removal of this surface is essential. The equipment used for surface removal usually removes also a part of good material, which will create unwanted mass loss.

Examples:
- French-fries: the peel loss is about 5-20% of the initial tuber weight.
- Poultry: approximately 6.5% loss occurs during defeathering (Dryer, 1987).

1.3.5. Internal losses
Product own components that are inside the raw material itself and are not suitable for human consumption (or cannot be a part of the end product) must be removed. A stone of a cherry can be seen as an example. The process equipment for these operations removes mostly also a

certain part of good material, which will create unwanted mass loss.

Example:
- Poultry: the blood loss during processing is about 4% of the live weight (Dryer, 1987).

1.3.6. Losses during size reduction and enlargement
During size reduction (cutting, breaking, crushing, trimming, milling, grinding, shredding, homogenisation, expression etc.) and size enlargement (agglomeration, granulation, flocculation etc.) wanted and unwanted mass losses occur which will create an additional drop in yield.

Examples:
- In the French-fries industry peeled potatoes are cut into strips by a water knife system (Somsen, 2001). During cutting, cell tissue adjacent to the knife blades is damaged and cell content is completely lost. This loss varies between 2 and 12% depending on the cut size, cutting velocity, knife assembly, knife fouling, wear out of the knives and the tissue characteristics of the potatoes (based on incoming potatoes into the cutting system).
- Dairy: milk is usually homogenised for cheese manufacturing, which increases the yield of almost all cheese varieties (Lucey & Kelly, 1994). This example indicates that size reduction can also improve production yield.
- Poultry: the whole transformation process is based on cutting techniques. The individual yield of each type of end product (wing, leg, breast etc.) depends on type of equipment used, maintenance, process settings and the human factor (Klopstra, 2001).
- Sugar: during processing of chicory roots the tail of the roots can break off (especially in the washing drum) and can create a drop in yield up to 2%. During cutting of the roots into small strips (about 3 by 3 mm), dull and foul knives can create an additional yield drop (Poiesz & Van Nispen, 2001).
- Beer: malt is milled with roll crushers to produce a coarse powder called “grist”. The milling process influences the production yield. Wrong roll settings can lead up to 5% drop in extract recovery (De Groen & Termijtelen, 2001).

1.3.7. Losses during separation and sorting operations
Separation and sorting operations achieve their objective by the creation of two or more coexisting zones. These zones can be separated due to differences in: shape, size, density, weight, structure, solubility, volatility, colour, magnetism, electrical conductivity, ionic charge, conductivity, pressure, mobility, concentration or surface tension. Table 1.4 represents the most important unit operations for separation and sorting processes that are commonly available in food processing industry (Mostly from Mulder, 1997; Perry & Green, 1988).

During separation and sorting processes wanted and unwanted losses will occur. Unwanted losses will influence the Yield Index negatively. Because water and diffusion losses are so common in food processing they will be discussed separately.

Examples:
- French-fries: in practice, unwanted sorting losses of 1-10% of the initial amount of potatoes are possible.
- Dairy: the milk is first centrifuged and standardised at the correct fat level before it is actually used for cheese-making. During this operation the centrifuge is frequently flushed

Table 1.4. Separation and sorting operations used in food processing

Principle of Separation	Typical unit operations
Shape	Manual sorting, computerised optical sorting
Size	Manual sorting, sieve grading, roller sorter, filtration
Density	Cyclone, centrifuge, brine bath, sedimentation, air classifiers, de-stoner
Weight	Check weigher, egg sorter
Structure	Manual sorting, computerised optical sorting (X-ray and laser)
Solubility	Extraction, crystallisation, absorption, stripping, freeze concentration
Volatility (boiling point)	Distillation, evaporation, sublimation
Colour	Manual sorting, computerised optical sorting,
Magnetism and electrostatic	Magnetic separators
Electrical conductivity	Electrostatic separation, metal detector
Ionic charge, chemical bonds and adhesion	Electrophoresis, di-electrophoresis, ion exchangers, adsorption
Pressure	Reverse osmosis
Mobility of molecules	Dialysis
Concentration	Diffusion
Surface tension, wettability	Flotation
Combined	Ultrafiltration is based on pressure, molecular size and shape Leaching is based on solubility, size and concentration Electrodialysis is based on charges of species and size

with a water shot. The loss caused by this action (about 0.1%) is used as animal feed (Menting, 2001).

- Sugar: ion exchangers are used during the production process from chicory roots to fructose. Because the ion exchangers must be regenerated after a certain running time this results in 1.1% loss of the initial amount of inulin (Poiesz & Van Nispen, 2001).
- Beer: after storage and post-fermentation the beer is filtered (post beer filtration). During this filtration step 1.3% of the end product is lost (De Groen & Termijtelen, 2001).

1.3.8. Addition of water, fat, ingredients, coatings, food additives and processing aids

In most food processing operations other components besides the basic raw material are also used. These components have functions to improve the overall appearance, taste, smell, colour, structure, microbiological or chemical stability, convenience, nutritional value or increase variety and add value to the basic product. These components can be added directly or indirectly to the main product and will increase obviously the production yield. The Yield Index is only affected if ineffective dosage and spillage occur, which will result in unwanted and expensive mass losses.

Adding water can be done directly (injecting, mixing, glazing etc.) or indirectly (washing, transport in water, cooling in water etc.).

Examples:
- French-fries: the fat uptake during frying is about 3-7% of the amount of end product.
- In the dairy industry the Gouda cheeses are coated with a plasticoat. This is done during the several stages of the ripening process. This results in 1% mass increment, but during storage 25-50% of the added plasticoat is lost due to evaporation (Lucey & Kelly, 1994).
- Beer: barley is the basic raw material for beer making, however hop, yeast and large amounts of water must be added to make the final product (De Groen & Termijtelen, 2001).

1.3.9. Losses due to chemical and microbiological reactions
Several wanted and unwanted chemical or microbiological reactions can influence the production yield.

Examples:
- Severe heat treatment of the milk used for cheese-making denatures whey proteins, which complexes with K-casein and thus are incorporated into curd. This will increase the yield (Lucey & Kelly, 1994).
- During the fermentation process of the beer production 2 kg pure extract is converted into 1 kg ethanol and 1 kg carbon dioxide. This results in a yield drop of about 2.1% (relative on end product) due to a partly loss of the carbon dioxide and otherwise the removal of the yeast during the filtration stage (De Groen & Termijtelen, 2001).

1.3.10. Transport losses during processing
In all modern production lines the product is transported from one unit operation to the other. This can be done by several techniques such as: belt conveyors, pneumatic conveyors, free fall, transport vibrators, elevators, screws, pipe systems etc. In many machines the product is also internally distributed, for instance a belt in an air dryer or freezer. During transport several types of forces and stresses are applied on the product which may result in unwanted additional losses. Spillage and leakage of product or additions will influence the yield also negatively.

Examples:
- French-fries easily break. Each strip that breaks will result in additional losses (length sorters, additional fouling and quality losses). Depending on cut size, length distribution and firmness 1-10% of the strips will break.
- Cheese: about 1-1.5% of all cheeses produced contain damages and are used for co-products (Menting, 2001).

1.3.11. Moisture losses
Moisture is one of the main ingredients of all basic raw materials (Fisher & Bender, 1979). There are many unit operations in food processing industry that remove water from the product. Operations like drying, frying, baking, roasting and membrane concentration are well known. Moisture losses can be wanted or unwanted. Moisture losses are often of essential

importance for instance to extend shelf life or to reach customer specifications or to get the typical product characteristics like crispiness, texture, colour, smell and taste.

Examples:
- French-fries: about 30-45% of the initial amount of water is evaporated.
- Dairy: the mass loss during cheese ripening is about 0.1-0.2% of its weight per day (Lucey & Kelly, 1994).
- Beer: during the boiling process of wort about 10% mass loss occurs due to water evaporation (De Groen & Termijtelen, 2001).

1.3.12. Diffusion losses
In many food processing operations soluble substances in the product will diffuse into the surrounding liquid. The tissue (membrane) of the product itself often hinders diffusion. The direction of mass transport can also be in the opposite direction. In that case the concentration of the substances in the surrounding liquid is higher than in the product. The diffusion of substances in food processing operations can be wanted or unwanted.

Examples:
- During the production of French-fries the raw potato strips are blanched in hot water. The loss of reducing sugars is wanted, but the loss of other nutrients like ascorbic acid is unwanted. Depending on cut size, temperature, water refreshment rate and residence time unwanted losses of 0.05-2.5% from the initial amount of raw material are possible.
- Gouda cheese loses about 3-4% of its weight during brining (Lucey & Kelly, 1994).

1.3.13. Losses during packaging
Packaging is an important part of all food processing operations. Accurate filling is very important to ensure compliance with fill-weight legislation and to prevent overfilling. Overfilling is unwanted and can be seen as a "give-a-way-effect" and will result in a decrease of production yield. Most of the processors measure the mass of end products as the number of packed items times the target weight.

Examples:
- French-fries: the packaging loss due to overfill is about 0.1-0.25% (of the final product).
- Beer: the packaging loss is approximately 2% (of the final product). This can be divided in 1% lost during filling of the bottles (spillage) and 1% lost due to over-fill (De Groen & Termijtelen, 2001).

1.3.14. Quality losses
The purpose of process and quality control is to reduce the variability in final products so that legislative requirements and consumer expectations of product quality and safety are met. Quality losses are unwanted and can be classified in:
- Losses due to sampling.
- Reject of product that is not according to the specifications (outside the control limits)
- Product that is within specification but not exactly on target.
- Product that is within specification but is wrongfully rejected (because of incorrect sampling, analysis errors, misjudgement etc.).
- Losses due to incorrect specifications.
- Product that used to be within specifications but is no longer (storage problems, out of shelf life etc.).

Examples:

- If moisture content of French-fries is one percent under specification this will cost 1.5-2.5% production yield.
- Cheese: about 0.15% of the end product must be rejected due to moulding during ripening in the storage house. These rejected products are used for co-products (Menting, 2001).
- To analyse the moisture and fat content of cheese a sector is cut out. This is a destructive way of sampling (Lankveld, 2001).

1.3.15. Reuse of products

During the transformation process from raw material into final product several losses will occur. Part(s) of the "lost" and or rejected materials (wanted and unwanted) are suitable for reuse. The reuse of products can lead directly or indirectly to an increase in the production yield. Directly means that the reused product is added back to the same production line where it comes from. Indirectly means that it is used for other production processes. The production yield is only influenced by direct reuse, because it reduces the overall mass losses of that particular production process. Indirect reuse influences the production yield of other processes and will increase the overall production yield of a company.

Examples:

- French-fries: the reject of the sorting processes is used to make co-products like potato flakes and formed potato specialities. This reuse increases the overall production yield by approximately 5%.
- The dairy industry made an enormous progress in the last decades. The whole industry functions like a refinery. Due to the refinery type of operations in the dairy industry the overall recovery of initial dry matter is 99.7% (Lankveld, 2001).

1.3.16. Losses during disturbances (starting up, changeovers, finishing production, malfunctions and others)

Modern production lines function only effectively during steady state conditions. During starting up, product changeovers, finishing, experiments, malfunctions and other disturbances additional unwanted losses occur.

Lines with a high capacity have many advantages but also one big disadvantage. The bigger the production line is the higher the losses are during unsteady conditions.

Examples:

- French-fries: about 0.1-0.50% mass loss (based on raw material) occurs due to all types of disturbances.
- In the beer-industry approximately 1% of the final product is lost due to unsteady conditions (De Groen & Termijtelen, 2001).

1.3.17. Fouling and cleaning losses

During operation, the inner surface of the food plant gradually becomes covered with a solid fouling deposit. Fouling is common in the food processing industry and is mainly caused by the thermal instability of food material. Deposition is most rapid in heating equipment, but can occur in all places.

It is necessary to clean process plants regularly. Firstly because of hygienic reasons to ensure food safety and secondly to keep the performance of the process at an acceptable level. Fouling, for instance, restricts heat and mass transfer.

Fouling can influence the production yield negatively in two ways:
- Directly, the deposit is the mass loss.
- Indirectly, because of non-optimum performance (ineffective mass transfer due to fouling).

During cleaning, additional unwanted losses will occur, which negatively influence the yield. In the first place because the production line (or part of it) has to be stopped, cleaned and started again (see paragraph 1.3.16). During cleaning not only the deposit has to be removed but also good product material that was left behind.

Examples:
- French-fries: losses due to fouling are 0.01-0.05% (based on raw material).
- Dairy: in most of the factories that produce consumption milk products, the production runs are 8 h long, after which Cleaning In Place of the equipment is necessary. In the newest factory of Campina in Heilbronn (Germany) production runs of 72 h are possible (Lankveld, 2001).

1.3.18. Losses due to malversations

Theft of raw materials, ingredients and end products will lead to an additional unwanted mass loss. How serious these losses are, is unknown.

1.4. General production yield model

The production yield is a function of:

$$PY = f\left(RM[1..v], A[1..w], R[1..x], TPR[1..y], QS[1..z]\right) \quad (1.3)$$

The maximum possible production yield is a function of:

$$PY\_max = f\left(RM[1..v], A[1..w], QS[1..z]\right) \quad (1.4)$$

The mass of pure raw material is equal to:

$$Mrm = Mrec - MT \quad (1.5)$$

Based on the overall mass balance:

$$Mfp = Mrec - MT - ML + MA \quad (1.6)$$

or

$$Mfp = Mrm - ML + MA \quad (1.7)$$

The overall mass loss is equal to:

$$ML = ML_{wanted} + ML_{unwanted} \quad (1.8)$$

The maximum amount of final product is reached when only wanted losses occur. That means that all of the unit operations work at 100% recovery and there is no spillage and leakage, no fouling, no quality losses, no packaging losses etc.

$$Mfp\_max = Mrm - ML_{wanted} + MA\_max \qquad (1.9)$$

The raw material efficiency of the production process can be described with the Yield Index:

$$YI = Mfp / Mfp\_max \qquad (1.10)$$

The overall unwanted mass loss is equal to:

$$ML_{unwanted} = (1 - YI)Mfp\_max + MA - MA\_max \qquad (1.11)$$

or

$$ML_{unwanted} = 0.01(1 - YI) * PY\_max * (Mrec - MT) + MA - MA\_max \qquad (1.12)$$

Because unwanted mass losses occur, additional raw material is needed to make the desired amount of final product. The amount of additional raw material needed is equal to:

$$Mrm_{unwanted} = Mrm(1 - YI) \qquad (1.13)$$

Substituting Eq. 1.1 into 1.13 gives:

$$Mrm_{unwanted} = 100Mfp(1 - YI) / PY \qquad (1.14)$$

The additional costs of the raw material are:

$$Crm_{unwanted} = Mrm_{unwanted} * Prm \qquad (1.15)$$

1.5. Problem definition and objectives for future work

There are indications throughout industry that products may be produced in a more efficient way than they currently are produced. Exact figures are not known, but the following may be assumed:

- Many food companies have insufficient information about their quality losses and insufficient knowledge about their process (De Groote, 2001).
- According to Dijkgraaf (2001) only 10% of industrial companies in The Netherlands are using a balanced scorecard and a considerable number of companies do not use any production performance indicators in their management reports.
- Fifteen percent of industrial plants claim to be using advanced maintenance strategies, but only 5% really pursue their policy. Continuous process plants, mainly in the petrochemical industries, are leading the way (Morris, 1999).
- Waste minimisation due to raw material savings offers the largest potential to achieve financial benefits (ETBPP, 1999; Hyde, Henningsson, Smith, & Smith, 2000).
- There is a large potential for waste minimisation in the food and drink industry. In the UK's food and drink industry £21 million/year turned out to be saved by more effective

waste management (Corcoran, 1997).

- Around 25% of companies in the food and retailing sector have been found to operate waste minimisation programmes (Bates & Phillips, 1999).
- A waste minimisation project can reduce waste by 20-40% in six months and lay the foundation for continuous improvement in the utilisation of materials (Dunstone & Cefaratti, 1995).
- The quantity of waste generated in the food industry vary widely and could represent almost 50% of the weight of the original raw materials (Zaror, 1992).
- The true costs of waste can be as high as 10% of the business turnover. Reducing waste means less use of raw materials (Corcoran, 1997).

Henningsson, Smith, and Hyde (2001) reported recently about a study in which waste minimisation lead to great cost saving. The majority of the achieved savings were due to raw material savings. Changes in technology brought significant savings with a fairly low payback time.

The objective of the food industry should be to produce their products according to sustainable lines, not spoiling nature's resources. Also from an economical point of view it is essential to produce efficiently. Literature (see references above) made clear that many serious attempts to reduce waste have led to substantial raw material savings. Literature pointed out also that many companies have insufficient information about their process. We suggest a method that is primarily looking to the efficiency of the transformation process, in which visualising plays an essential role. In our opinion it is possible to improve raw material efficiency when management has correct figures to benchmark yield performance continuously. This can be achieved by solving Eq. 1.4 for each production process and measuring the actual production yield. Enabling fact-based management is the way to improve the current processes.

In this thesis a method called PYA (Production Yield Analysis) will be discussed. The PYA-method can be seen as a stepwise procedure to guide companies through a visualising and increasing awareness stage, showing them the yield potential of the transformation process. Development of this method was started at Aviko in the early nineties by the author of this thesis, which resulted in an enormous and continuos improvement. Two practical cases will be reported, to explain how to develop a model predicting the maximum possible production yield.

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PART 2

Yield modelling of par-fried French-fries production

CHAPTER 2

Production yield as a function of number of tubers per kilogram

Abstract
Mass losses during peeling and size sorting of cut strips in French-fries production are heavily influenced by potato size and shape. In this study the number of tubers per kilogram (N) is used as a raw material parameter to estimate the average principal dimensions, volume, surface area and specific surface area of potato tubers. A method called "numerical shell" was developed to estimate the surface area of ellipsoid bodies. This method can be used for other three-dimensional objects as well when the analytical surface area equation is not applicable. The study is focused on *Solanum tuberosum* L. cv.: Agria, Asterix and Bintje.

The paper outlines also the relationship between production yield and number of tubers per kilogram. It was shown that the peel losses and specific surface area increase proportional by $N^{1/3}$. Mass losses due to sliver removal increase linearly proportional with N.

Nomenclature

A	*Surface area (m²)*
D	*Thickness of outer shell removed during peeling (m)*
d	*Characteristic dimension (m)*
H	*Tuber height (m)*
k	*Geometrical volume factor (-)*
L	*Tuber length (m)*
M	*Mass (kg)*
Map	*Mass of peeled potatoes (kg)*
Mas	*Mass of raw sorted strips (kg)*
Mfp	*Mass of final product (kg)*
Mn	*Mass of nubbins (kg)*
Mrm	*Mass of raw material (kg)*
Ms	*Mass of slivers (kg)*
Muw	*Mass of material weight under water (kg)*
N	*Number of tubers per kilogram (kg^{-1})*
NL	*Nubbin loss (w/w %)*
SE	*Standard error*
SG	*Specific gravity ($kg\ m^{-3}$)*
SL	*Sliver loss (w/w %)*
SS	*Specific surface area ($m^2\ m^{-3}$)*
PL	*Peel loss (w/w %)*
PY	*Final production yield (w/w %)*
PYrs	*Yield of raw sorted strips (w/w %)*
V	*Tuber volume (m^3)*
Vε	*Volume of inner object (m^3)*
W	*Tuber width (m)*
UWW	*Under-water-weight (g)*
ε	*Constant in numerical shell method (m)*
ρ_w	*Density of water ($kg\ m^{-3}$)*

2.1. Introduction

Size and shape of potato tubers are of great importance for the manufacturing of French-fries. Mainly during peeling and size sorting of cut strips substantial mass losses occur, which are directly related to the size and shape of the raw material. During peeling the skin is removed and during size sorting, undesired potato strips, such as slivers (too thin strips) and nubbins (too short strips) are removed. In general smaller potatoes will give higher losses during peeling and sorting than bigger potatoes (Smith & Huxsoll, 1987; Lisińska & Leszczyński, 1989).

In chapter 1 (Somsen & Capelle, 2002) a method called Production Yield Analysis (PYA) was presented. The PYA-method is a structured system approach to improve the raw material yield efficiency of production processes. One of the first steps in a PYA project is to define key parameters of the raw material that affect production yield. Therefore it is necessary to find raw material parameters that are measurable at factory conditions (for example during raw material intake control) and show a good relationship with production yield. Knowledge about these parameters is necessary to predict the maximum production yield as pointed out by Somsen and Capelle (2002). In general it is preferable for a food processor to use raw material parameters that can be measured in a reliable, simple, low cost, and non-destructive way instead of parameters, which are scientifically preferable but are expensive, time consuming and hard to measure.

Average number of tubers per kilogram is such a raw material parameter that can be easily measured at factory conditions. Finding the relationship between production yield and number of tubers per kilogram is the subject of this paper. To understand this relationship it is necessary to know the relationship between shape (tuber dimensions), tuber volume, surface area and number of tubers per kilogram. This knowledge is important to understand each individual unit operation. During peeling for example a small shell (periderm plus a part of the underlying tissue) with a certain thickness (D) is removed from the tubers surface (A), which will result in a peel loss (PL). As average potato size decreases the ratio between surface area and volume (V) will increase, which will result in a higher peel loss. This ratio [Eq. (2.1)] is defined as the specific surface area (SS) and is assumed to be directly related to the peel loss [Eq. (2.2)]. The peel loss is expressed in percentage mass loss of the initial tuber weight, for that reason a factor of 100 was put into Eq. (2.2).

$$SS = A/V \qquad (2.1)$$

$$PL \approx 100SS * D \qquad (2.2)$$

A second example is size sorting. To predict losses due to size sorting of cut strips, information about the shape and size of the potatoes is needed, because the length distribution of the cut strips is fully defined by the dimensions of the tubers. This study concentrates on *Solanum tuberosum* L. cv.: Agria, Asterix and Bintje. These three varieties are widely used for the manufacturing of French-fries in Europe.

2.2. Materials and methods

2.2.1. Materials

- Measuring calliper: Mitutoya ± 0.05 mm.
- Top pan balance: Mettler PM34-K, ± 0.1 g.

- Mechanical cutter: Slitmaster, knife assembly 11.00 x 11.00 mm, mirror polished knives.
- Steam peeler: K+K, type SSC-F60R, 60 l vessel.
- Drum washer to remove the peel residue: K+K, type WTB-1500/R, length 1.5 m, and diameter 0.6 m.
- Equipment for measuring under-water-weight:
  - Standard set-up: metal basket (0.4 x 0.4 x 0.4 m), water basin of 250 l, balance (±0.1 g) and thermometer (±0.1 °C).
  - Set-up for individual tubers: nylon string connected between the balance and a fish-hook.
- Fryer: Senking type S.

2.2.2. Raw material and sampling method

Ware-potatoes (*Solanum tuberosum* L. cv.: Agria, Asterix and Bintje) were used, grown on sandy, loam and clay soils in The Netherlands under the usual regime. Potatoes were harvested in September-October and stored at 6-8 °C until required. Before shipment potatoes were reconditioned for 2-3 weeks at 15-18 °C. Potatoes used for the experiments were taken at random by holding a basket (about 25 kg) under a belt at a factory intake during unloading of the trailer (batch size about 35 metric tons). When more potatoes were necessary, several successive baskets were filled from the same truck. The tubers were washed carefully by hand with tap water of 12 °C ± 2 and after that thoroughly dried with paper tissues.

2.2.3. Relationship between tuber volume and principal dimensions

The principal dimensions (Figure 2.1) of each individual tuber were measured with a calliper. Accordingly, each tuber was weighed above (Mrm) and under water (Muw). The exact water temperature was measured with a thermometer and density of the water (ρ_w) was estimated based on a density table (Weast, 1972). Specific gravity (SG) and volume (V) of each tuber were calculated by Eqs. (2.3) and (2.4). Other workers (Schippers, 1976; Smith, 1987; Rastovski & Van Es, 1987; Burton, 1989) used *1000Mrm/(Mrm-Muw)* to calculate the specific gravity of potatoes, however this equation neglects the density of the water used, which can result in serious errors (Ludwig, 1972). For that reason we modified the existing equation into Eq. (2.3), to be scientifically correct.

$$SG = 1000 + \rho_w * Muw/(Mrm - Muw) \qquad (2.3)$$

$$V = Mrm / SG \qquad (2.4)$$

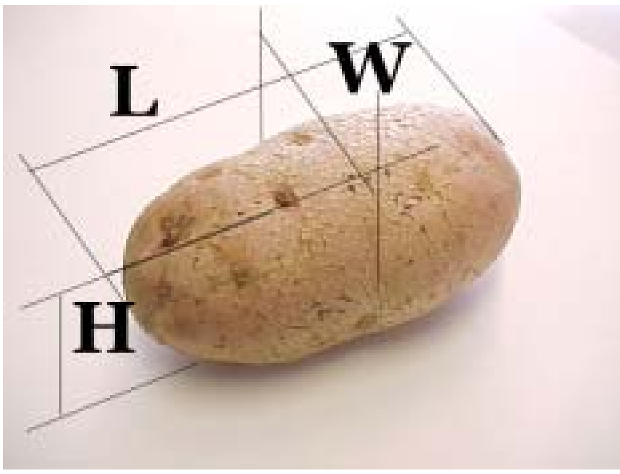

Figure 2.1. Principal dimensions of a potato tuber.

For each variety 200 tubers of crops 1993, 1995, 1996 and 2001 were examined (50 tubers of each crop). Basic linear regression (Statgraphics Plus version 4.0) with force true origin was used to find the relationship between the observed volume (V) and the fictitious volume ($L * W * H$).

2.2.4. Tuber dimensions versus tubers per kilogram

Per batch of potatoes 200 randomly chosen tubers were selected. Total mass of the sample was weighed. Subsequently the principal dimensions (Figure 2.1) of each individual tuber were measured with a calliper. The average L, W and H of the sample and the number of tubers per kilogram were calculated. For each variety 80 potato samples were used of crops 1993, 1995, 1996 and 2001 (20 samples of each crop). Statistical software "Statgraphics Plus version 4.0." was used to apply basic linear regression to the observations (L, W and H versus N). Ultimate model was selected on comparing goodness of fit of linear and standard non-linear models.

2.2.5. Production yield

For each variety a sample of 100 kg potatoes was graded manually by length and classified in length classes: <75, 75-<90, 90-<100 and ≥100 mm. About 9 kg of tubers per class were randomly selected (sub samples 1 till 4). Per sub sample each individual tuber was measured (L, W and H; Figure 2.1) and number of tubers was counted. The sub sample was weighed in air (Mrm) and under water (Muw). Under-water-weight (UWW) was calculated based on Eq. (2.5). The basic equation for under-water-weight (*5000Muw/Mrm*) was adapted to include the influence of the density of water used (for additional information see paragraph 2.2.3). Sub samples were peeled for 13 s at 15 bar atmospheric, washed in a drum washer, dried with paper tissues and weighed (Map). Peel loss was calculated by Eq. (2.6).

$$UWW = 5000Muw/Mrm + 5(\rho_w - 1000) \tag{2.5}$$

$$PL = 100(Mrm - Map)/Mrm \tag{2.6}$$

Subsequently, potatoes were cut (11 x 11 mm) in perfect longitudinal direction to reach the maximum possible length of the strips. The cut strips were dipped in cold water and washed thoroughly. Strips were de-watered by shaking them manually for 10 s in a perforated crate. Slivers smaller than 6.6 mm were taken out manually and weighed (Ms). The sliver loss was calculated according to Eq. (2.7). Nubbins shorter than 25 mm were manually removed and weighed (Mn). The loss was calculated according to Eq. (2.8). The remaining good strips were weighed (Mas) and yield of raw sorted strips (PYrs) was calculated [Eq. (2.9)].

$$SL = 100Ms/Mrm \tag{2.7}$$

$$NL = 100Mn/Mrm \tag{2.8}$$

$$PYrs = 100Mas/Mrm \tag{2.9}$$

The strips were par-fried in palm oil at 160 °C. Frying time was chosen according to Table 2.1. This table is based on practical experience. Intermediate points were linearly interpolated. It makes clear that at lower under-water-weight (meaning more initial water) a longer frying time is needed to reach the desired final moisture content of 65%. After frying, strips were cooled (15 min till 25 °C), chilled (15 min till 2 °C) and deep-frozen (20 min till -20 °C). Product was weighed (Mfp) and divided into approximately 3 equal portions. Moisture and fat

Table 2.1. Frying time versus under-water-weight

UWW (g)	Frying time (s)
380	175
400	161
420	149
440	139

content of each portion were analysed according to standard EAPR methods (Burton, n.d.). Final product yield was calculated based on Eq. (2.10).

$$PY = 100Mfp / Mrm \qquad (2.10)$$

2.3. Results and discussion

2.3.1. Predicting tuber volume

Tuber shapes may vary from near spherical to very elongated (Burton, 1989; Meredith, 1989). Gray (1973), Wurr (1977), Ahmed and Sagar (1981) assumed that the tuber volume can be approximated by the volume equation of a perfect ellipsoid [Eq. (2.11)], where k is equal to π/6 and L, W and H are the principal axes as shown in Figure 2.1.

$$V = k * L * W * H \qquad (2.11)$$

For bodies that approach an ellipsoid shape, the constant π/6 can be modified as suggested by McRae, Glasbey, Melrose, and Fleming (1986). In this study linear regression of the observed tuber volume versus the fictitious volume (*L*W*H*) was used to estimate the geometrical volume factor (k) [Eq. (2.11)]. Results of regression analysis are shown in Table 2.2.

Significant but small differences between the varieties were found. The regression constant for overall k (Table 2.2) is about 4% higher than for a perfect ellipsoid (*π/6=0.524*). Meaning that the volume of potato tubers is about 4% higher than that of ellipsoids with equal principal dimensions. These findings are in the same order of magnitude as those of McRae et al. (1986) k=0.58. In fact, McRea et al. (1986) over-estimated the geometrical volume factor by about 8%, because they used the mass instead of the volume of the tubers as appeared from the methods section of their own manuscript. This results in k=0.54 instead of k=0.58, because the specific gravity of potatoes is about 1080 kg/m^3 instead of 1000 kg/m^3.

Table 2.2. Geometrical volume factor of the varieties Agria, Asterix and Bintje

Variety	Geometrical volume factor		R^2	Number of experiments
	Avg	SE		
Agria	0.543	0.00256	0.997	200
Asterix	0.558	0.00269	0.996	200
Bintje	0.532	0.00322	0.995	200
Overall	0.544	0.00173	0.995	600

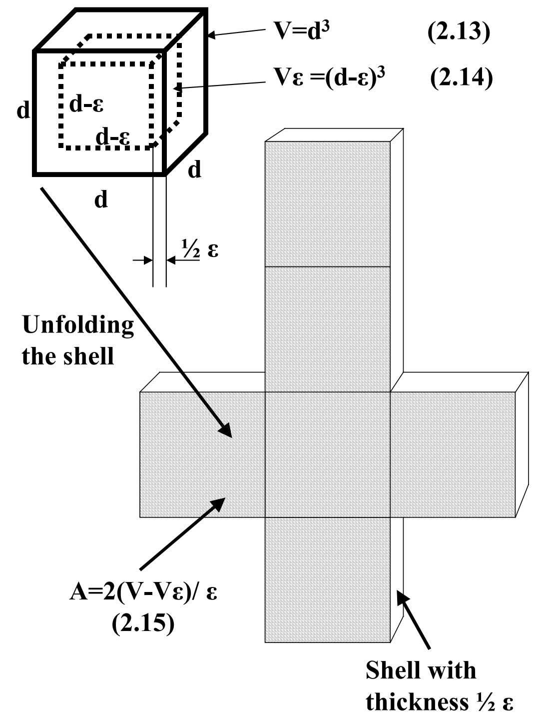

Figure 2.2. Numerical shell method applied on a cube.

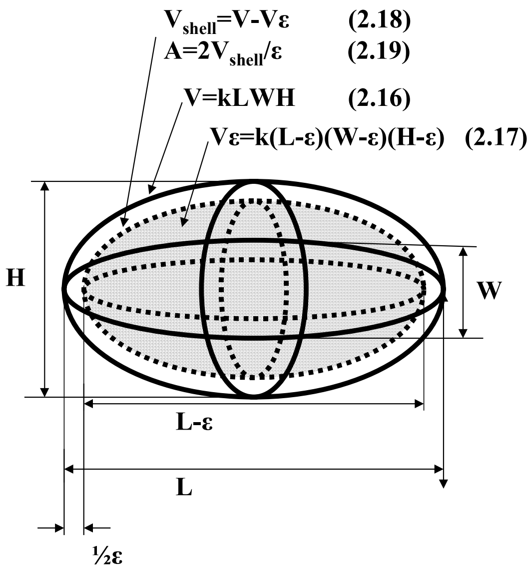

Figure 2.3. Numerical shell method applied on an ellipsoid shape body.

2.3.2. Predicting tubers surface area

The surface area of an ellipsoid cannot be calculated based on an analytical equation, because the surface integral is unsolvable. Igathinathane and Chattopadhyay (1998a; 1998b) used several numerical methods to predict the surface area of ellipsoids. In subsequent work Igathinathane and Chattopadhyay (2000) used a regression technique to derive a surface area equation [Eq. (2.12)] for ellipsoids. However, we modified one constant in their equation, because they apparently made a typing error, as appears from the results in their own manuscript, which resulted in large errors! Therefore we changed the initial constant $4.92988817 \times 10^{-2}$ into $4.92988817 \times 10^{-1}$ as shown in Eq. (2.12). Nevertheless, this equation is not really suitable for potatoes, because potatoes deviate from a perfect ellipsoid as mentioned in the previous paragraph.

$$A = \pi[-1.02274828 \times 10^{-2} L^2 + 4.92988817 \times 10^{-1} LW + 3.43560219 \times 10^{-1} LT - 5.29422959 \times 10^{-2} WH + 2.35999474 \times 10^{-1} WH^2/L] \quad (2.12)$$

We developed a new mathematical technique, called "numerical shell method", to estimate the surface area of three-dimensional objects. This numerical shell method can be used when the analytical volume equation of a three-dimensional body is known and the surface area equation is not available. This method transforms the volume equation into a surface area equation and is based on the assumption that the volume of the outer shell is equal to the surface area of that shell divided by the shell thickness. In Figure 2.2 the basic principle is shown for a cube. The volume of the shell (V-$V\varepsilon$) is equal to the volume of the outer cube [Eq. (2.13)] minus the volume of the inner cube [Eq. (2.14)]. When this shell, with thickness ½ε, is unfolded the surface area of the cube can be seen (the cross-shaped layer in Figure 2.2) and can be approximated by Eq. (2.15). The accuracy of this method approaches the true

Table 2.3. Surface area of a sphere, bar and ellipsoid based on analytical equations versus numerical shell method

	Sphere	Bar	Ellipsoid
Characteristic dimensions (m)	d = 0.1	L = 0.1; W = 0.07; H = 0.05	L = 0.1; W = 0.07; H = 0.05
Volume equation (m^3)	$V = \pi.d^3/6$	V = L.W.H	$V = \pi.L.W.H/6$
Surface area equation (m^2)	$A = \pi.d^2$	A = 2(LW+LH+HW)	not applicable
Analytical solution (m^2)	0.03141593	0.031 m^2	not applicable
Surface area (m^2), based on modified Igathinathane and Chattopadhyay (2000) equation	0.03171057	Not applicable	0.01663206
Surface area (m^2) based on numerical shell method:			
$\varepsilon = 1x10^{-4}$ m	0.03135314	0.03091208	0.01618553
$\varepsilon = 1x10^{-6}$ m	0.03141530	0.03099912	0.01623110
$\varepsilon = 1x10^{-8}$ m	0.03141582	0.03099999	0.01623156
$\varepsilon = 1x10^{-10}$ m	0.03141593	0.03100000	0.01623156

surface area when ε is infinitely small. In Figure 2.3 the same principle is shown for an ellipsoid shaped body.

This numerical technique is more accurate at a smaller shell thickness as Table 2.3 shows. For objects where the analytical equation for volume and surface area are known, this numerical shell method can be tested. Results are shown in Table 2.3. For the chosen dimensions in Table 2.3 the estimated surface is about equal to the analytical one at a ε=$1x10^{-10}$ m.

Based on the set of equations in Figure 2.3, Eq. (2.20) was derived to predict the surface area of ellipsoid shape bodies. For ε a value of $1x10^{-10}$ m will be used for the rest of this study, because this led to accurate test results (Table 2.3).

$$A = 2k[(L*W*H) - (L-\varepsilon)(W-\varepsilon)(H-\varepsilon)]/\varepsilon \qquad (2.20)$$

2.3.3. Predicting tuber dimensions

In Table 2.4 regression results for the relationship average tuber dimensions (L, W and H) and number of tubers per kilogram are given.

For all dimensions in Table 2.4 a power relationship versus N was found. McRae et al. (1986) used L, W and H as an independent variable to estimate the average mass of the tubers. These equations were transformed into the same form we used, resulting in: $L=e^{6.38}N^{-0.476}1x10^{-3}$, $W=e^{6.91}N^{-0.366}1x10^{-3}$ and $H=e^{6.42}N^{-0.360}1x10^{-3}$. It makes clear that they found also a power relationship. At N values between 8 and 16 the results of McRae et al. (1986) are approximately equal to our overall results as are shown in Figure 2.4. At N values below 8 kg^{-1} their results deviate from ours. These deviations were investigated more closely by looking to the average tuber mass in two different ways:

1. Number of tubers per kilogram can be used to calculate the average tuber weight (*M=1/N*).
2. Number of tubers per kilogram can be used to estimate the average tuber dimensions [Eqs. (2.21)-(2.23) in Table 2.4]. These dimensions can be used to estimate the average tuber mass when specific gravity is know, resulting in: *M = k.L.W.H.SG*.

Table 2.4. Results of regression analysis for average tuber dimensions versus number of tubers per kilogram

Equation	Intercept	Slope	SE $x10^{-3}$ (m)	R^2	Number of experiments
$L=e^{intercept}*N^{slope}*1x10^{-3}$ (2.21)					
Agria	5.421	-0.4944	0.0237	0.960	80
Asterix	5.464	-0.4975	0.0241	0.973	80
Bintje	5.442	-0.4943	0.0224	0.968	80
Overall	5.442	-0.4954	0.0274	0.966	240
$W=e^{intercept}*N^{slope}*1x10^{-3}$ (2.22)					
Agria	4.630	-0.2917	0.0274	0.941	80
Asterix	4.604	-0.2775	0.0325	0.928	80
Bintje	4.598	-0.2514	0.0292	0.935	80
Overall	4.611	-0.2735	0.0331	0.931	240
$H=e^{intercept}*N^{slope}*1x10^{-3}$ (2.23)					
Agria	4.298	-0.2139	0.0284	0.889	80
Asterix	4.280	-0.2250	0.0274	0.879	80
Bintje	4.309	-0.2543	0.0230	0.853	80
Overall	4.296	-0.2311	0.0344	0.864	240

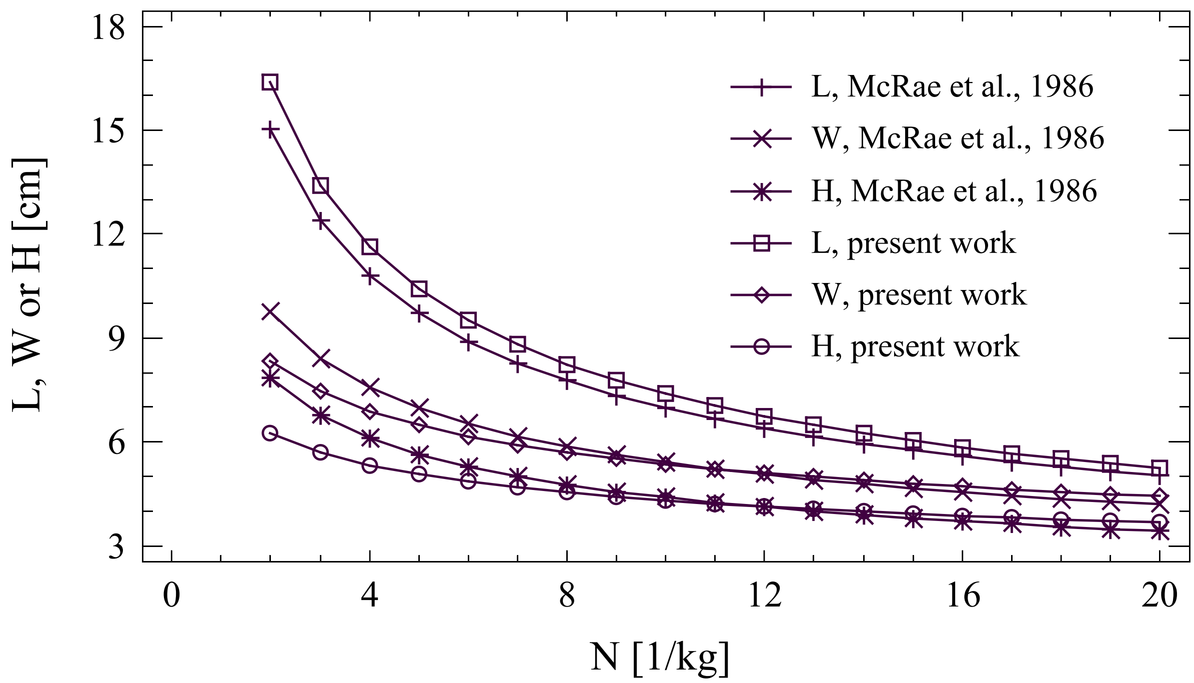

Figure 2.4. Predicted principal tuber dimensions versus number of tubers per kilogram.

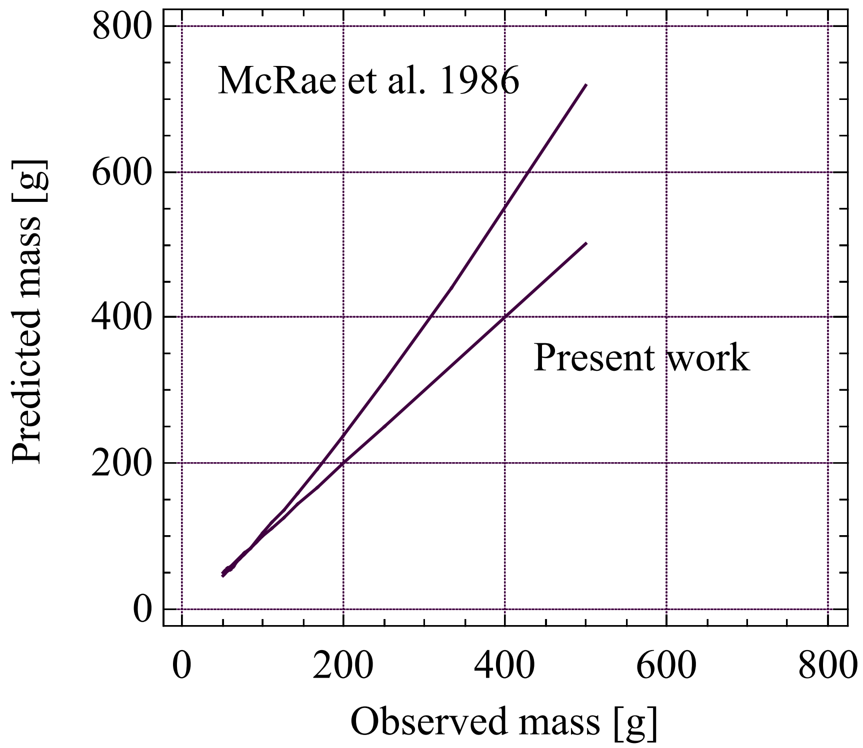

Figure 2.5. Predicted versus observed average tuber mass.

The specific gravity of potatoes used for French-fries normally falls between 1075 and 1098 kg/m^3. This means that when specific gravity is assumed to be constant, at 1080 kg/m^3, this only leads to a small error of about –0.5 till 1.7%. Based on our set of equations, those of McRae et al. (1986) and assuming that specific gravity is 1080 kg/m^3, Figure 2.5 was made. The x-axis represents the observed mass based on $M=1/N$ and the y-axis shows the predicted mass based on $M = k.L.W.H.SG$. The observed and predicted values should be approximately equal, representing a line with a slope of 45°. For our study this is true, but the results of McRae et al. (1986) show major deviations, especially at tuber weights above 150 g ($N \leq 6$ kg^{-1}). This indicates that the equations of McRae et al. (1986) are only suitable for tuber weights between 40 and 125 g.

2.3.4. Tubers per kilogram versus production yield

For a sphere it can be calculated that the specific surface area is proportional to $M^{-1/3}$ or $N^{1/3}$. Based on the "numerical shell method" as explained in Figure 2.3, simulations were carried out to find this relationship for ellipsoid shaped bodies with a geometrical volume factor of 0.544 (overall value of Table 2.2). Eqs. (2.1), (2.16), (2.20)-(2.23) were used for this simulation. The results are shown in Figure 2.6. The curve matches Eq. (2.24) completely, meaning that we found also $N^{1/3}$ as a proportional factor for potatoes. Our results are in line with findings of Smith and Huxsoll (1987) who used $M^{-1/3}$ to correlate peeling losses.

$$SS = 7.876 + 47.81N^{1/3} \qquad (2.24)$$

Experimental results of yield experiments are shown in Table 2.5. For these results the ratio between peel loss and specific surface area [Eq. (2.24)] is approximately constant and in average equal to 0.070 m (SD=0.0028). This confirms the previous assumption, as mentioned in the introduction of this chapter, that at equal steam peeling conditions the observed peel loss is proportional to the specific surface area of the tubers.

Table 2.5. Several losses and yield of 11 x 11 mm French-fries

Variety	UWW (g)	N (kg^{-1})	Peel loss (w/w %)	Sliver loss (w/w %)	Yield of raw sorted strips (w/w %)	Final par-fried product: Yield (w/w %)	Final par-fried product: Moisture content (w/w %)	Final par-fried product: Fat content (w/w %)
Bintje	400	9.08	7.45	5.91	84.9	61.2	65.6	6.34
Bintje	398	6.78	6.60	5.24	86.4	62.3	65.2	6.40
Bintje	399	4.51	5.90	4.52	87.8	63.1	65.4	6.64
Bintje	397	3.50	5.73	4.19	88.3	63.7	64.6	6.50
Asterix	432	10.4	8.17	6.29	83.0	62.8	64.9	5.72
Asterix	435	6.91	6.70	5.29	85.5	65.2	64.5	5.71
Asterix	427	4.43	6.35	4.44	86.6	65.4	64.7	5.71
Asterix	428	3.20	5.64	4.05	87.7	66.1	65.6	5.99
Agria	395	9.57	7.39	6.14	84.3	60.5	65.4	6.24
Agria	391	6.72	7.01	5.20	85.6	60.9	64.2	6.45
Agria	396	4.63	6.46	4.62	86.7	62.4	65.4	6.58
Agria	391	3.33	5.37	4.11	88.3	62.8	64.9	6.41

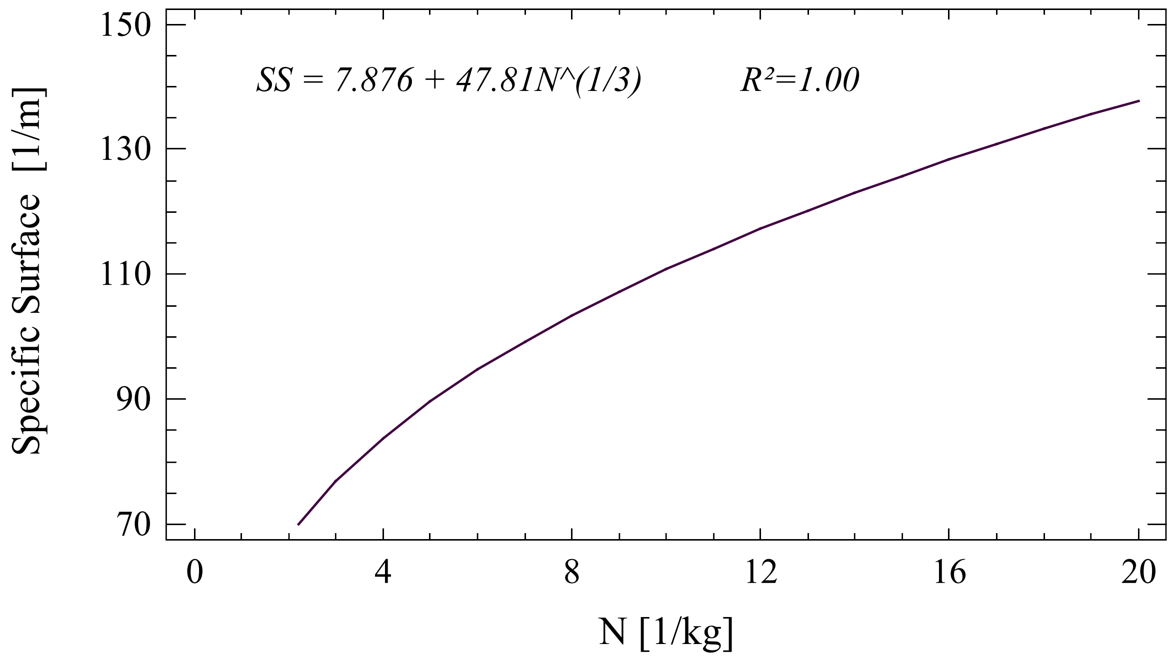

Figure 2.6. Simulated specific surface area versus number of tubers per kilogram.

After peeling and cutting the strips need to be sorted and slivers and nubbins have to be removed. The mass losses due to sliver removal are linearly proportional to N (R^2=0.997) as can be seen in Table 2.5. Per unit increase of N the sliver loss increases by 0.31%. Nubbin losses were not detected; all strips that were not classified as sliver were considerable longer as 25 mm.

The yield of raw sorted strips (Table 2.5) is not only influenced by losses due to peel and sliver removal but also by losses during cutting. This is proven by the fact that the sum of the yield of raw sorted strips plus peel and sliver losses are all less than 100% (about 98%). This cutting loss, which seems to be in the order of magnitude of 2%, needs to be explored in future research and will be outlined in chapter 4 of the thesis.

The yield of raw sorted strips decreases about linearly with N (R^2=0.929). Per unit increase of N yield of raw sorted strips decreases by 0.63%. The yield of final product is not only depending on number of tubers per kilogram but also on under-water-weight, final moisture and fat content. At a higher under-water-weight, less water needs to be evaporated during frying to reach the required final moisture content, resulting in a higher final product yield. The final product yield of Asterix is considerable higher than for Bintje, because the UWW is about 30 g higher. Differences between Agria and Bintje are also explained by 10 g differences of UWW.

2.3.5. Final discussion

It is our aim to develop an overall model to estimate the maximum possible raw material yield of French-fries production. Detailed information about peeling will be outlined in chapter 3 and the overall yield model will be reported in chapter 4. Knowing this maximum makes it possible to measure the yield efficiency of the current process. This PYA approach was discussed extensively in chapter 1 (Somsen & Capelle, 2002). The current study makes clear that number of tubers per kilogram is one of the important raw material key parameters necessary to predict peeling and sorting losses. Big advantage of this parameter is that number of tubers per kilogram can be easily measured in practice, because weighing and counting can be automated. Big sample sizes are also possible due to the non-destructive way of working and easiness of operation. This helps to reduce the sampling error.

This paper makes clear that number of tubers per kilogram influences the peel loss, because the specific surface area is related to the number of tubers per kilogram. The yield of raw sorted strips decreases when number of tubers per kilogram increases, not only due to a higher peel loss but also because more slivers have been sorted out. However, losses due to sliver and nubbin removal are also affected by the cut size of the strips and needs to be explored in future research.

The biggest mass losses (Table 2.5) were observed during frying. These losses are heavily influenced by the under-water-weight of the raw material. However, evaporation of water during frying is wanted and is necessary to reach the desired final product specifications (65% moisture content in this case). Peel losses were the second highest. These losses can be wanted (periderm removal) and unwanted (removal of good potato flesh). In chapter 3 the yield efficiency of this unit operation will be examined in more depth.

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CHAPTER 3

Modelling yield efficiency of peeling

Abstract
The paper outlines the yield efficiency of steam peeling. It was proven that peeling potatoes manually with sandpaper results in the lowest possible peel losses. These losses were desired or wanted losses. However, in practice steam peeling results not only in wanted losses but also in substantial unwanted losses of about 7.9%. A model was developed to predict peel losses and heat ring development during steam peeling. Based on this model it was shown that creating a homogeneous peel removal effect with minimum heat ring development should be the main approach to decrease unwanted losses during steam peeling in the future.

Nomenclature

AE	*Abrasive effect of peel remover (w/w %)*
Dp	*Periderm thickness (m)*
HR	*Heat ring (m)*
Map	*Mass of product after peeling operation (kg)*
Mbpr	*Mass of product before peel remover (kg)*
Mrm	*Mass of clean raw material (kg)*
N	*Number of tubers per kilogram* (kg^{-1})
P	*Steam pressure (bar)*
PL	*Peel loss (w/w %)*
SA	*Skin appearance (-)*
SPL	*Specific peel loss (w/w %)*
SS	*Specific surface* ($m^2\ m^{-3}$)
T	*Initial tuber temperature (°C)*
t	*Steam exposure time (s)*
UWW	*Under-water-weight (g)*
YI	*Yield Index (-)*

Subscripts:

Wanted	*Indicates a wanted mass loss*
Unwanted	*Indicates an unwanted mass loss*

3.1. Introduction

During the manufacturing of French-fries many mass losses occur. These losses can be wanted or unwanted. Wanted losses are necessary to transform the raw material into the desired final product. Unwanted losses will decrease the yield efficiency of the process and can be caused by inefficient unit operations, poor practice, spillage, fouling etc. as was discussed in chapter 1 (Somsen & Capelle, 2002). To transform potatoes into French-fries the following unit operations are most commonly used: peeling, cutting, size sorting, defect sorting, blanching, drying, frying, chilling, freezing and packaging. Peeling results in the highest unwanted mass losses as explained previously in chapter 2 (Somsen, Capelle, & Tramper, 2004) and is therefore of particular interest for yield efficiency studies, which are the subject of this paper.

Many techniques are available to peel potatoes. Well-known examples are abrasive-, lye- and steam peeling (Lisińska & Leszczyński, 1989; Radhakrishnaiah, Vijayalakshmi, & Usha, 1993). Steam peeling is currently the state of the art; all major French-fries processors are using this peeling technique. A complete peeling line contains a pre-washer to remove adherent soil from the tubers, the steam peeler itself, peel remover and after-washer. The peel remover removes the softened peel from the tubers based on scrubbing or centrifugal techniques (Van Nielen, 1977; Smith & Huxsoll, 1987; Van Nielen, 1989; Van der Schoot, 1998; Anon, 2000).

The objective of peeling is skin removal without wasting the underlying good tissue. The skin is a layer of corky periderm, approximately 5-15 cells deep (Fedec, Ooraikul, & Hadziyev, 1977; Talburt, Schwimmer, & Burr, 1987; Burton, 1989). These cork cells are dead cells and contain no starch or protein and have much thicker cell walls than parenchyma cells. The skin has a total thickness of 100-250 μm, which is equal to 1.5-2.5% of the fresh weight of the tuber (Burton, 1989). Under ideal conditions, peeling should remove only the skin and surface defects, leaving the rest of the tissue unattached. In this ideal situation the observed mass loss can be specified as a wanted loss. However, during steam peeling high losses are reported: 8-10% (Ratcliffe, 1975), 15-20% (Wolf, Spiess, & Jung, 1978), 10-15% (Ingram, 1980), 10-20% (Smith & Huxsoll, 1987), 10-15.5% (Van Nielen, 1989), up to 15% (Anon, 1992), 5-12% (Van der Schoot, 1997), 9.8-13.2% (Anon, 1999) and 6-18% (Den Hertog, 2002). This indicates not only wanted losses but also much higher unwanted losses!

The objectives of the present investigation were: (a) to estimate the wanted peel loss based on raw material parameters (b) to examine the yield efficiency of steam peeling (c) to examine the most critical factors during steam peeling that cause over-peeling.

3.2. Materials and methods

3.2.1. Materials

- Measuring calliper, Mitutoya ±0.05 mm.
- Stereo microscope (Olympus SZ60), digital camera (Olympus DP10), software SIS-analysis v.3.
- Top pan balance, Mettler PM34-K, ± 0.1 g.
- Sandpaper, Segro P120.
- Steam peeler (K+K, type SSC-F60R, 60 l vessel volume, tumbling vessel).
- Drum washer to remove the peel residue (K+K, type WTB-1500/R, length 1.5 m, diameter 0.6 m).

- Peel remover "old" type: Gouda-GMF dry brushing machine, type B1201C.
- Peel remover "new" type: Gouda-GMF dry brushing machine, type BE 145/12, (Van der Schoot, 1998).
- After-washer: Gouda-GMF, type WTR 12.35.
- Equipment for measuring under-water-weight:
    - Standard set-up: metal basket (0.4 x 0.4 x 0.4 m), water basin of 250 l, balance (±0.1 g) and thermometer (±0.1 °C).
    - Set-up for individual tubers: nylon string connected between the balance and a fishhook.

3.2.2. Raw material and sampling method

Ware-potatoes (*Solanum tuberosum* L. cv.: Agria, Asterix and Bintje) were used, grown on sandy, loam and clay soils in The Netherlands under the usual regime. Potatoes were harvested in September-October and stored at 6-8 °C until required. Before shipment potatoes were reconditioned for 2-3 weeks at 15-18 °C. Potatoes used for the experiments were taken at random by holding a basket (about 25 kg) under a belt at a factory intake during unloading of the trailer (batch size about 35 metric tons). When more potatoes were necessary, several successive baskets were filled from the same truck. The tubers were washed carefully by hand with tap water of 12 °C ± 2 and after that completely dried with paper tissues.

3.2.3. Peel thickness measurements (Table 3.2)

Potatoes were selected with a skin appearance between 6 and 8 (Table 3.1). A potato was cut in half over the width and height axes. With a razor blade four thin slices of approximately 0.5 mm thick were cut at random out of one of the tuber halves parallel to the existing cutting surface. These four sub samples were washed and investigated under a microscope (128x magnification) and periderm thickness was measured by digital imaging software. This procedure was repeated with fifty tubers (crop 2001, stored till May 2002) of each variety.

3.2.4. Manual peeling experiments (Table 3.3)

Per skin appearance class (Table 3.1) five normally shaped potatoes per variety were selected. These potatoes were selected out of many batches to fill each class with enough potatoes (crop 2001 and 2002). Especially tubers with a skin appearance below 5 were hard to find, because they are normally unsuitable for the manufacturing of French-fries. Each tuber was washed with tap water, dried with paper tissues and weighed (Mrm). Each tuber was carefully peeled manually with sandpaper and some tap water until clean. Surface defects were removed but penetrable defects were not. Subsequently the tuber was washed with tap water, dried with paper tissues and weighed (Map). Peel loss (PL) was calculated according to Eq. (3.1) and specific peel loss (SPL) was calculated based on Eq. (3.2) (Somsen et al., 2004). Statistical software "Statgraphics Plus version 4.0." was used to apply basic linear regression on the observations (SPL versus SA). Ultimate model was selected on comparing goodness of fit of linear and standard non-linear models.

$$PL = 100(Mrm - Map) / Mrm \qquad (3.1)$$

$$SPL = PL / N^{1/3} \qquad (3.2)$$

Table 3.1. Skin appearance appreciation according to Russo, Evensen, and Braun (1988)

Skin appearance scale	Description
10	Very smooth, >80% of surface is smooth
9	Smooth, 20-80% of surface is smooth
8	Slightly smooth, <20% of surface smooth
7	Slightly net, <20% of surface netted
6	Net, 20-80% of surface netted
5	Very net, >80% of surface netted
4	Slightly russet, <20% of surface russet
3	Russet, 20-80% of surface russet
2	Very russet, >80% of surface russet
1	Rough, <80% of surface rough
0	Very rough, >80% of surface rough

3.2.5. Peel loss and heat ring model (Table 3.4 and 3.5)

From a potato batch 10 regular shaped tubers were selected to fill the following weight classes: <85, 85-<120, 120-<155, 155-<190, 190-<225, 225-<260, 260-<295, 295-<300, 300-<365 and ≥365 g. Each tuber was individually weighed. Under-water-weight of each tuber was measured according to the procedure described by Somsen et al. (2004). Tubers were stored for 2 h in tap water to reach the desired temperature. The steam peeler was warmed up by running one dummy cycle. Subsequently the peeler was filled with the 10 tubers and the peeler was started. After peeling, the potatoes were immediately washed in a drum washer with tap water (12 °C ± 2) to remove the peel pulp (no abrasive effect). Each potato was dried with paper tissue and weighed. Peel loss percentage for each individual tuber was calculated based on Eq. (3.1). Subsequently, the potato was cut in half over the length and width axes and the heat ring was measured with a calliper at four locations (left and right lateral parts and bud and stem ends). Average heat ring thickness was calculated by averaging these four data.

The experimental design was based on following factors: potato size (10 levels as mentioned above), potato-conditioning temperature (4 levels: 10, 30, 50 and 60 °C), steam exposure time (9 levels: 5, 10, 15 s etc.) and steam pressure (3 levels: 12, 15 and 18 bar atmospheric pressure). Agria, Asterix and Bintje potatoes of crop 1996 were randomly used for these experiments. Based on the experimental data two models were developed to predict the heat ring as a function of independent variables (under-water-weight, potato size, variety, conditioning temperature, steam pressure and steam exposure time) and a second model to predict the peel loss as a function of these independent variables. Independent variables were only included in the model when $P \leq 0.05$. The strategy of Neter, Kutner, Nachtsheim, and Wasserman (1996) for building regression models was used. Standard multiple regression analysis (Statgraphics Plus version 4.0.) was used for the model building process.

3.2.6. Peel removal effect (Figure 3.5 and Table 3.6)

From a potato batch (Agria crop 2001, stored till June 2002) sixty equally shaped potatoes were selected with a mass between 200 and 300 g and a skin appearance appreciation of 6. Under-water-weight of the whole sample was measured and overall mass. Potatoes were split in five equal sub samples. Sub sample 1 was conditioned for 2 h in water of 4 °C. Sub sample 2 at 14 °C, sub sample 3 at 30 °C, sub sample 4 at 45 °C and sub sample 5 at 60 °C. Sub sample 6 was used to test the peel removal effect at different exposure times. For that, each individual tuber of sub sample 6 was steam peeled at 13.0 bar. Tuber one was peeled for 7 s and each successive tuber was steam peeled by plus one second compared to the previous one. After steam peeling each tuber was washed with tap water (12 °C ± 2) to remove the adherent peel pulp (no abrasive effect). Peel removal effect was classified by eye. The peeling time of the first tuber that has less than one-percent peel residues was taken as optimal exposure time. Each individual tuber of sub sample 2 was weighed (Mrm) and processed at optimum steam exposure time, dried with paper tissue, weighed (Mbpr) and peel removal effect was observed by eye. Five tubers were cut in half over the length and width axes and heat ring thickness was measured. Five other tubers were digitally photographed (Figure 3.5) and marked with red beetroot juice. Subsequently, the potatoes were mixed with the potatoes at the production line just before the peel remover (type BE 145/22, settings 66 and 76 mm gap size). The marked potatoes were collected after the after-washer, dried with paper tissue and weighed (Map). The abrasive effect (AE) was calculated according to Eq. (3.3). Other sub samples (1, 3-5) were processed at other exposure times to reach an equal specific peel loss according to Eq. (3.2) (Somsen et al., 2004) and Eq. (3.8).

$$AE = 100(Mbpr - Map)/Mrm \qquad (3.3)$$

3.2.7. Abrasive effect of peel remover (Figure 3.6)

Ten potato tubers at random selected were individually weighed (Mrm), marked with a knife (roman number) and dipped in red beetroot juice. After steam peeling (13 s at 15 bar) the potatoes were immediately washed in a drum washer with tap water (12 °C ± 2), dried with paper tissue and individually weighed (Mbpr). Subsequently, the potatoes were mixed with the potatoes at the production line just before the peel remover (settings 66 and 76 mm gap size). The marked potatoes were collected after the after-washer, dried with paper tissue and individually weighed (Map). The abrasive effect (AE) was calculated according to Eq. (3.3). This procedure was repeated 12 times (4 batches of each variety, crop 1996) with a peel remover (type B1201C) and was repeated again in 2001 (crop 2001) with a newer type of peel remover (type BE 145/22).

3.2.8. Variability in peel removal effect (Table 3.7)

From a potato batch (Agria crop 2001, stored till June 2002) sixty equally shaped potatoes were selected with a mass between 200 and 300 g and a skin appearance appreciation of 6. Under-water-weight of the whole sample was measured and overall mass. The sample was split in two fractions of 30 tubers each. Each tuber of sample 1 was individually steam peeled (14 s at 15 bar), washed with tap water and the peel removal effect was judged by eye. All potatoes of sample 2 were processed together (14 s at 15 bar), washed with tap water and the peel removal effect was judged by eye.

3.3. Results and discussion

3.3.1. Wanted peel loss - a theoretical approach

From a theoretical point of view the minimum possible peel loss is a function of the periderm thickness (Dp) and specific surface (SS) of the tuber [Eq. (3.4)]. Periderm thickness can be measured by microscope and specific surface can be estimated out of the number of tubers per kilogram (N) (Somsen et al., 2004). For the varieties Agria, Asterix and Bintje they found overall Eq. (3.5).

$$PL \cong 100SS * Dp \qquad (3.4)$$

$$SS = 7.876 + 47.81N^{1/3} \qquad (3.5)$$

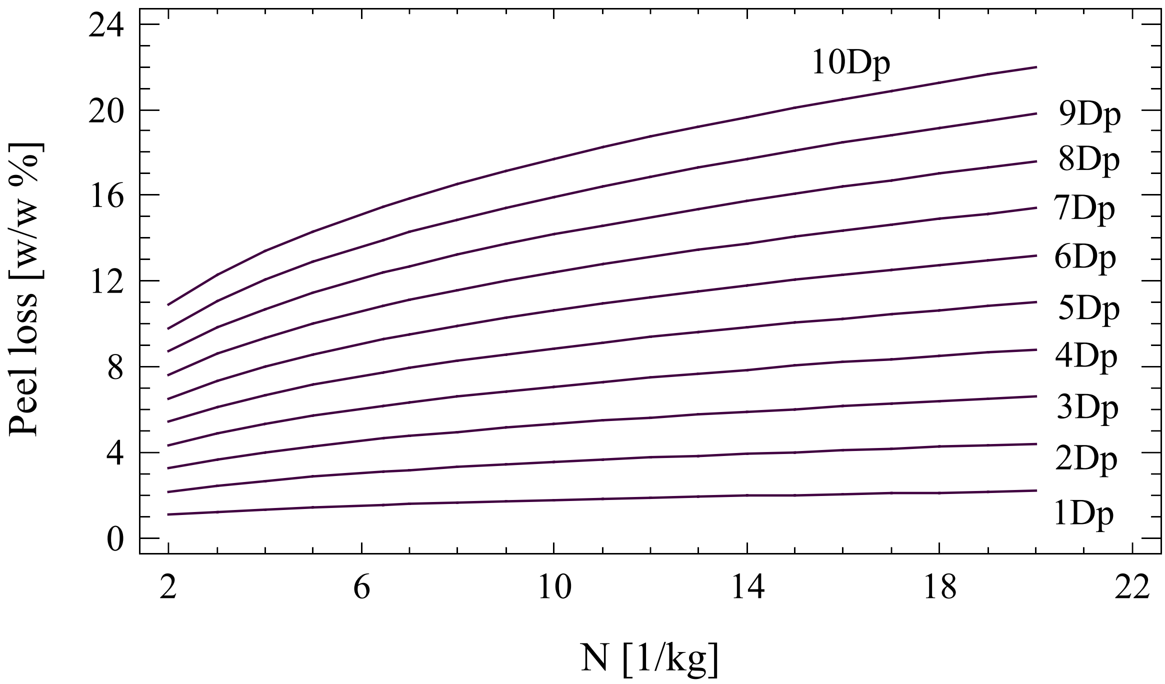

Figure 3.1. Predicted peel loss versus number of tubers per kilogram per unit (Dp=159.7 μm) of tissue removal.

Table 3.2. Periderm thickness of varieties Agria, Asterix and Bintje

Variety	Periderm thickness (μm)		Number of experiments
	Mean	SE	
Agria	152.0	2.96	200
Asterix	165.9	3.16	200
Bintje	161.3	3.29	200
Total	159.7		600

Results of skin thickness measurements for several varieties of ware-potatoes are presented in Table 3.2. These findings are in the same order of magnitude as findings by Cutter (1978) and Burton (1989). A significant difference between the mean peel thickness of Agria versus Asterix and Bintje was found ($P<0.01$).

Peel loss simulations were carried out based on Eqs. (3.4) and (3.5) versus the number of tubers per kilogram. The results of these simulations are presented in Figure 3.1. The lowest curve (legend 1Dp) represents the peel loss if only the periderm is removed (with a thickness of 159.7 μm). The other curves simulate the effect of over-peeling, meaning a removal of multiple Dp layers of good valuable potato tissue. Generally, potato batches for French-fries processing contain 4 till 10 tubers per kilogram, indicating a wanted mass loss of approximately 1.3 till 1.8 w/w% (Figure 3.1). In this case the wanted specific peel loss [Eq. (3.2)] is equal to 0.83 w/w%. As mentioned in the introduction of this paper other workers found losses during steam peeling between 5 till 20 w/w%, indicating that at factory conditions 4 till 15 times the actual periderm thickness is removed (0.6-2.4 mm).

Table 3.3. Minimum peel loss versus skin appearance

Skin appearance	Peel loss (w/w %)		Average tuber weight (g)	Specific peel loss (w/w %)	Number of experiments
	Avg	SD			
10	0.57	0.29	195.4	0.33	15
9	1.05	0.43	145.0	0.51	15
8	1.32	0.61	158.5	0.67	15
7	1.53	0.41	171.2	0.84	15
6	1.96	0.47	179.3	1.09	15
5	1.94	0.46	198.5	1.18	15
4	2.06	0.79	197.2	1.59	15
3	2.83	0.49	182.4	1.67	15
2	3.00	0.62	186.6	1.86	15
1	3.33	0.78	197.5	2.08	15
0	4.55	1.05	161.0	2.45	15

3.3.2. Wanted peel loss - a practical approach

From a yield perspective the most efficient way to remove the peel is scrubbing the tubers manually with sandpaper until clean. Surface defects that are non-penetrating into the tuber should be scrubbed away, but penetrating defects must be left untouched. The latter should be removed after the cutting process in the form of defected strips. Cutting off the defected part of each strip and feeding back the good part to the other good strips can revalorise these strips. This way of defect removal is most yield efficient and should be preferred to over-peeling.

The skin appearance of the tubers can differ from smooth to rough (Table 3.1) as pointed out by Russo et al. (1988). It is assumed that a smooth surface tuber surface will result in a small peel loss and a rough surface in higher losses. In Table 3.3 the experimental results are given.

Regression analysis was used to find the relationship between specific peel loss and skin appearance [Eq. (3.6)]. Observed R^2 was 0.860, SE was 0.12 and number of experiments was 165.

$$SPL_{wanted} = (1.572 - 0.09595SA)^2 \qquad (3.6)$$

Substituting Eq. (3.6) in (3.2) give:

$$PL_{wanted} = (1.572 - 0.09595SA)^2 N^{1/3} \qquad (3.7)$$

Very smooth potatoes (class 10) will give exceptionally low peeling losses and very rough potatoes (class 0) give much higher losses. Generally, ware-potatoes used for French-fries have a skin appearance appreciation between 6 and 8. Potatoes directly processed after harvesting contain a very smooth surface (class 8-10). Batches with an appreciation below 5 are often not accepted for French-fries processing. Based on Eq. (3.7) the wanted peel loss can be estimated when the skin appearance appreciation and the number of tubers per kilogram are known. Potatoes with a skin appearance appreciation between 6 and 8 will give a specific peel loss [Eq. (3.6)] between 0.65% (SA=8) and 0.99% (SA=6). These results are of the same order of magnitude as the simulated specific peel loss (0.83%) of Figure 3.1 at "1Dp". This proves the fact that the observed peel losses in Table 3.3 are wanted, meaning only periderm removal.

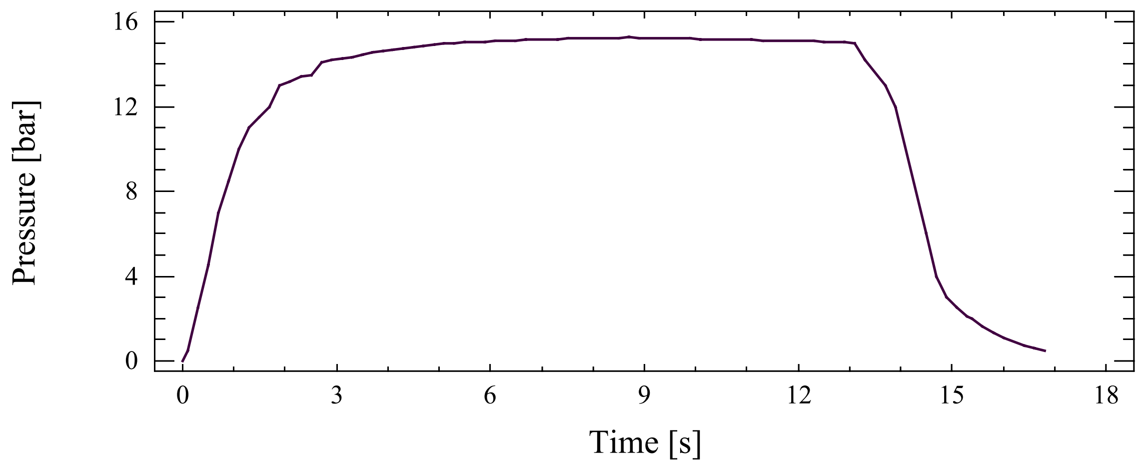

Figure 3.2. Pressure curve during steam peeling.

3.3.3. The yield efficiency of steam peeling

During the last decade Den Hertog (2002) carried out many peel loss measurements in practice in many of the major French-fries plants in Europe. Van der Schoot (1997), an ex-colleague of Den Hertog, reported some of these results. Most of them are not published but are available on request by Den Hertog (2002). Peel losses varied between 6-18%. Average peel loss was 9.64%, average tuber weight was 155 g ($N=6.45\ kg^{-1}$) and average steam exposure time was 12.9 s at 15 bar. These experiments were carried out under supervision of product specialists who adjusted the steam exposure time till the absolute minimum, indicating that optimum settings where used at these factory conditions. Based on Eq. (3.7) and assuming that the skin appearance appreciation was approximately 6, a wanted peel loss of 1.85% can be calculated. Based on Figure 3.1 we can conclude that at factory conditions often six times the actual periderm thickness is removed.

Somsen and Capelle (2002) described a dimensionless number, called Yield Index, to express the yield efficiency of a transformation process or unit operation. The Yield Index is equal to the ratio between the current production yield and maximum possible production yield. Based on the findings of Den Hertog (2002) and the developed wanted peel loss model [Eq. (3.7)], it is possible to calculate the Yield Index of the unit operation steam peeling.

$$YI_{steam\ peeling} = (100-9.64) / (100-1.85) = 0.921$$

Because the Yield Index is below one, additional raw material is needed to compensate the unwanted mass loss. Therefore it can be concluded that currently available peeling technology for French-fries production leads to an additional raw material usage of approximately 7.9%. Inherently, this statement indicates that there must be possibilities to improve the current peeling technology.

3.3.4. Exploring critical factors of steam peeling

Figure 3.2 shows a typical pressure curve of a steam peeler (Den Hertog, 2002). After filling the vessel with potatoes and closing the product door the steam inlet valve opens. During the first seconds pressure is built up rapidly till about 15 bar. In this example the inlet valve is closed at 13 s and after 13.7 s the exhaust valve is opened. This short-time-high-temperature treatment creates superheated steam below the skin, which flashes upon release of pressure and loosens the skin uniformly (Frazier, Arutunian, & Robe, 1978). Adjusting the time delay between opening and closing the steam valve (steam exposure time) can control the amount of peel removal. Peel removal effect is defined as the percentage peel that is removed and is usual judged by eye.

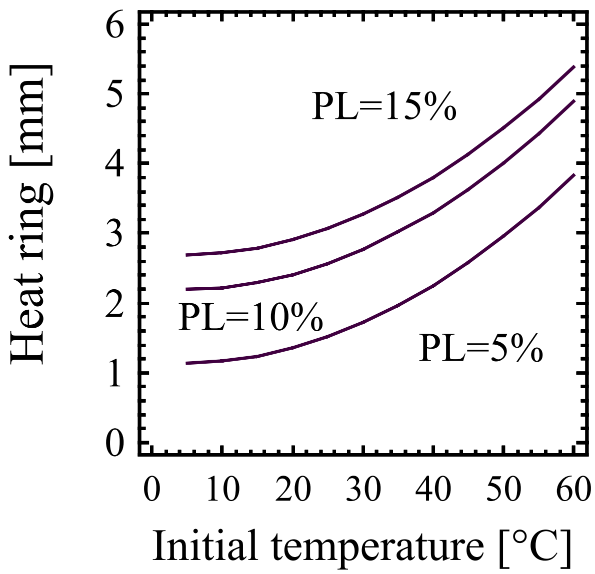

Figure 3.3. Predicted heat ring versus initial tuber temperature at equal peel loss.

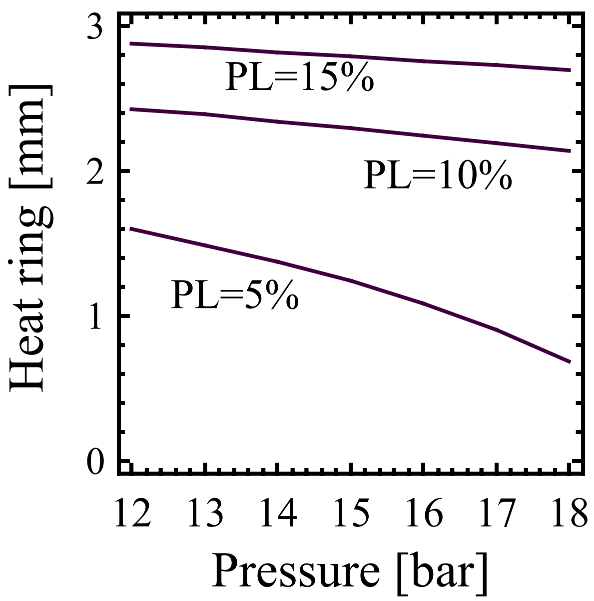

Figure 3.4. Predicted heat ring versus steam pressure at equal peel loss.


Tuber temperature 4 °C
Steam exposure 15.0 s
Heat ring = 1.5 mm
Specific peel loss = 3.0 %
Peel removal >99%


Tuber temperature 14 °C
Steam exposure 14.0 s
Heat ring = 1.9 mm
Specific peel loss = 3.2 %
Peel removal >99%


Tuber temperature 30 °C
Steam exposure 12.6 s
Heat ring = 2.3 mm
Specific peel loss 3.4 %
Peel removal >95-99%


Tuber temperature 45 °C
Steam exposure 11.6 s
Heat ring = 3.3 mm
Specific peel loss = 3.0 %
Peel removal >90-95%


Tuber temperature 60 °C
Steam exposure 10.7 s
Heat ring = 4.4 mm
Specific peel loss = 3.3 %
Peel removal >90-95%

Figure 3.5. Peel removal effect at equal peel loss but different initial tuber temperature.

During the steam treatment saturated steam condenses at the surface of the tubers. The condensation heat is transmitted to the surface and conducted towards the internal tissue. As a consequence the outer shell will rise in temperature. Starch tissue that will be above 65 °C will gelatinise. This tissue is darker in colour and has a translucent appearance. After steam peeling this heat ring is clearly visible. This heat ring was exposed to pressure and heat, which causes mechanical failure of the cell tissue and a break down of essential cell components such as pectins and polysaccharides (Floros & Chinnan, 1988). Basically the heat ring is more sensitive for abrasive forces than the initial tissue.

It was assumed that at equal peel loss a better peel removal effect would occur when the heat ring thickness would be thinner. A thinner heat ring means a higher concentration of heat more closely to the periderm, resulting in a more intense flash evaporation during pressure release. Secondly a smaller heat ring means less tissue removal during abrasive peel removal. To proof these assumptions two models were developed to estimate the peel loss [Eq. (3.8)] and thickness of the heat ring [Eq. (3.9)]. Accompanying multiple regression results of these equations are given in Tables 3.4 and 3.5.

$$PL = c_1 + c_2t + c_3N^{1/3} + c_4P + c_5tT \qquad (3.8)$$

$$HR = (d_1 + d_2\ln(t) + d_3N + d_4T^2)/1000 \qquad (3.9)$$

These models were used to simulate the effect of heat ring development at different process conditions. Results of simulations are shown in Figures 3.3 and 3.4. For these simulations number of tubers per kilogram and under-water-weight were kept constant at 6.45 kg^{-1} and 380 g. The iso-peel-loss curves made clear that a minimum heat ring development could be established at lower initial temperatures (Figure 3.3) and at higher pressures (Figure 3.4). Extended experiments were necessary to proof the assumption that a better peel removal effect would occur when the heat ring thickness will be thinner at equal peel loss. These results are shown in Figure 3.5. For these experiments potatoes (UWW=381 g, N=4.18 kg^{-1} and SA=6) were pre-conditioned at different temperatures. Used steam exposure times were 15.0, 14.0, 12.6, 11.6 and 10.7 s, to reach an equal peel loss of 5.1% [Eq. (3.8)] at conditioning temperatures of 4, 14, 30, 45 and 60 °C respectively.

Table 3.4. Multiple regression results of Eq. (3.8)

Parameter	Estimate	P-value
c_1	-14.6006	P<0.0001
c_2	3.25869×10^{-1}	P<0.0001
c_3	6.07524	P<0.0001
c_4	3.77747×10^{-1}	P<0.0001
c_5	2.46101×10^{-3}	P<0.0001
R^2 = 0.907; SE = 0.99; number of experiments =1080		

Table 3.5. Multiple regression results of Eq. (3.9)

Parameter	Estimate	P-value
d_1	-1.04002	P<0.0001
d_2	9.87825×10^{-1}	P<0.0001
d_3	2.11292×10^{-2}	P<0.0001
d_4	8.46080×10^{-4}	P<0.0001
R^2 = 0.831; SE = 0.00041; number of experiments =1080		

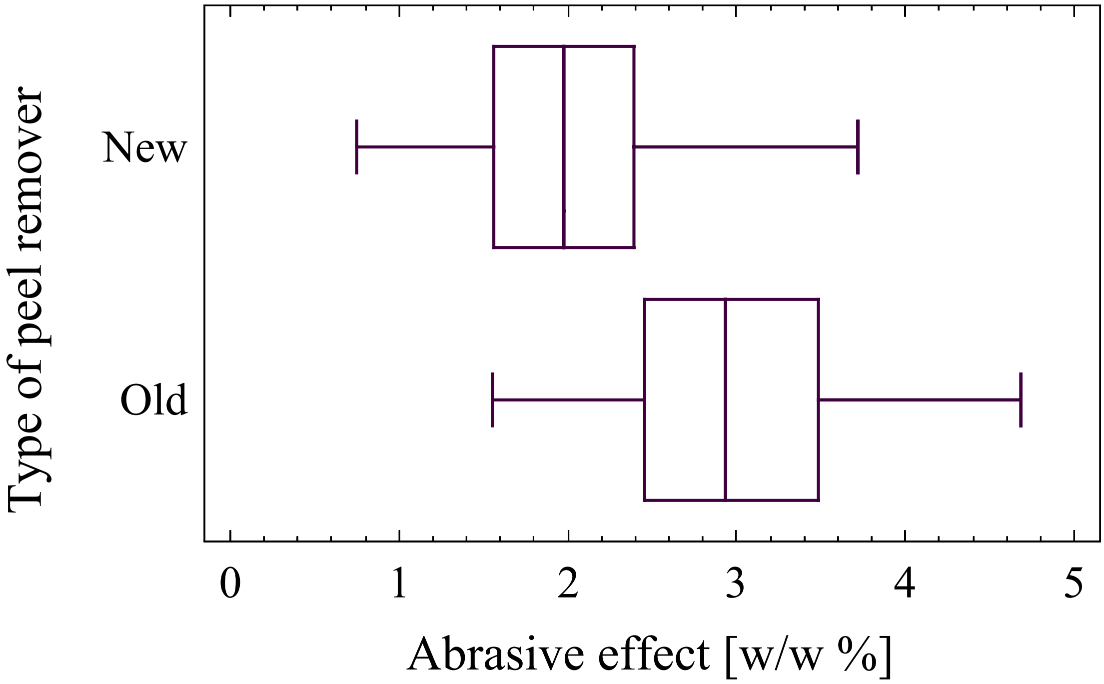

Figure 3.6. Box and Whisker plot of the abrasive effect of two different peel removers.

Table 3.6. Specific abrasive effect of peel remover in relation to thickness of the heat ring

Initial tuber temperature (°C)	Heat ring (mm)	Specific abrasive effect, $AE/N^{1/3}$ (%)	
		Mean	SE
4	1.5	1.08	0.143
14	1.9	1.65	0.188
30	2.3	1.73	0.125
45	3.3	1.85	0.067
60	4.4	2.02	0.115

Table 3.7. Variability in peel removal effect

Class of peel removal effect	>99%	>95 – 99%	>90 - 95%	>75 - 90%	<=75%	
	Percentage tubers in specific peel removal class (n/n%)					Number of experiments
Individually peeled tubers	100	0	0	0	0	30
30 tubers peeled together	40	16.7	16.7	0	26.7	1

According to Eqs. (3.2) and (3.8) specific peel loss at experimental conditions as given in Figure 3.5, should be 3.19%; the observed losses (3.0 till 3.4%) are quite close to that. The different photographs in Figure 3.5 demonstrate clearly that a better peel removal effect can be obtained at equal peel loss but smaller heat ring development.

At factory conditions the overall peel loss is depending on the amount of peel pulp (predicted by Eq. (3.8)) and the abrasive effect of the peel remover. A peel remover will not only remove the peel pulp but will scrape-off also a part of the pericyclic cortex that will increase the peel loss additionally by 1-5%. As a consequence, the overall peel loss will be considerable higher than predicted by Eq. (3.8) and the heat ring will be smaller than predicted by Eq. (3.9). Ratcliffe (1975) mentioned also a reduced heat ring due to the abrasive effect of peel removers. In Figure 3.6 the abrasive effect of two peel removers are shown. Average abrasive effect was 2.98% mass loss (SD=0.66) for an old type of peel remover and 2.00% mass loss (SD=0.58) for a new type.

A thicker heat ring will also mean that a bigger part of the pericyclic cortex is cooked resulting in a softer tissue that intensifies the abrasion of the peel remover as illustrated by Table 3.6.

Non-homogeneous peeling is another critical factor for substantial unwanted losses. Non-homogeneous peel removal is caused by the way of heat transfer during steam peeling. Condensate is formed from saturated steam and will cool down each part of the tuber surface touched, especially with tumbling instead of stationary steam vessels (Van der Schoot, 1997; Anon, 1999). The potatoes will be alternately steamed and dipped in much colder condensate. These parts will be peeled less efficiently. To reach an overall satisfying peel removal effect, longer steam exposure times are required, meaning that many tubers will be over-peeled. Table 3.7 proofs that non-homogenous peeling plays an important role during steam peeling. Potatoes were all steam-peeled for 14 s and had an average under-water-weight of 379 g, skin appearance appreciation of 6 and 3.75 tubers per kilogram.

3.3.5. Final discussion

In this study it was shown that peeling potatoes manually with sandpaper results in the lowest possible peel losses. It was proven that these losses were wanted losses. The wanted peel loss can be estimated when the raw material parameters skin appearance and number of tubers is known. In practice, steam peeling results not only in wanted losses but also in substantial unwanted losses of about 7.9%. The Yield Index of current steam peel technology is approximately 0.92. The observed peeling depth during steam peeling was about 1 mm although the periderm is only 0.16 mm thick. Removal of penetrating defects during peeling should be avoided, because these defected spots can be removed more yield efficient later on. Non-homogeneous heat transfer during steam exposure and the thickness of the heat ring in combination with the abrasive effect of the peel remover mainly causes this over-peeling. This indicates great potential for future improvements in the peeling technology of potatoes. Creating a homogenous peel removal effect with minimum heat ring development will be the main issue to improve raw material yield.

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CHAPTER 4

A blueprint to predict the maximum production yield

Abstract
Very little research on the production yield of par-fried French-fries has been reported in the literature. This paper bridges the knowledge gap and outlines the development of a model to predict the maximum production yield of par-fried French-fries. This yield model can be used to calculate the yield efficiency of French-fries processing, according to the PYA-method (Production Yield Analysis).

Nomenclature

A	*Additions that influence production yield*
CS	*Cut size (m)*
Dcell	*Average cell size of internal phloem (m)*
DL	*Defect load of strips before defect sorting (w/w %)*
DM	*Dry-matter content (w/w %)*
FC	*Fat content of final product (w/w %)*
FFDM	*Fat-free dry matter (w/w %)*
L	*Length [m]*
N	*Number of tubers per kilogram* (kg^{-1})
M	*Mass (kg)*
MA_max	*Additions at optimum process (kg)*
Mfp_max	*Maximum mass of final product (kg)*
Minp	*Mass of input (kg)*
ML	*Mass loss (kg)*
Mout	*Mass of product after specific unit operation (kg)*
Mrm	*Mass of clean raw material (kg)*
Muw	*Mass of a sample weighed under water (kg)*
PN	*Percentage nubs, based on mass after cutting (w/w %)*
PL	*Percentage peel loss (w/w %)*
PS	*Percentage slivers, based on mass after cutting (w/w %)*
QS	*Specifications of final product that influence production yield*
RC	*Response coefficient (-)*
RM	*Raw material variables that influence production yield*
SA	*Skin appearance (-)*
SC	*Reducing sugar content of raw material (w/w %)*
SCS	*Specific cut surface* ($m^2\ m^{-3}$)
TDL	*Target defect load of strips after defect removal (w/w %)*
TMC	*Target moisture content of final product (w/w %)*
TPS	*Target percentage of slivers after sliver removal (w/w %)*
TSC	*Target reducing sugar content of strips after blanching (w/w %)*
UWW	*Under-water-weight (g)*
v	*Number of raw material parameters that influence production yield*
w	*Number of added ingredients*
z	*Number of specifications that influence production yield*
ρ_w	*Density of water* ($kg\ m^{-3}$)

Nomenclature continued

Subscripts:

blanching	*Indicates the blanching process*
criticals	*Strips with a critical defected area*
cutting	*Indicates the cutting process*
defect_removal	*Removal of defect strips*
defect_reuse	*Reuse of the good part of the defected strips*
defect_sorting	*The net loss of defect sorting, meaning removal of defects minus the amount of reuse*
drying	*Indicates the drying process*
evaporation	*Indicates all processes that evaporates water (drying, frying and freezing)*
freezing	*Indicates the chilling and freezing process*
frying	*Indicates the frying process*
peeling	*Indicates the peeling process*
majors	*Strips with a major defected area*
minors	*Strips with a minor defected area*
nubs_removal	*Indicates the removal of nubbins*
sliver_removal	*Indicates the removal of slivers*
wanted	*Indicates a wanted or unavoidable mass loss*
unit	*Indicates an unit operation*
unwanted	*Indicates an unwanted mass loss*

4.1. Introduction

Food processors face increasing demands to improve their raw material yield efficiency. The basic approach to increase the raw material yield efficiency is to minimise unwanted mass losses (Somsen & Capelle, 2002). Wasting raw materials should be avoided, because the largest proportion of the overall business costs is associated with the purchase of raw materials. This wasting will therefore put the company's profit under pressure (Somsen & Capelle, 2002). From a sustainability point of view, it is also important to transform raw materials efficiently into final products. There is an increasing interest to find appropriate measures to track the yield efficiency of food processes in order to guide organisational actions to reduce unwanted mass losses. Many unwanted mass losses are hidden and need to be explored to make the management fully aware of these losses and the corresponding economic impact. Poor practice, poor maintenance, outdated equipment and technologies must first be visualised before they can be corrected.

The raw material yield efficiency of a process can be expressed in the Yield Index, as described by Somsen and Capelle (2002). To measure the Yield Index, a food processor should measure the actual production yield and compare this with the maximum production yield. However, for many food processors the maximum production yield is unknown because of the lack of knowledge. With a systematic approach and considerable research effort it is possible to build a model that can predict the maximum production yield with respect to raw material parameters, additions and final product specifications (Somsen & Capelle, 2002). This model can then be used to pinpoint unwanted mass losses in the production process. This paper will describe the development of a model to predict the maximum production yield of French-fries. For the unit operation peeling this approach was discussed extensively in chapter 3 (Somsen, Capelle, & Tramper, 2004b).

There is little information in literature about the actual production yield of French-fries. Talburt, Weaver, Reeve, and Kueneman (1987) and Lisińska and Leszczyński (1989a) reported figures between 30 and 45%. Recently, there are no papers published that describe the influence of each individual unit operation on production yield of French-fries. In this chapter this knowledge gap will be filled and a blueprint is presented to predict the maximum production yield of French-fries.

4.2. Model development

The maximum amount of final product (Mfp_max) that can be transformed out of a certain mass of raw material (Mrm) and additions (MA_max) can be realised when there are only wanted or unavoidable mass losses (ML_{wanted}). The overall mass balance of this process is given by Eq. (4.1) (Somsen & Capelle, 2002). Out of this mass balance, the maximum production yield (PY_max) can be calculated as expressed by Eq. (4.2).

$$Mfp\_max = Mrm - ML_{wanted} + MA\_max \tag{4.1}$$

$$PY\_max = 100 Mfp\_max / Mrm \tag{4.2}$$

Wanted mass losses during French-fries production can be divided into individual losses per unit operations as stated by Eq. (4.3).

$$\begin{aligned} ML_{wanted} = {} & ML_{wanted,peeling} + ML_{wanted,cutting} + ML_{wanted,sliver\_removal} + ML_{wanted,nubs\_removal} + \\ & ML_{wanted,defect\_sorting} + ML_{wanted,blanching} + ML_{wanted,evaporation} \end{aligned} \tag{4.3}$$

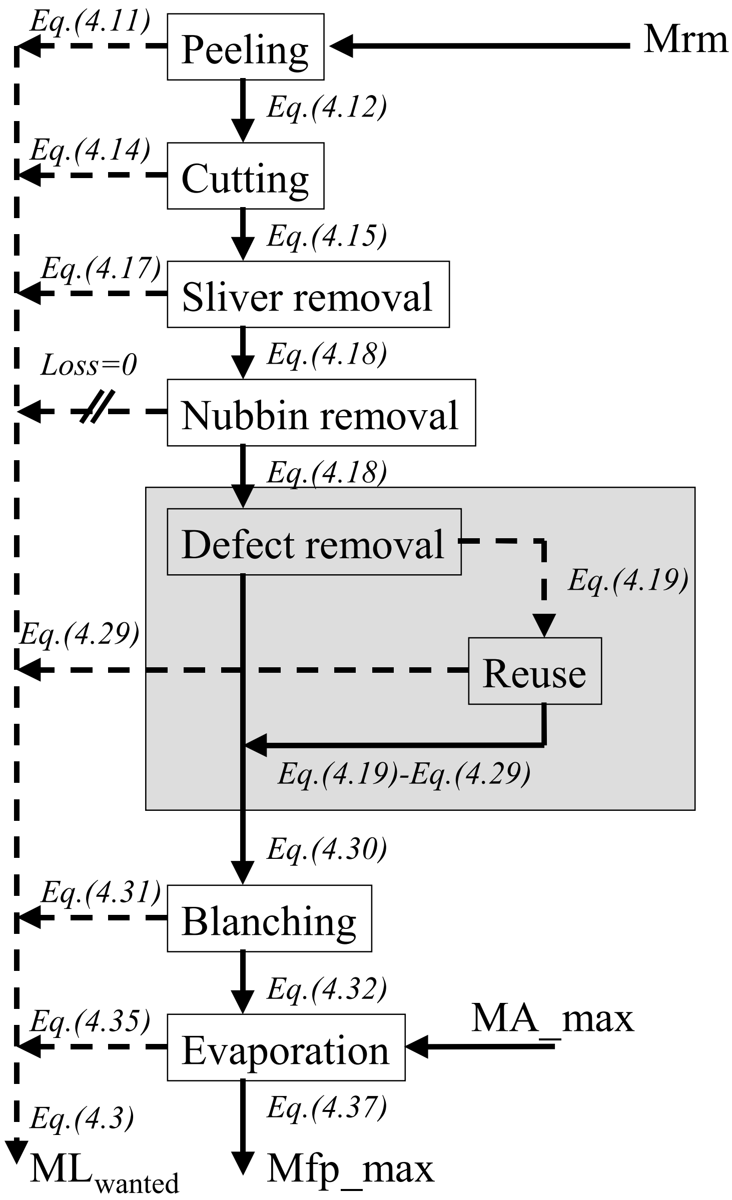

Figure 4.1. Blueprint of the yield model.

The last mentioned mass loss in Eq. (4.3) is not realised by one single unit operation. Traditionally strips were par-fried after the blanching operation, which resulted in the evaporation of water. Nowadays blanched strips are first dried in a hot air dryer and subsequently par-fried. After par-frying, the strips are chilled and deep-frozen. To some extent, water is also evaporated during chilling and freezing. From a yield perspective the overall water evaporation is of interest and not the particular unit operations that were used. For that reason the term "evaporation" was used to include all of these particular unit operations.

In previous work (Somsen & Capelle, 2002), a generic equation was given to predict the maximum production yield as a function of raw material parameters (RM), additions (A) and quality specifications (QS). In this study, the wanted mass loss for each individual unit operation will be investigated when the mass of input ($Minp_{unit}$) is known. Therefore, Eq. (4.4) will be solved for each relevant unit operation. These series of equations can be used to calculate the overall mass loss [Eq. (4.3)], maximum amount of final product [Eq. (4.1)] and the maximum production yield [Eq. (4.2)].

$$ML_{wanted,unit} = f\left(Minp_{unit}, RM[1..v], A_{unit}[1..w], QS[1..z]\right) \qquad (4.4)$$

A blueprint of the model is given in Figure 4.1. The lines represent the main process flow and the dashed lines the wanted mass loss per unit operation. Per unit operation, one equation is given to calculate the wanted mass loss and one to calculate the output, which is the input for the next unit operation. All these equations will be extensively discussed in this chapter.

4.3. Materials and methods

4.3.1. Raw material and sampling method

Ware-potatoes (*Solanum tuberosum* L. cv.: Agria, Asterix and Bintje) were used, grown on sandy, loam and clay soils in The Netherlands under the usual regime. Potatoes were harvested in September-October and stored at 6-8 °C until required. Before shipment potatoes were reconditioned for 2-3 weeks at 15-18 °C. Potatoes used for the experiments were manually taken from a running belt at factory intake during unloading of the trailer (batch size about 35 metric tons). The tubers were washed carefully by hand with tap water of 12 °C ± 2 and after that completely dried with paper tissue.

4.3.2. Method of transformation for measuring peel and sorting losses

For each run 3-3.5 kg, potatoes were used. The exact mass (Mrm) was weighed (Mettler PM34-K ±0.1 g) and number of tubers was counted. The average skin appearance of the sample was judged by eye (Somsen et al., 2004b) according to the scheme of Russo, Evensen, & Braun (1988). Potatoes were weighed under water (Muw) and temperature of the water was measured (Somsen, Capelle, & Tramper, 2004a). Next potatoes were peeled manually by scrubbing the tubers with sandpaper (Segro P120) by running tap water over it until clean. All surface defects that penetrate into the underlying tissue were left untouched. The tubers were dried with paper tissue and weighed ($Mout_{peeling}$). The mass loss during peeling was calculated by Eq. (4.5) and percentage loss (PL_{wanted}) by Eq. (4.6) (Somsen et al., 2004b). Next, the tubers were weighed under water ($Muw_{peeling}$) and individually cut in perfect longitudinal direction into strips (LT cutter, type CS). All strips were collected including all small pieces and washed thoroughly (each strip individually) with tap water to remove all adherent potato substances. The sample was de-watered partly by shaking it manually for 10 s in a perforated crate. Additionally all material was weighed in air and under water ($Muw_{cutting}$). The cutting loss was calculated according Eq. (4.7). The cutting loss cannot be measured accurately by subtracting the mass after cutting from the mass before cutting, because water uptake during cutting and washing disturbs this mass balance. Removal of the adherent water with paper tissues was no option as was found out during preliminarily studies because initial capillary water of the potato tissue was removed also, which made it impossible to measure the cutting loss correctly. Uptake of water does not influence the mass of the sample weighed under water and therefore Eq. (4.7) was derived to measure the mass loss accurately.

$$ML_{wanted,peeling} = Mrm - Mout_{peeling} \qquad (4.5)$$

$$PL_{wanted} = 100(Mrm-Mout_{peeling})/Mrm \qquad (4.6)$$

$$ML_{wanted,cutting} = Mout_{peeling}(Muw_{peeling}-Muw_{cutting})/Muw_{peeling} \quad (4.7)$$

Losses due to sliver, nubs and defect removal were calculated based on the same principal. The sample was de-watered again by a perforated tray as previously mentioned. Strips with a size smaller than 60% of the initial cut size, defined as slivers, were all manually removed and weighed. The remaining strips were weighed in air and under water and de-watered again. Subsequently strips with a length shorter than 25 mm, defined as nubbins, were manually removed and weighed. The remaining strips were weighed in air and under water and de-watered again. Next strips with a defected area (green, blue, brown or black coloured spot) ≥7 mm² were sorted out manually. For this study, defects were classified in three size classes i.e. minor, major and critical defects. Minor defects were defined as having a defected area of ≥7 till <28 mm², majors ≥28 till <113 mm² and criticals ≥113 mm². Defects smaller than minors were not classified as a defect. This classification scheme is commonly used in the French-fries industry. The mass of defected strips per class was weighed. From the defected strips, the defected area was cut-off with a knife (Figure 4.2) directly along the defected area. From the remaining good parts, all strips shorter than 25 mm were manually removed. The rest of the recovered good and long strips were weighed per defect class and this amount was added to the other good strips. Overall mass of good strips was weighed in air and under water. Three randomly chosen strips were selected and with a microtome a tissue sample was cut off. The tissue was carefully washed and investigated under a microscope (Olympus SZ60; magnification 128x), which was connected to a digital camera (Olympus DP10) and computer system (SIS-analysis v.3). The longest dimension off each cell was measured and one exactly perpendicular to it.

The experimental design was based on the factors: variety, number of tubers per kilogram and cut size. Three varieties were used (see paragraph 4.3.1). Number of tubers per kilogram was varied at six levels (<3.5, 3.5-<4.5, 4.5-<6, 6-<9, 9-<13, ≥13 kg^{-1}) and cut size was varied at four levels (6x6, 8x8, 10x10 and 13x13 mm). Statistical software "Statgraphics Plus version 4.0" was used to apply multiple regression analysis on the observed mass losses versus raw material parameters and quality specifications.

4.3.3. Method for measuring moisture losses during frying

For each run 9-10 kg, potatoes were used. Quarter sector was cut lengthwise out of each tuber. The sectors were homogenised in a Hobart blender. The dry-matter content (DM) of the homogenate was determined in duplicate according to standard EAPR-method (Burton, n.d.). The rest of the potatoes (¾-tubers) were weighed in air (M) and under water (Muw). Water temperature was measured (±0.1 °C) to estimate the density of the water (ρ_w) (Weast, 1972). The under-water-weight (UWW) was calculated according to Eq. (4.8) (Somsen et al., 2004a).

$$UWW = 5000Muw/M+5(\rho_w-1000) \quad (4.8)$$

The ¾-tubers were cut into strips (10x10 mm). Strips were washed thoroughly with tap water to remove adherent cell substances and de-watered by shaking them for 10 s in a perforated crate. Slivers smaller than 6 mm were rejected manually. Strips were mixed by hand and divided in 4 approximately equal portions. Strips from portion 1 were homogenised in a blender. The dry matter (DM) of the homogenate was determined in duplicate according to standard EAPR-method (Burton, n.d.). The exact mass of portion 2, 3 and 4 was weighed in air and under water. Under-water-weight of these portions was calculated by Eq. (4.8). Portion two until four were separately par-fried in unhardened palm oil (melting point 36-37 °C) at 170 °C for respectively for 1.5, 3 and 4.5 minutes. After frying, strips were cooled

Figure 4.2. Defect removal of cut strips.

(15 min till 25 °C), chilled (15 min till 2 °C) and deep-frozen (20 min till -20 °C). Product of each portion was weighed and divided into approximately two equal sub samples. Dry-matter and fat content of each sub sample were analysed to conform standard by EAPR-method (Burton, n.d.). Fat-free dry-matter content (FFDM) of fried samples was calculated based on Eq. (4.9).

$$FFDM=DM-FC \tag{4.9}$$

Statistical software (Statgraphics) was used to apply basic linear regression to the observations (DM versus UWW). For the frying experiments, it was assumed that the initial amount of dry matter (prior to frying) would be fully retained. This assumption was checked by a pairwise comparison (Student t-test) of the mass of dry matter prior to frying versus the mass of fat-free dry matter after frying. The initial fat content of the raw strips was neglected in this study, because this content is relatively low, 0.01-0.126% (Cherif & Ben Abdelkader, 1970; Galliard, 1973) and hard to analyse precisely at contents below 0.1%.

4.4. Results and discussion

4.4.1. Peeling

In chapter 3 (Somsen et al., 2004b), a model was described extensively to calculate the wanted peel loss [Eq. (4.10)]. These results were based on experiments in which potatoes were manually peeled by use of sandpaper until clean. This way of peeling is most yield efficient and results in solely periderm removal. The wanted peel loss is affected by two raw material parameters, namely skin appearance (SA) and the number of tubers per kilogram (N) as was shown. The wanted peel loss will increase when potato size decreases (larger N values) and the surface of the skin becomes rougher (smaller SA values) and follows the following equation.

$$PL_{wanted} = (1.572 - 0.09595\ SA)^2\ N^{1/3} \tag{4.10}$$

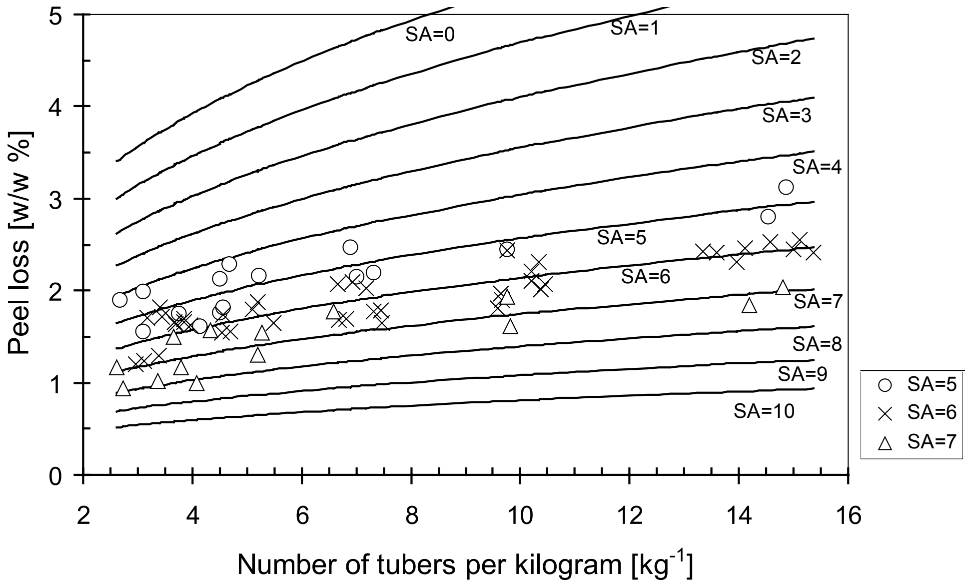

Figure 4.3. Wanted peel loss as a function of number of tubers per kilogram and skin appearance (SA).

Based on Eq. (4.10), Eq. (4.4) for the peeling operation can be solved, resulting in Eq. (4.11).

$$ML_{wanted,peeling} = 0.01 * Mrm * (1.572 - 0.09595 * SA)^2 N^{1/3} \tag{4.11}$$

The mass of product after the peeling operation is equal to the mass of raw material minus the peel loss, as expressed by Eq. (4.12).

$$Mout_{peeling} = Mrm - ML_{wanted,peeling} \tag{4.12}$$

Results of the present study are shown in Figure 4.3 together with the predicted curves based on Eq. (4.10). The observed peel losses are in the same order of magnitude as the predicted losses. It makes clear that wanted peel losses are relatively small (1-2.5%) instead of peel losses under factory conditions (5-20%) (Somsen et al., 2004b). This finding shows that there is a high potential to reduce unwanted mass losses in the future by improved peeling technologies.

4.4.2. Cutting

During cutting, cell tissue adjacent to the knife blades is damaged and the cell content is completely lost. The internal phloem (perimedullary zone) occupies about 75% of the total tuber volume (Fedec, Ooraikul, & Hadziyev, 1977) and is therefore the most relevant part of the tuber to correlate cutting losses. Table 4.1 shows significant differences ($P<0.05$) in cell sizes between varieties. According to Burton (1989), the cell size of potatoes ranges from 100 to 200 μm. These results are within this range.

Cutting tubers into strips is a two-dimensional operation because all cutting actions are parallel to the tuber length axis. The surface of a perfect bar shaped strip that was damaged by the knives is equal to *4CS.L* and the volume is equal to CS^2L. The ratio between cut area and

Table 4.1. Average cell size in the perimedullary zone

	Cell size			
Variety	Average (μm)	SD (μm)	SE (μm)	Number of experiments
Agria	166.8	43.76	0.799	3000
Asterix	176.9	52.06	0.967	2900
Bintje	154.7	44.09	0.804	3010

volume is defined as specific cut surface (SCS) and is equal to *4CS.L/CS²L*. This indicates that the specific cut surface is only affected by the cut size (CS) and not by the length of the strips [Eq. (4.13)]. This is important to know because strips are often not perfectly bar shaped at the tips of the strip, meaning that each side of the strip can have a different length (Figure 4.4).

$$SCS = 4/CS \qquad (4.13)$$

Results of cutting experiments are shown in Figure 4.5. A significant difference in percentage cutting loss ($P<0.05$) between varieties and cut size can be seen. Differences between varieties can be explained due to differences in average cell size (Table 4.1). The average percentage cutting loss of Asterix (4.11 %) for example is a factor 1.14 higher than Bintje (3.59 %), which is approximately equal to the ratio of the average cell size (176.9/154.7=1.14) of these two varieties. Based on the observations in Figure 4.5 it can be calculated that the ratio between percentage cutting loss and specific cut surface is approximately constant. For Agria, an average ratio of 8.4×10^{-3} m^{-1} ($SD=4.7\times10^{-4}$) was observed, for Asterix 8.8×10^{-3} m^{-1} ($SD=4.5\times10^{-4}$) and for Bintje 7.7×10^{-3} m^{-1} ($SD=3.6\times10^{-4}$). From these results, it can be deduced that the cutting loss is related to the cut size and the average cell size, as pointed out by Eq. (4.14). Based on these results it can be concluded that a single cell layer is disrupted during a cutting action. These cut cells will form two new surfaces at two different strips, for that reason a factor 2 was included in Eq. (4.14) instead of a factor 4 that was showed in Eq. (4.13).

$$ML_{wanted,cutting} = 2Mout_{peeling} Dcell / CS \qquad (4.14)$$

Mass of product after the cutting operation can be calculated by Eq. (4.15).

$$Mout_{cutting} = Mout_{peeling} - ML_{wanted,cutting} \qquad (4.15)$$

Cutting is generally one of the unit operations that is poorly and not often discussed in literature. For the manufacturing of French-fries the cutting loss was never quantified before in a proper way. We found a method to measure the cutting loss, based on a simple under-water weighing technique [Eq. (4.7)]. It made clear that the cutting loss is related to the average cell size and the specific cut surface and can be predicted by Eq. (4.14). We found also significant differences between the cutting losses of varieties due to differences in average cell size. This can be of importance by selecting varieties for processing.

4.4.3. Grading slivers

Slivers are too small strips, in this study defined as cut strips with a thickness smaller than 60% of the cut size. Percentage slivers will increase linearly proportional with the number of tubers per kilogram as was pointed out in chapter 3 (Somsen et al., 2004a). Besides the size of the potatoes, the sliver loss is also affected by the cut size of the strips as can be seen in

Figure 4.4. Bar shaped strip with four different length axis.

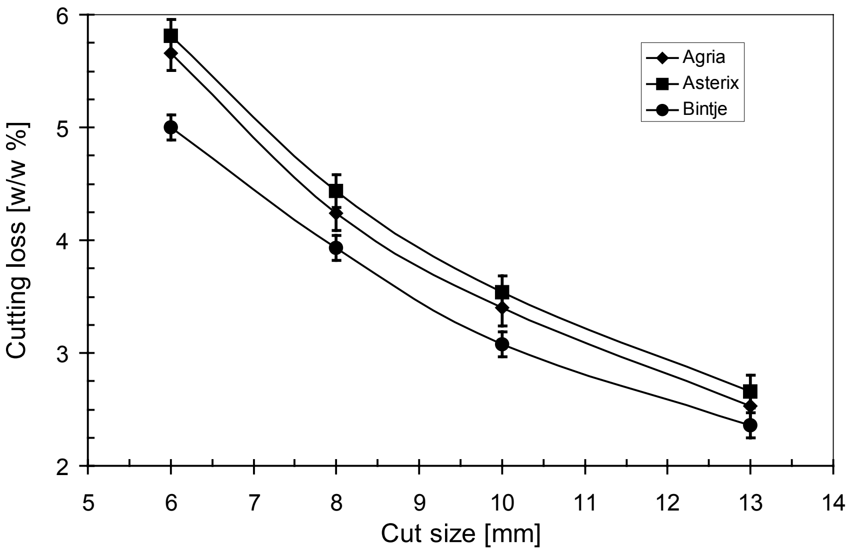

Figure 4.5. Percentage cutting loss and standard error as a function of cut size.

Figure 4.6. Based on multiple regression analysis Eq. (4.16) was found. The R^2 was 0.998, SE 0.24 and number of experiments was 72.

$$PS = 277.4\ CS + 30.12\ CS.N \qquad (4.16)$$

Slivers need only to be rejected when the actual percentage is higher than the target percentage (quality specification). When the target percentage (TPS) is higher than the actual percentage (PS), Eq. (4.17) is not valid because nothing has to be sorted out.

$$ML_{wanted,sliver\_removal} = Mout_{cutting}\left[1 - \frac{100 - PS}{100 - TPS}\right] \qquad (4.17)$$

Mass of product after sliver removal can be calculated by Eq. (4.18).

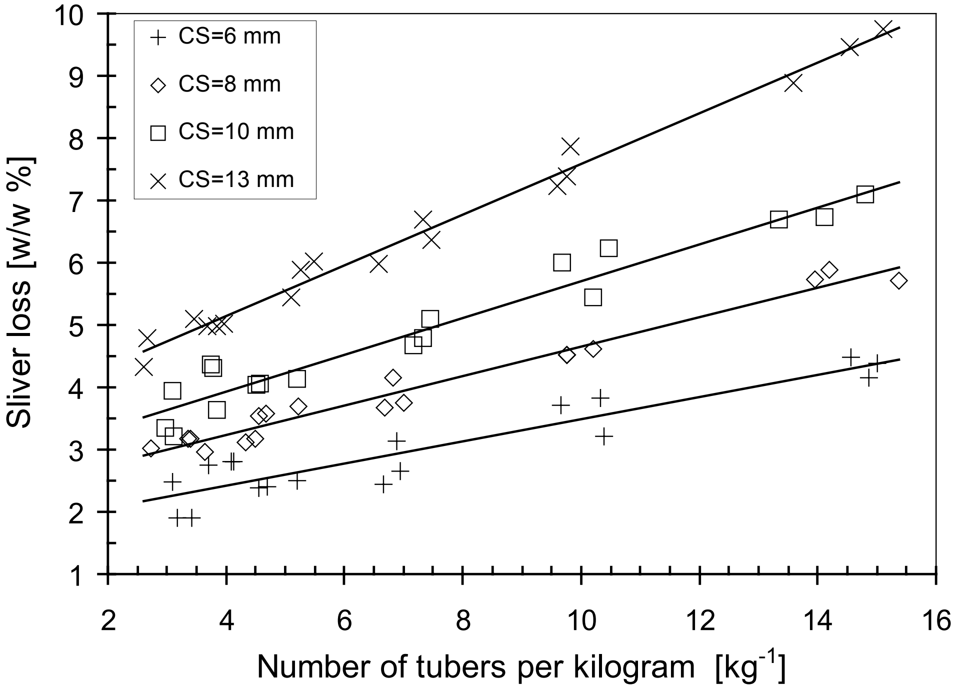

Figure 4.6. Percentage sliver loss as a function of number of tubers per kilogram.

$$Mout_{sliver\_removal} = Mout_{cutting} - ML_{wanted,sliver\_removal} \tag{4.18}$$

4.4.4. Grading nubs

Nubbins are short strips, with a length shorter than 25 mm. Nubbins were not detected in this study, all strips that were shorter than 25 mm were removed during sliver removal because these pieces were smaller than 60% of the initial cut size. Under factory conditions, nubbins often arise (Talburt et al., 1987; Lisińska & Leszczyński, 1989a), probably because tubers are not aligned in perfect longitudinal direction during cutting or because of breakage of strips, resulting in a considerable decrease of the length of the strips. However, these losses are often unnecessary and can be reduced as we found out in practice. Therefore, we developed a special patented knife assembly to approach the perfect way of cutting (Somsen, 2001).

4.4.5. Defect sorting

Diseases, pests, bruises and injuries will result in a decline of raw material quality, which will lead to a certain amount of defected strips after cutting and sliver removal. The defected area of these strips is mostly located at the tip of the strip and can be black, brown, blue or green coloured. The defects are classified by size in minor, major and critical defects. The total mass of these defected strips expressed in weight percentage of total mass of strips is defined as the defect load (DL). This initial defect load should be reduced till a certain specified level (TDL) by removal of defected strips during defect sorting, which will result in a wanted mass loss as expressed by Eq. (4.19).

$$ML'_{wanted,optical\_sorting} = Mout_{nubbin\_removal}\left[1 - \frac{100 - DL}{100 - TDL}\right] \tag{4.19}$$

This mass loss can be separated into mass losses per class of defect size as pointed out by Eqs. (4.20)-(4.22).

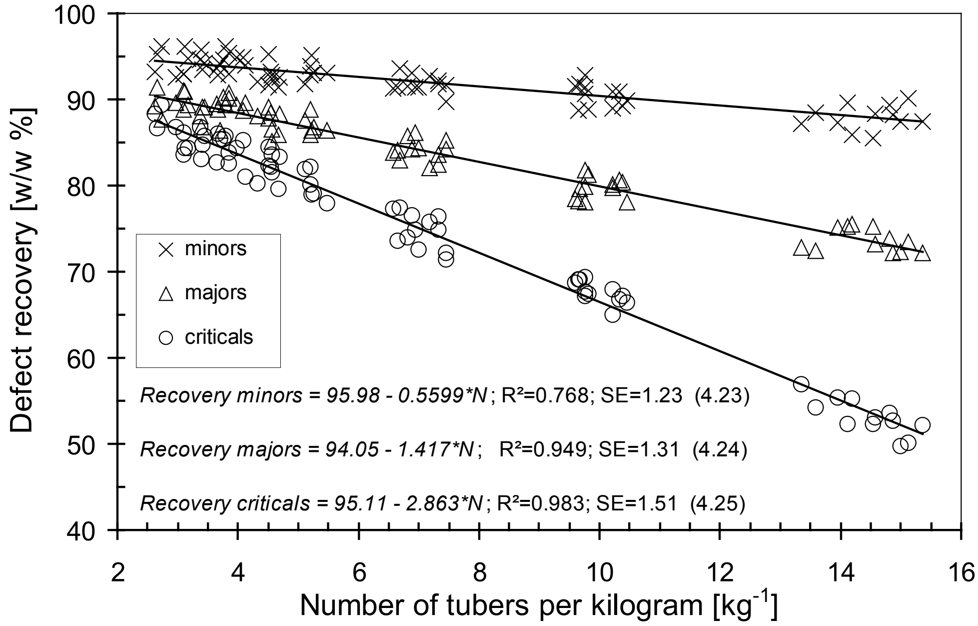

Figure 4.7. Percentage defect recovery versus number of tubers per kilogram.

$$ML'_{wanted,minors} = Mout_{nubbin\_removal} \frac{DL_{minors} - TDL_{minors}}{DL - TDL}\left[1 - \frac{100 - DL}{100 - TDL}\right] \qquad (4.20)$$

$$ML'_{wanted,majors} = Mout_{nubbin\_removal} \frac{DL_{majors} - TDL_{majors}}{DL - TDL}\left[1 - \frac{100 - DL}{100 - TDL}\right] \qquad (4.21)$$

$$ML'_{wanted,criticals} = Mout_{nubbin\_removal} \frac{DL_{criticals} - TDL_{criticals}}{DL - TDL}\left[1 - \frac{100 - DL}{100 - TDL}\right] \qquad (4.22)$$

Eqs. (4.19)-(4.22) are only valid if the target defect load (TDL) is less than the actual defect load (DL). When this boundary condition is not satisfied, the mass loss due to defect removal will be zero.

Defected strips that are rejected during defect sorting can partly be reused by cutting-off the defected area of the strips (Figure 4.2). When the good part of the strips is longer than 25 mm, this strip can be reused and this will substantially reduce the mass loss. Figure 4.7 shows experimental results of percentage reuse per class of defect size. The percentage reuse is higher at smaller defect sizes and at bigger tuber sizes (smaller N values), because cutting-off a small defected part from a long strip will result in a higher recovery than doing the same for a small strip with a large defected part. The Eqs. (4.23)-(4.25) in Figure 4.7 were used to develop Eqs. (4.26)-(4.28). These equations express the net sorting loss (reject minus reuse) per class of defect size. The net mass loss (ML) is equal to the rejected mass during defect sorting (ML') minus the amount that was recovered. Net overall mass loss of defect sorting can be calculated by Eq. (4.29) and the corresponding mass of output by Eq. (4.30)

$$ML_{wanted,minors} = ML'_{wanted,minors}(1 - 0.9579 + 0.005333N) \tag{4.26}$$

$$ML_{wanted,majors} = ML'_{wanted,majors}(1 - 0.9415 + 0.01430N) \tag{4.27}$$

$$ML_{wanted,criticals} = ML'_{wanted,criticals}(1 - 0.9504 + 0.02854N) \tag{4.28}$$

$$ML_{wanted,optical\_sorting} = ML_{wanted,minors} + ML_{wanted,majors} + ML_{wanted,criticals} \tag{4.29}$$

$$Mout_{defect\_sorting} = Mout_{nubbin\_removal} - ML_{wanted,optical\_sorting} \tag{4.30}$$

From practical experience we know that currently available equipment to cut-off defected parts are operated far from the optimum as was expressed by Figure 4.7. Losses up to 4 times more are common. This indicates that there is a potential to improve this unit operation in the future.

4.4.6. Blanching

Hot water blanching is commonly used and is needed to inactivate enzymes, to gelatinise starch and to extract reducing sugars (glucose and fructose) until an acceptable level. The average reducing sugar content in potatoes is about 0.3% (Lisińska & Leszczyński, 1989b). A higher reducing sugar content than approximately 0.5% disqualifies potatoes for the manufacturing of French-fries, indicating that the French-fries industry needs potatoes with a relatively low reducing sugar content.

During blanching reducing sugars are leached out; this mass loss is wanted and necessary to prevent the production of too dark-coloured fries. However, all other soluble components (organic acids, minerals, amino acids etc.) are leached out also. This will result in an unwanted mass loss. Ascorbic acid for example has a 25% higher diffusion coefficient than glucose (Garotte, Silva, & Bertone, 1986). Rice, Selman, and Abdul-Rezzak (1990) showed that the overall diffusion coefficient of all soluble substances in potato tissue is approximately equal to the specific diffusion coefficient of reducing sugars. In the most yield efficient process, reducing sugars are leached out exclusively, leaving the rest of the components unattached. This means that soluble components in the tissue, with the exception of reducing sugars, must be in equilibrium with the surrounding medium. This wanted mass loss is calculated by Eq. (4.31).

$$ML_{wanted,blanching} = Mout_{optical\_sorting}\left[1 - \frac{100 - SC}{100 - TSC}\right] \tag{4.31}$$

Mass of product after blanching can be calculated by Eq. (4.32).

$$Mout_{blanching} = Mout_{optical\_sorting} - ML_{wantd,blanching} \tag{4.32}$$

An average initial reducing sugar concentration of about 0.3% (SC) and a wanted level of about 0.07% (TSC) indicate the minor influence of the blanching operation on production yield. In the most yields efficient process, the mass loss will be in average 0.23% of the mass prior to blanching. This mass loss will result in a decrease of the dry-matter content of the strips.

4.4.7. Evaporation of water during drying and frying

Production yield decreases if dry-matter content of raw material decreases. This is because of the necessity to evaporate more water during drying and frying to achieve customer requirements for final solids (Somsen et al., 2004a). The dry-matter content of the raw material can be estimated by measuring the under-water-weight (Von Schéele, Svensson, & Rasmusson, 1937; Verma, Malhotra, Joshi, & Sharma, 1971; Ludwig, 1972; Schippers, 1976; Gormley & O'Donovan, 1992). In the present study the under-water-weight of tubers and cut strips was measured. Results are shown in Figure 4.8. There was no difference in the relationship (dry matter versus under-water-weight) between tubers and strips found. We found $DM=1.996+0.04927UWW$, SE of intercept was 0.503, SE of the slope was 0.00129 and SE of estimate was 0.30%. These results are not significantly different ($P<0.05$) from equations found by Von Schéele et al. (1937) and Ludwig (1972). They found $DM=1.95+0.0493UWW$ and $DM=2.00+0.0492UWW$, respectively.

The mass loss during drying and frying is caused by the evaporation of water. In this study, it was assumed that the initial amount of dry matter would be left unchanged during these unit operations. This assumption is often used in literature but never checked on correctness. Figure 4.9 show the mass of fat-free dry matter after frying (y-axis) versus mass of dry matter prior to frying (x-axis). A paired-wise comparison of these data (Figure 4.9) proofs that there is no significant difference between both masses. This means that mass losses during drying and frying can be solely explained by loss of moisture.

The dry-matter content after blanching is equal to the initial dry-matter content [Eq. (4.33) in Figure 4.8] minus the amount of reducing sugars that was leached-out during blanching [Eq. (4.34)].

$$DM = 1.996 + 0.04927 * UWW - (SC - TSC) \qquad (4.34)$$

The amount of final product is equal to the amount of product prior to drying minus the total amount of water that is evaporated [Eq. (4.35)] during drying, frying and freezing plus the fat uptake during frying as mathematically formulated by Eq. (4.36).

$$ML_{wanted,evaporation} = 0.01 Mout_{blanching}\left[(100 - DM) - \frac{DM * TMC}{100 - TMC - FC}\right] \qquad (4.35)$$

$$Mfp\_max = Mout_{blanching} - ML_{wanted,evaporation} + 0.01 Mout_{blanching} TFC \frac{DM}{100 - TMC - FC} \qquad (4.36)$$

Substituting Eqs. (4.34) and (4.35) into Eq. (4.36) will give:

$$Mfp\_max = Mout_{blanching} \frac{1.996 + 0.04927 * UWW - (SC - TSC)}{100 - TMC - FC} \qquad (4.37)$$

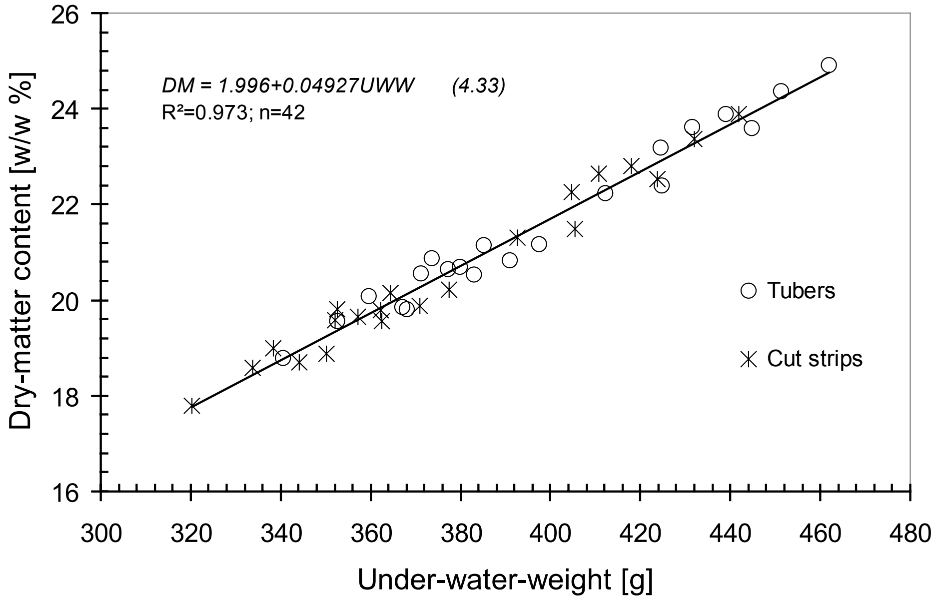

Figure 4.8. Dry-matter content versus under-water-weight.

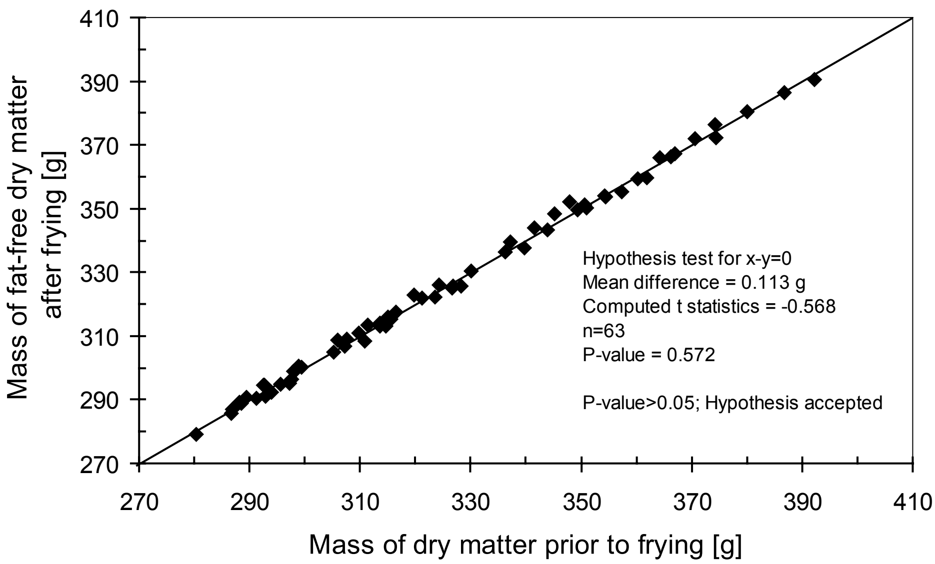

Figure 4.9. Fat-free dry matter of final product versus dry matter prior to frying.

4.5. Final discussion and conclusions

The measurement of mass losses during each unit operation cannot be simply measured based on the mass before and after each unit operation. The mass of cut strips for example was higher than the mass of initial raw material because of the presence of surface water. This additional mass of water was higher than the total loss during peeling and cutting. Therefore, the wet mass (product plus surface water) was measured and the mass weighed under water.

These values can be used to calculate the true loss of initial potato material as explained in the materials and methods section of this paper. The amount of surface water is strongly influenced by cut size and is linear proportional to the specific surface of the strips. We observed 0.179 kg adherent water per square meter of strip surface (SD= 0.021 kg/m²).

Based on the developed model (Figure 4.1) the true mass loss (without surface water) can be calculated per unit operation. The model inputs, as described by Eq. (4.4), can be grouped in raw material parameters, additions and product specifications, respectively RM[N, UWW, SA, DL, Dcell, SC], A[FC] and QS[CS, TDL, TSC, TMC]. The maximum production yield of French-fries cannot be specified by one typical number, because the yield depends on 11 variables. To visualise the magnitude of the wanted mass loss per unit operation a simulation was done. Figure 4.10 show that the highest mass loss is observed during the evaporation operation. The three example cases in Figure 4.10 show that the "evaporation loss" is strongly influenced by the target moisture content of the final product. The additions of fat per 100 kg of raw material, which are reported in Figure 4.10, are based on practical experiences. For the examples chosen in Figure 4.10, the maximum yield varies between 64% and 73.5%.

A basic sensitivity analysis was applied to the model to investigate the relative importance of accuracy in model inputs versus output. Product specifications and addition of fat were kept constant at the specified levels of Figure 4.10 (case 1). Each raw parameter (RM) was varied in the range 0.75-1.25 times the setpoint value specified in Figure 4.10, keeping all other variables constant. Figure 4.11 shows the results of the sensitivity analyses. The response coefficient (RC) for each raw material parameter was calculated by Eq. (4.38).

$$RC = \frac{\mathrm{d}(\ln(PY\_max))}{\mathrm{d}(\ln(RM))} \tag{4.38}$$

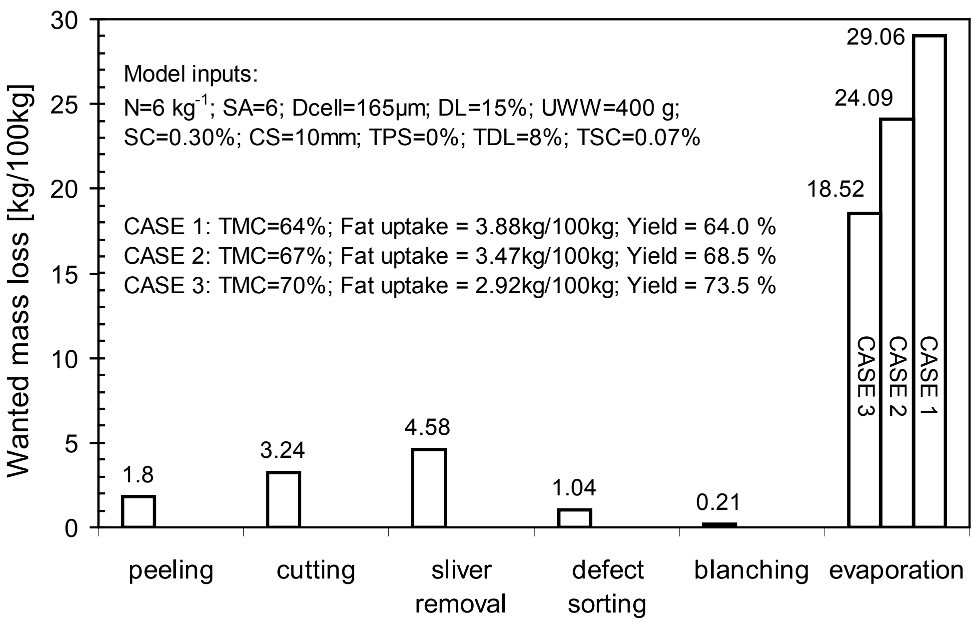

Figure 4.10. Simulated unwanted mass losses for 10x10 mm French-fries per unit operation.

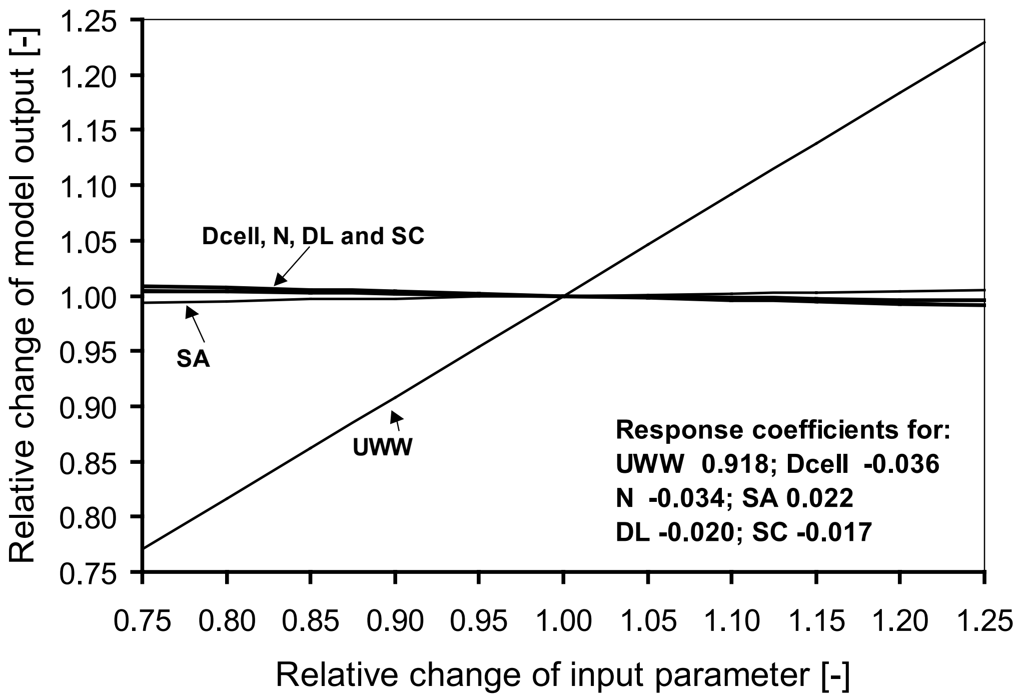

Figure 4.11. Sensitivity analysis of the model for all raw material parameters.

Figure 4.11 show that all raw material parameters, with the exception of under-water-weight, are insensitive parameters. The under-water-weight is by far the most sensitive parameter and needs therefore precisely be measured in practice. However, the measurement of under-water-weight is relatively simple, costs little and is non-destructive to the sample taken. This makes it possible to use large sample sizes at factory intake to reduce the sampling error to assure accurate model predictions.

Part 2 of this thesis can be complemented with the following major conclusions:

- Peeling potatoes manually with sandpaper results in the lowest possible peel losses (1-2.5%). Current steam peeling technology realises a yield efficiency of about 0.92 under factory conditions, which indicates a substantial potential for improvements.
- A method was developed to measure cutting losses. Wanted cutting losses between 2 until 6% were found depending on cut size and average cell size. Significant differences between cutting losses of varieties were found.
- When tubers are perfectly aligned in longitudinal orientation during cutting no nubbins were found.
- Defected strips that are rejected during defect sorting can be reused by cutting-off the defected area of the strips. Recoveries between 50 until 96% were found depending on number of tubers per kilogram and defect size.
- It was proven that the initial amount of dry matter prior to frying is left unchanged during frying. Many workers assumed this true, but it was never proven before.
- The production yield of French-fries cannot be specified by one typical figure, but is influenced by many factors. The development of a model will help to understand the influence of these factors on production yield, which forms the foundation for yield optimisation based on the PYA-philosophy as pointed out by Somsen and Capelle (2002).

Acknowledgements

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PART 3

Yield modelling of a poultry-slaughtering line

CHAPTER 5

Production yield analysis in the poultry-processing industry

Abstract
The paper outlines a case study where the PYA-method (production yield analysis) was implemented at a poultry-slaughtering line, processing 9000 broiler chicks per hour. It was shown that the average live weight of a flock of broilers could be used to predict the maximum production yield of the parts (fillet, legs, wings etc.). For all parts a strong linear relationship for the weight of the parts with the average live weight (LW) was found. Significant differences ($p \leq 0.05$) between the strains Ross 308 and 508 were observed. Ross 308 showed significant higher yields for feet, guts and lungs, heart (LW<1626.2 g), skinned gizzard, neck without skin, tail (LW>1907.4 g), skeleton frame of the breast, saddle and legs. Ross 508 showed significant higher yields for chilled carcass, heart (LW>1626.2 g), tail (LW<1907.4 g), breast, fillet and upper back.

The Yield Indexes that were calculated for the various parts varied between 0.5 and 1.0 and showed remarkable potentials for yield improvement. Yield improvements were realised by many actions like: good housekeeping, training and instructing of employees, fine-tuning of equipment and replacement of out dated machinery or parts of it.

Nomenclature

A	*Additions that influence production yield*
c	*Intercept of regression equation*
d	*Slope of regression equation*
FTE	*Full time employee*
LW	*Average live weight of the broilers (kg)*
M	*Average mass (kg)*
MA_max	*Additions at optimum process (kg)*
Mfp_max	*Maximum possible mass of final product (kg)*
ML	*Mass loss (kg)*
Mrm	*Mass of raw material (kg)*
PY	*Current production yield (w/w %)*
PY_max	*Maximum production yield (w/w %)*
QS	*Specifications of final product that influence production yield*
RM	*Raw material variables that influence production yield*
SE	*Standard error*
SEE	*Standard error of estimate*
YI	*Yield Index (-)*
v	*Number of raw material parameters that influence production yield*
w	*Number of added ingredients*
z	*Number of specifications that influence production yield*

Subscripts:

part	*Indicates a typical part of the broiler*
wanted	*Indicates a wanted or unavoidable mass loss*

5.1. Introduction

Poultry is the world's second most consumed type of meat. Currently, the annual worldwide growth rate is about 5%. Broiler meat dominates the world poultry consumption over 70% (Roenigk, 1999) and is therefore of particular interest for raw material yield efficiency studies. This is proven by the fact that studies about the yield of the meat parts of broiler chickens are a popular subject in the scientific literature. Swanson, Carlson, and Fry (1964), Carlson, Marion, Miller, and Goodwin (1975) and Orr and Hunt (1984) reviewed many factors that affect poultry-processing and subsequent meat yields.

From a general perspective, food processors face increasing demands to improve their raw material yield. For a broiler processing company this is also true, because the raw material costs are a considerable part of the overall business costs. In chapter 1 (Somsen & Capelle, 2002), an example of a broiler processing company was given where about 69% of the overall business costs were used to purchase the raw material. Improvement of the raw material yield will therefore result in a substantial and immediate reduction of the production costs. Additionally this leads to waste reduction end of pipe. Already small differences in production yield will result in significant financial benefits in large volume operations as pointed out by Benhoff (1986), Dryer (1987) and Fletcher and Carpenter (1993).

From a raw material yield perspective, many food processors are facing some or more of the following key problems:

- Food processes are often seen as an artisanal activity instead as a technology.
- Raw materials and final products are often complex products, indicating that the relationship between them is often poorly understood or unknown. This knowledge gap forms a weak foundation for process optimisation to improve the production yield.
- Many mass losses are often hidden and nobody seems to be concerned about the true costs of these losses.
- Poor practice is often not classified as poor but as common practice.
- In most companies, there is a big gap between the work floor and the management.
- The management is often not convinced of the fact that unwanted mass losses are significant in economic terms and that they can be reduced by corrective management actions.
- The "technology push" is often absent because of the above-mentioned problems.

These findings are our conclusions based on our experiences over the last two decades, personal conversations with specialists from other food processing companies (Somsen & Capelle, 2002) and literature research (mostly from: Zaror, 1992; Anon, 1994; Dunstone & Cefaratti, 1995; Van Berkel, 1995; ETBPP, 1996; Bates & Phillips, 1999; Henningsson, Smith, & Hyde, 2001). We found a way to improve the raw material yield by a structured approach, called Production Yield Analysis (PYA) that was introduced in chapter 1 (Somsen & Capelle, 2002). PYA was developed to solve the above-mentioned key problems by realising three essential goals:

- Filling up the existing knowledge gap about production yield in a company. For that goal, experiments are carried out which form the basis for the development of a model to predict the maximum production yield. Additionally all mass losses that may arise during food processing need to be discussed and understood by the production management. Somsen and Capelle (2002) provided a comprehensive overview about possible losses that affect production yield.
- Showing a company the yield efficiency of the current transformation process (raw material into final product(s)) to convince the management about the necessity to reduce

unwanted losses. For that goal the actual production yield is compared with the maximum production yield.
- Applying a suitable performance indicator in a company to monitor and benchmark the yield efficiency, because what gets measured gets managed. For that goal the Yield Index was developed (Somsen & Capelle, 2002; Somsen, Capelle, & Tramper, 2004a)

This PYA-method is of general interest for the food processing industry. In chapter 4 a model was presented to calculate the yield efficiency of French-fries production (Somsen, Capelle, & Tramper, 2004b). This paper will present a second case study in which PYA was implemented at a poultry-slaughtering line, processing 9000 broiler chicks per hour.

5.2. Model development

During the production process, broilers are transformed into multiple valuable final products like fillet, legs, wings and other meat parts. Under ideal conditions, the overall mass of final products ($\sum Mfp\_max_{part}$) that can be transformed out of a certain mass of raw material (*Mrm*) can be realised when there are only wanted or unavoidable mass losses (ML_{wanted}). The overall mass balance of this process is given by Eq. (5.1) (Somsen & Capelle, 2002).

$$\sum Mfp\_max_{part} = Mrm - ML_{wanted} + MA\_max \qquad (5.1)$$

The maximum production yield for each individual final product (PY_max_{part}) is defined by Eq. (5.2) (Somsen & Capelle, 2002). Overall maximum production yield (PY_max) is defined by Eq. (5.3).

$$PY\_max_{part} = 100 Mfp\_max_{part} / Mrm \qquad (5.2)$$

$$PY\_max = \sum PY\_max_{part} \qquad (5.3)$$

The maximum production yield of each individual final product can be estimated out of raw material parameters (*RM*), additions (*A*) and quality specifications (*QS*) as formulated by generic Eq. (5.4) (Somsen & Capelle, 2002).

$$PY\_max_{part} = f\left(RM[1..v], A_{part}[1..w], QS_{part}[1..z]\right) \qquad (5.4)$$

Substitution of Eq. (5.2) into Eq. (5.4) will give Eq. (5.5).

$$Mfp\_max_{part} = f\left(Mrm, RM[1..v], A_{part}[1..w], QS_{part}[1..z]\right) \qquad (5.5)$$

The transformation of broilers into meat parts can be split into three main processing stages (Dryer, 1987) as shown by Figure 5.1. First, the broilers are "New York dressed" in the picking department, secondly the broilers are eviscerated and internal parts are removed. Thirdly the remaining carcass is dissected into meat parts. Wanted mass losses during this transformation process arise due to blood and feathers removal plus some other small losses during evisceration (removal of the gall-bladder, crop and gizzard contents and skin of the gizzard) expressed by the term miscellaneous in Figure 5.1. These wanted mass losses are

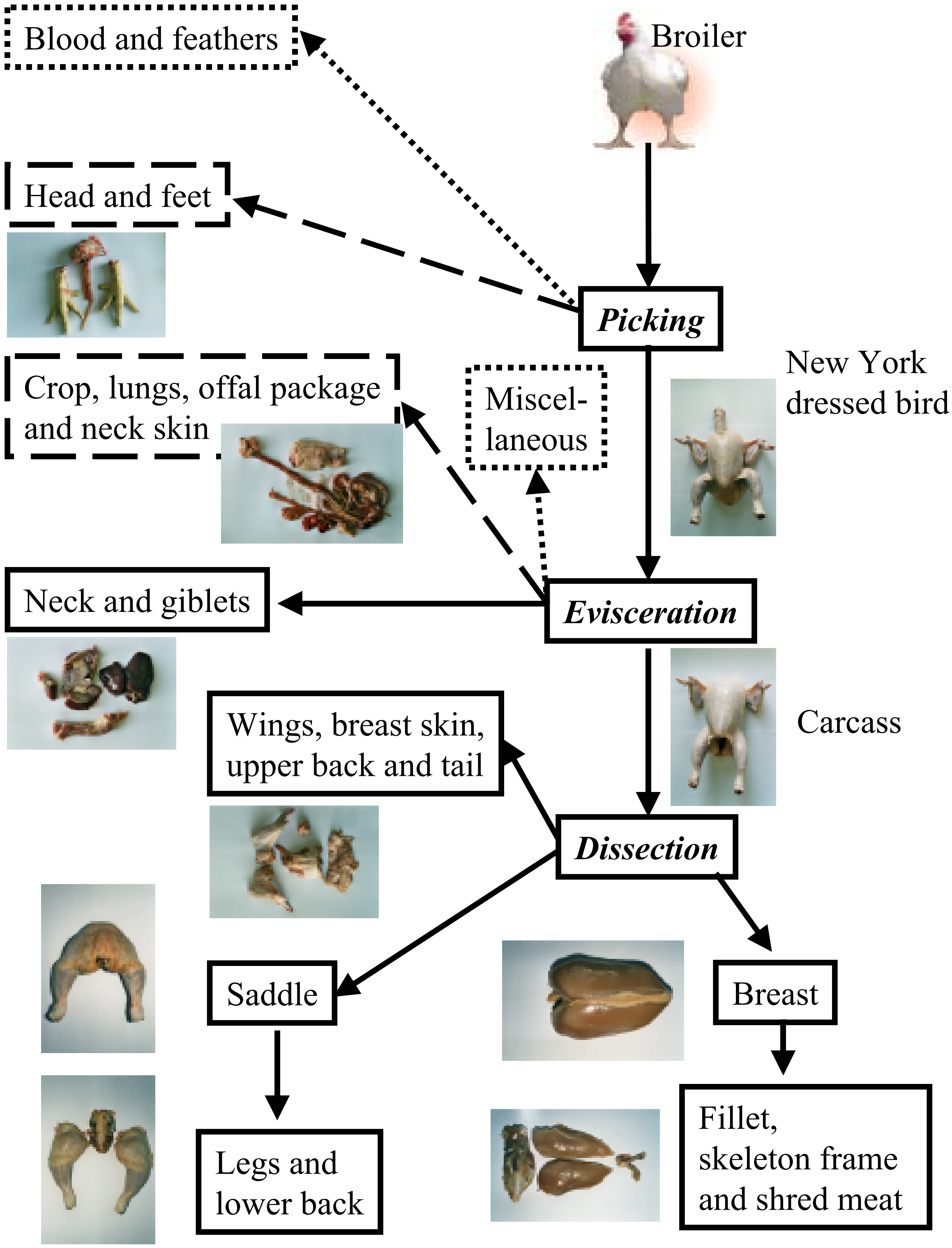

Figure 5.1. Schematic presentation of the transformation process.

characterised by the dotted lines in Figure 5.1. To dump this waste, a processor must pay money. Other parts like the head, feet, crop, lungs, neck skin and offal package (including spleen and cloaca) are saleable low valuable co-products used for the petfood-industry. These co-products are characterised by the dashed lines in Figure 5.1. All valuable final products are characterised by the solid boxes in Figure 5.1. When these products are arranged by their market prices (in decreasing order) the fillet, legs, wings, heart, gizzard, tail, liver, neck, lower and upper back, skeleton frame of the fillet and shred meat are the most valuable products.

Eq. (5.5) can be simplified because this particular transformation process (Figure 5.1) shows no additions of other materials. Secondly, the specifications of the final products are clearly defined and can be seen as constants instead of variables. Therefore, Eq. (5.5) can be simplified into Eq. (5.6).

$$Mfp\_max_{part} = f\left(Mrm, RM[1..v]\right) \quad (5.6)$$

In this study the maximum mass of each final product will be investigated, therefore Eq. (5.6) will be solved for each relevant meat part. These series of equations can be used to calculate the maximum production yield [Eq. (5.2)] and maximum overall production yield [Eq. (5.3)]. This information is needed to calculate the Yield Index [Eq. (5.7)] of the transformation process (Somsen & Capelle, 2002).

$$YI = PY\ / PY\_max \quad (5.7)$$

The Yield Index describes the yield efficiency of the transformation process. When this ratio is one, the actual production yield (PY) is equal to the maximum production yield. Broiler chickens are transformed into multiple final products (various meat parts). Because of that, the Yield Index per final product (YI_{part}) should be calculated [Eq. (5.8)].

$$YI_{part} = PY_{part} / PY\_max_{part} \quad (5.8)$$

5.3. Materials and methods

One of the first steps during a PYA-project is to define the optimum transformation process to realise the maximum mass of final product(s). The definition of this optimum process can be company specific and should therefore be developed in practice to ensure applicability, acceptance, understanding and collaboration of involved employees during following project stages. A general thesis is that conducting research under field conditions is most meaningful to the industry. For this PYA-project, the optimum process and the specifications of the meat parts were defined by the Plukon Royale Group and will be described in this paragraph.

5.3.1. Raw material and sampling method

Live chicken broilers were removed from a running belt in a commercial factory just prior to the production process. The time of sampling was arbitrarily selected over a 9h-production shift. Each time an individual broiler was randomly taken and this procedure was repeated four times per day. Two commercial strains (Ross 308 and 508) were used for the experiments all originated from commercial growers located in The Netherlands. The experimental study was carried out each production day from October 2001 till October 2002.

5.3.2. Method of transformation

Each bird was live weighed (±0.1 g), marked with a label and hung on the rail at the production line. Next, the bird was electrically stunned by waterbath stunner and killed with an outside neck cut and allowed to bleed for 160 s. The bird was immersed in a scalding tank for approximately 90 s at 58.6 °C. Subsequently, the bird was picked in an automatic feather picker for 34 s. The labelled bird was removed from the rail and weighed. The head was manually subtracted and weighed. Both feet were cut-off with a mirror polished knife at the tibia-metatarsus joint and weighed together. The "New York" dressed carcass was weighed. The abdominal cavity was opened from the sternum to the vent. The cloaca was cut off and weighed. The bird was carefully manually eviscerated and the sex of the bird was defined. All internal organs, except the kidneys, were removed from the body. A record of the weights of the heart, liver (minus gall bladder), gizzard (opened and skinned), abdominal fat, crop, intestines and lungs was made. The neck was cut off (without skin) at the shoulder joint and weighed. Neck skin was cut off from the carcass and weighed. Carcass was cleaned by use of running tap water and drained for exactly 20 s. The carcass was weighed, labelled again and hung on the rail just before the chiller. Carcass was chilled in a forced airflow (3 °C, 100% humidity) for 49 minutes till approximately 10 °C. The carcass was removed directly from the rail after chilling, de-labelled and weighed. The wings were removed and weighed. The complete breast skin was pulled-off from the clavicle to the end of the keel and weighed. Next, the whole breast portion including keel bone was removed by cutting through the ribs, thereby separating the breast portion from the back. The breast portion was weighed, packed in a plastic bag to prevent it against moisture losses and stored at 4 °C for 24 h. During weekends or national holidays, breasts were stored up to 72 h. After storage the breast was weighed again and the breast muscle (fillet or Pectoralis) was carefully dissected from the skeletal frame and weighed. From the remaining carcass, the upper back was cut off and weighed. The tail was cut off and weighed. The remaining saddle was weighed. Finally, both legs were dislocated at the hip joint, weighed together, and the remaining lower back was weighed.

5.3.3. Statistical analysis

Data were analysed by Statgraphics Plus version 4. The basic strategy of Neter, Kutner, Nachtsheim, and Wasserman (1996a; 1996b) was followed to find the appropriate regression model to solve Eq. (5.6) for each type of final product. Comparison of the regression lines between Ross 308 and 508 was performed with the procedure "comparison of regression lines" of Statgraphics. Significant differences between the regression lines were based on $p \leq 0.05$.

5.4. Results and discussion

The average live weights of the examined broilers are given in Table 5.1. The mixed population (hatched) can be divided in female and male broilers. The results show that the number of females is approximately equal to the number of males. By comparing the confidence intervals *(mean ± 1.96xSD/√n)* of the average live weight between sexes, it can be

Table 5.1. Average live weight and 95% confidence interval of mean at time of slaughter (SD; number of experiments) of examined broilers [g]

	Hatched	Female	Male
Ross 308	1935 ± 31 (247; 245)	1801 ± 28 (160; 125)	2074 ± 44 (245; 120)
Ross 508	1882 ± 18 (231; 648)	1752 ± 19 (173; 328)	2017 ± 23 (205; 320)
Total	1897 ± 16 (236; 893)	1765 ± 16 (171; 453)	2033 ± 20 (218; 440)

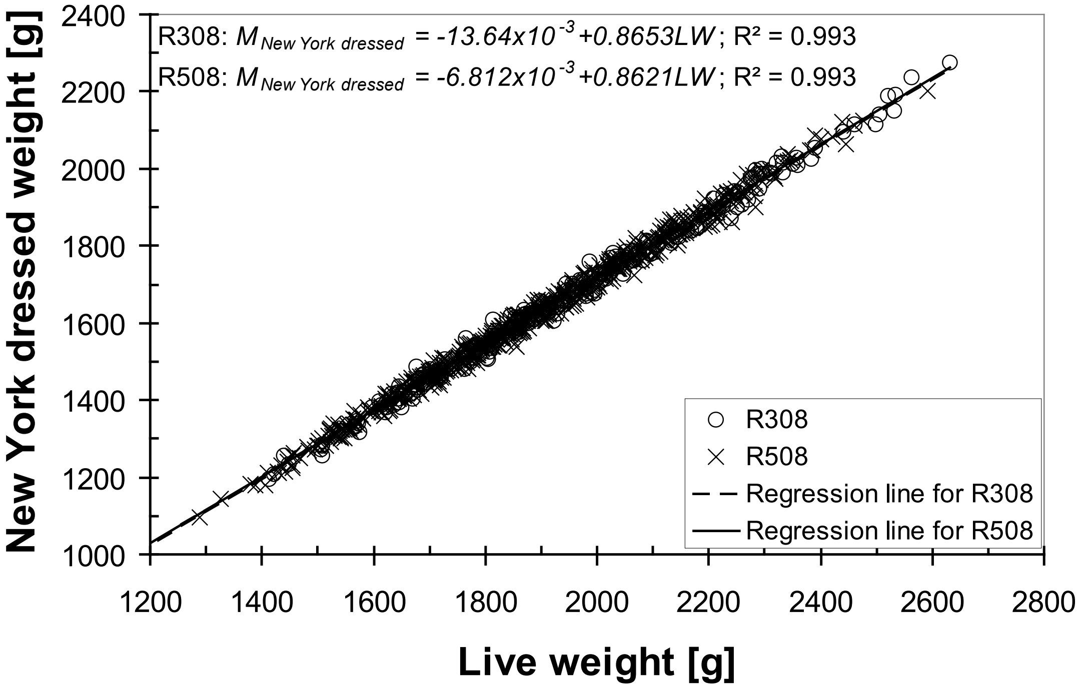

Figure 5.2. Weight of the New York dressed broiler versus live weight prior to slaughtering.

seen that these bounds do not overlap each other. Based on student t-statistics a significant ($P<0.001$) difference between the average live weight of sexes was calculated. The average live weight of both strains showed also a significant ($P<0.01$) difference. The Ross 308 was on average heavier than Ross 508 broilers at about equal age. The average age of the Ross 308 broilers was 38.4 days (SD=1.64) and that of Ross 508 38.3 days (SD=1.38). This shows that Ross 308 is growing faster than Ross 508 under the pertinent practical conditions.

Figure 5.2 shows a strong linear relationship between the weight of the New York dressed broiler versus live weight. An equally strong linear pattern is observed for the chilled carcass (Figure 5.3), wings (Figure 5.4), fillet (Figure 5.5) and the legs (Figure 5.6). For the relationship fillet versus live weight, (Figure 5.5) the separate regression lines for both strains can be clearly seen. It shows that Ross 508 yields more fillet than Ross 308 at equal live weight. For the other figures (Figure 5.2-5.4 and 5.6), the separate regression lines of both strains are oriented very close to each other and hard to distinguish by eye in these graphs. Tables 5.2-5.4 give an overall summary of the regression results for all parts. For this statistical analysis, basic linear, non-linear and polynomial regression analysis was performed, but for all parts the linear relationship [Eq. (5.9)] showed the best fit. The effect of live weight and age of the broilers on the weight of the parts was also investigated by multiple regression analysis, but the effect of age was not significant ($p>0.05$) for all parts. This finding confirms the conclusions of Jull, Phillips, and Williams (1943), McNally and Spicknall (1949; 1955) and Grey, Robinson, and Jones (1982) who also found a strong linear relationship for the weight of the parts versus live weight. This overall linear behaviour makes it possible to

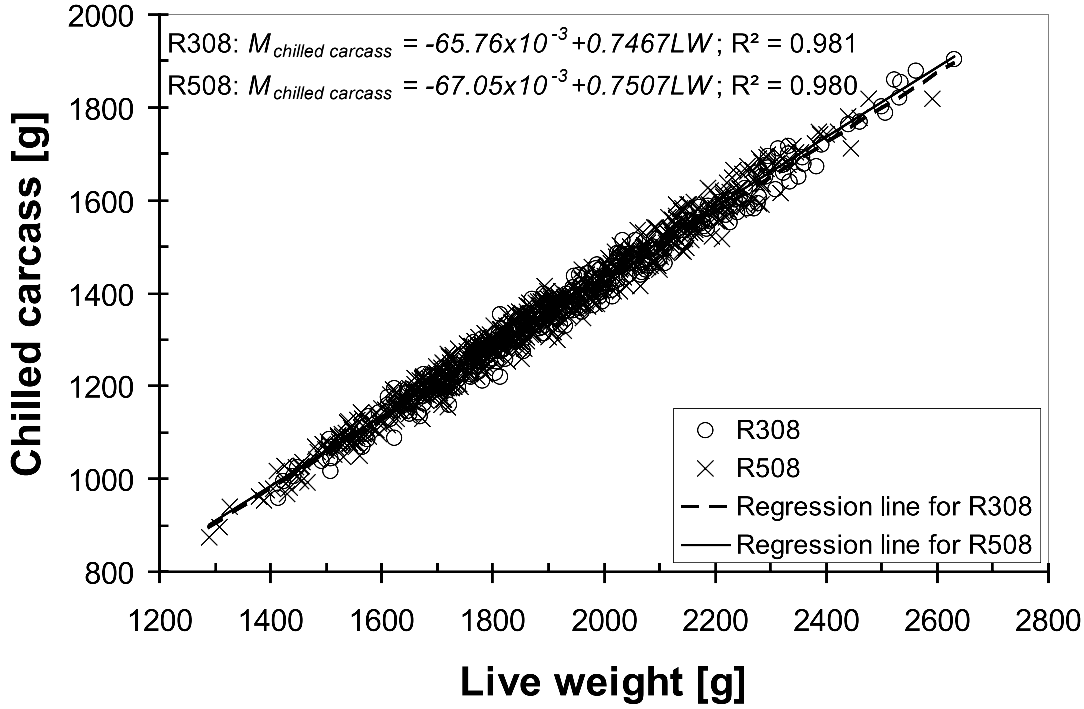

Figure 5.3. Weight of the chilled carcass versus live weight prior to slaughtering.

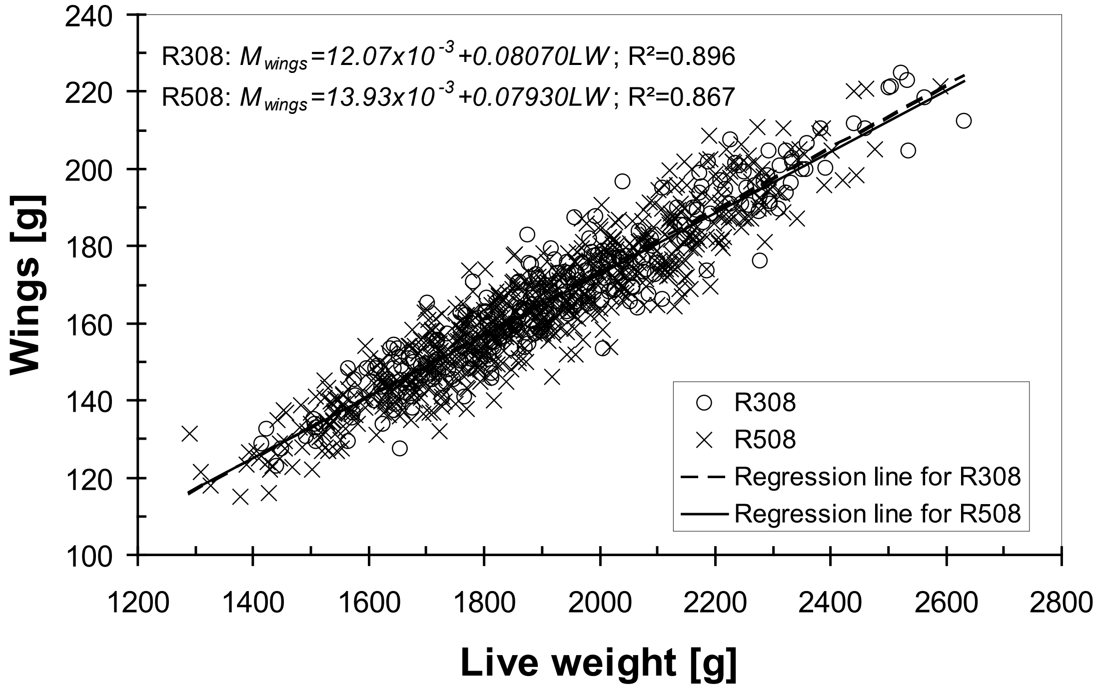

Figure 5.4. Weight of the wings versus live weight prior to slaughtering.

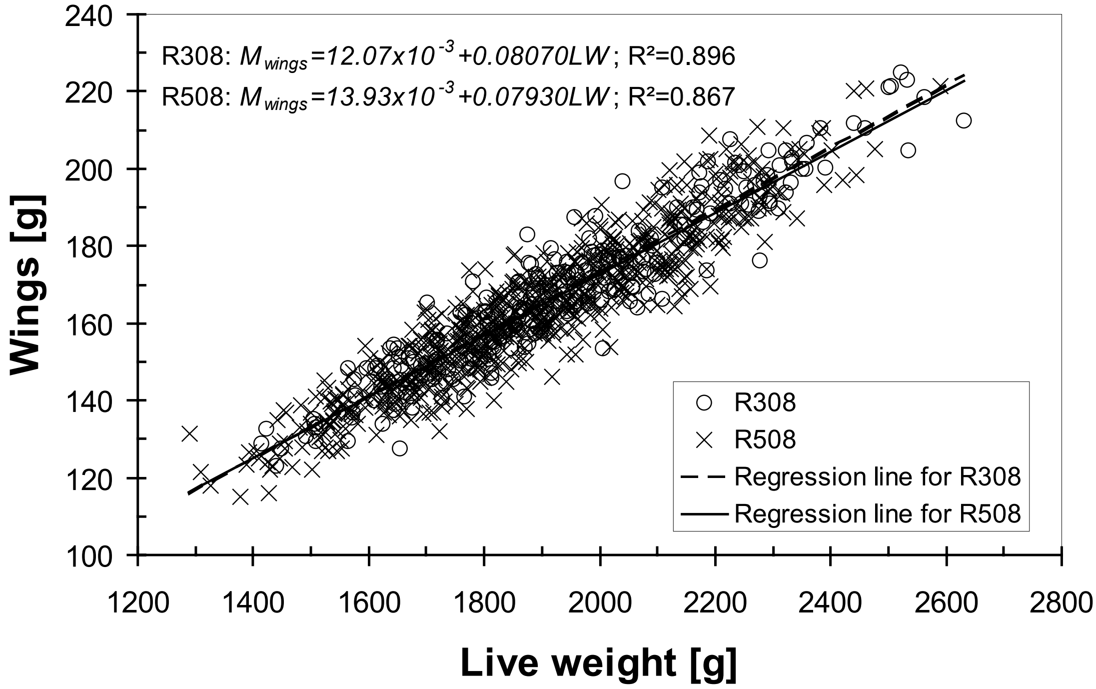

Figure 5.5. Weight of fillet versus live weight prior to slaughtering.

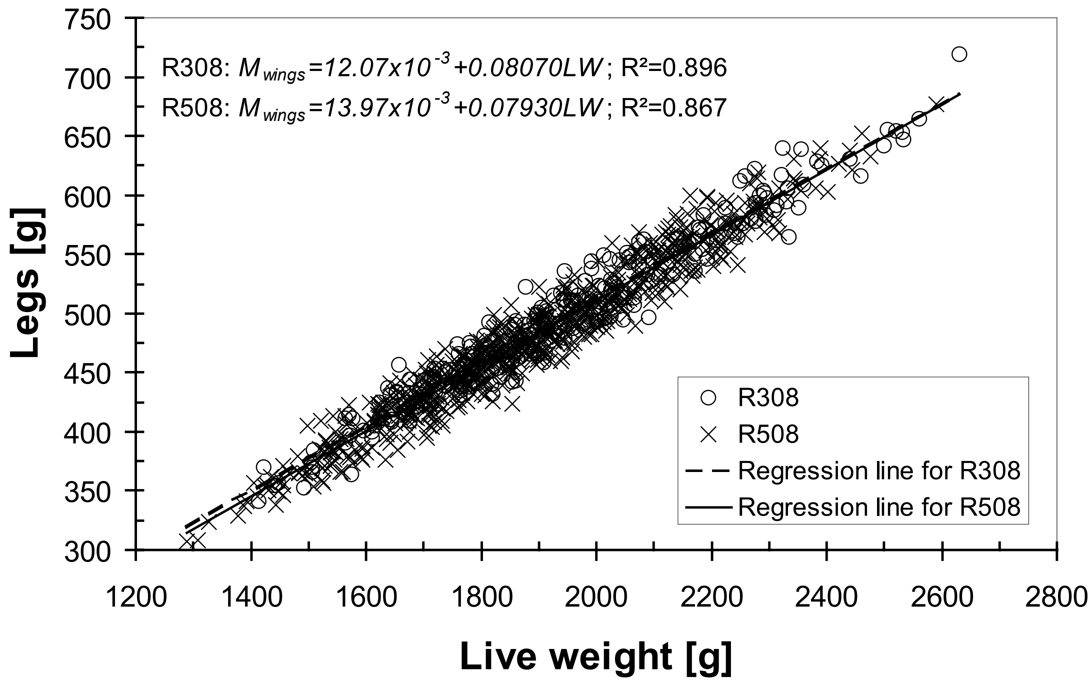

Figure 5.6. Weight of the legs versus live weight prior to slaughtering.

Table 5.2. Linear regression constants for the relationship between mass of parts [kg] in the picking department and average live weight [kg] prior to slaughtering for the strains Ross 308 and 508

Mass of part (kg)	Strain	Intercept x10^{-3} (c_{part})		Slope (d_{part})		R²	SEE x10^{-3}
		Estimate	SE	Estimate	SE		
Blood and feathers	R308	29.51	6.94	0.05784	0.00355	0.541	13.3
	R508	23.82	4.57	0.06164	0.00241	0.510	13.9
	Total	25.89	3.80	0.06011	0.00199	0.518	13.7
Head[1]	R308	-5.771	2.87	0.02843	0.00147	0.624	5.52
	R508	-6.050	1.54	0.02875	0.00081	0.669	4.68
	Total	-5.838	1.36	0.02859	0.00071	0.656	4.91
Feet	R308	-11.21	4.54	0.04892	0.00233	0.645	8.97
	R508	-10.07	2.71	0.04734	0.00143	0.629	8.39
	Total	-11.12	2.33	0.04817	0.00121	0.638	8.59
New York dressed	R308	-13.64 *	9.78	0.8653	0.00500	0.993	18.8
	R508	-6.812 *	5.65	0.8621	0.00298	0.993	17.2
	Total	-8.552 *	4.87	0.8629	0.00254	0.993	17.6

*/ Non-significant estimate (P>0.05)
1/ Including esophagus and trachea

derive one generic equation for all the parts [Eq. (5.9)]. The regression constants c_{part} and d_{part} in Eq. (5.9) can be found in Tables 5.2-5.4 for each specific part.

$$M_{part} = c_{part} + d_{part} * LW \qquad (5.9)$$

Based on Eq. (5.9), Eq. (5.6) can be solved which results in Eq. (5.10).

$$Mfp\_max_{part} = \left(\frac{c_{part}}{LW} + d_{part}\right) Mrm \qquad (5.10)$$

Substitution of Eq. (5.10) into Eq. (5.2) results in Eq. (5.11), which is the solved expression of generic Eq. (5.4).

$$PY\_max_{part} = 100\left(\frac{c_{part}}{LW} + d_{part}\right) \qquad (5.11)$$

The yield of the parts is influenced by average live weight as shown by Eq. (5.11). All the parts that have a negative c_{part}-value (Tables 5.2-5.4) will show an increased yield per unit increase of live weight. Parts that contain a positive c_{part}-value will show a decreased yield per unit increase of live weight. For the most valuable final products, which are the fillet and the legs, the yield will increase when the average live weight increases. For the wings, the yield will decrease when the live weight increases. This shows that processors should not only look to the production yield itself to benchmark the yield performance, because the effect of the average live weight itself must also be taken in account as shown by Eq. (5.11). Wrong conclusions about the yield differences between strains can also be easily drawn, when

Table 5.3. Linear regression constants for the relationship between mass of parts [kg] in the evisceration department and average live weight [kg] prior to slaughtering for the strains Ross 308 and 508

Mass of part (kg)	Strain	Intercept x10^{-3} (c_{part})		Slope (d_{part})		R^2	SEE x10^{-3}
		Estimate	SE	Estimate	SE		
Internal package[1]	R308	27.39	5.85	0.04792	0.00300	0.513	11.6
	R508	27.31	3.57	0.04675	0.00188	0.489	11.1
	Total	26.46	3.04	0.04754	0.00159	0.507	11.2
Heart	R308	0.9928 *	0.793	0.004941	0.000406	0.378	1.57
	R508	-1.079	0.549	0.006215	0.000290	0.416	1.70
	Total	-0.3265 *	0.454	0.005761	0.000237	0.398	1.68
Liver[2]	R308	4.783 *	2.76	0.01820	0.00141	0.406	5.45
	R508	6.167	1.53	0.01761	0.000804	0.427	4.70
	Total	5.618	1.34	0.01789	0.000703	0.422	4.95
Skinned gizzard	R308	10.66	2.59	0.01252	0.00133	0.268	5.11
	R508	13.69	1.47	0.009562	0.000778	0.190	4.56
	Total	12.32	1.32	0.01066	0.000690	0.212	4.86
Abdominal fat	R308	0.1310 *	3.67	0.01621	0.00188	0.235	7.21
	R508	-0.4291 *	2.36	0.01596	0.00125	0.204	7.24
	Total	-0.6694 *	1.98	0.01624	0.00103	0.218	7.24
Neck without skin	R308	5.626	2.36	0.01414	0.00121	0.359	4.68
	R508	6.119	1.33	0.01332	0.000702	0.358	4.12
	Total	5.567	1.17	0.01377	0.000610	0.364	4.30
Neck skin	R308	3.078 *	2.49	0.006996	0.00128	0.110	4.92
	R508	8.585	1.57	0.004156	0.000826	0.038	4.85
	Total	6.977	1.32	0.005002	0.000690	0.056	4.87
Chilled carcass[3]	R308	-65.76	13.0	0.7467	0.00664	0.981	25.6
	R508	-67.05	8.08	0.7507	0.00426	0.980	24.8
	Total	-64.19	6.86	0.7483	0.00358	0.980	25.1

*/ Non significant estimate (P>0.05)
1/ Lungs, crop, spleen, caudal esophagus, proventriculus, duodenum, pancreas, small intestine, ceca, large intestine and cloaca
2/ Minus gall bladder
3/ Emptied carcass including abdominal fat, genital organs and kidneys but without neck and neck skin

differences in average live weight are not taken into consideration. We looked in more depth to the yield differences between Ross 308 and 508 by a statistical comparison of the regression lines of both strains. This analysis showed only significant differences ($p \leq 0.05$) between both strains for feet, internal package, heart, skinned gizzard, neck without skin, chilled carcass, breast, fillet, skeleton frame of the breast, upper back, tail, saddle and legs. The separate regression lines of both strains for the heart and tail cross each other at a live weight of 1626.2 g and 1907.4 g, respectively. Ross 308 showed significant higher values for feet, internal package, heart (LW<1626.2 g), skinned gizzard, neck without skin, tail

Table 5.4. Linear regression constants for the relationship between mass of parts [kg] in the dissection department and average live weight [kg] prior to slaughtering for the strains Ross 308 and 508

Mass of part (kg)	Strain	Intercept x10^{-3} (c_{part})		Slope (d_{part})		R^2	SEE x10^{-3}
		Estimate	SE	Estimate	SE		
Wings	R308	12.07	3.44	0.08070	0.00176	0.896	6.79
	R508	13.93	2.32	0.07930	0.00122	0.867	7.12
	Total	13.05	1.92	0.07988	0.00100	0.877	7.04
Breast skin	R308	0.4309 *	4.39	0.02767	0.00225	0.383	8.67
	R508	-0.9891 *	2.72	0.02817	0.00143	0.375	8.35
	Total	-0.7410 *	2.30	0.02810	0.00120	0.381	8.44
Breast[1]	R308	-47.08	13.1	0.2495	0.00674	0.849	26.0
	R508	-41.60	8.16	0.2524	0.00430	0.842	25.1
	Total	-39.09	7.01	0.2495	0.00367	0.839	25.8
Fillet[2]	R308	-54.31	12.8	0.2149	0.00658	0.814	25.4
	R508	-44.59	8.20	0.2160	0.00432	0.795	25.2
	Total	-43.01	7.01	0.2134	0.00367	0.792	25.8
Skeleton frame of the breast	R308	5.683	2.63	0.02964	0.00135	0.666	5.19
	R508	1.437 *	1.81	0.03137	0.000956	0.626	5.57
	Total	2.350 *	1.49	0.03102	0.000781	0.640	5.48
Upper back	R308	3.370 *	4.06	0.04364	0.00208	0.644	8.02
	R508	5.970	2.56	0.04301	0.00135	0.613	7.85
	Total	5.723	2.16	0.04294	0.00113	0.620	7.92
Tail	R308	2.829	0.852	0.004801	0.000437	0.332	1.69
	R508	5.526	0.529	0.003387	0.000279	0.187	1.62
	Total	4.712	0.448	0.003821	0.000235	0.230	1.65
Saddle	R308	-36.28	8.51	0.3209	0.00436	0.957	16.8
	R508	-48.95	5.43	0.3257	0.00286	0.953	16.7
	Total	-46.48	4.57	0.3249	0.00239	0.954	16.8
Legs	R308	-33.16	7.84	0.2734	0.00402	0.950	15.5
	R508	-42.52	5.07	0.2764	0.00267	0.943	15.6
	Total	-41.10	4.25	0.2762	0.00222	0.945	15.6
Lower back	R308	-4.038 *	2.58	0.04762	0.00132	0.842	5.11
	R508	-7.449	1.92	0.04940	0.00101	0.787	5.89
	Total	-6.422	1.55	0.04886	0.000811	0.804	5.69

*/ Non significant estimate (P>0.05)
1/ Including skeleton frame of the breast
2/ Pectoralis

(LW>1907.4 g), and skeleton frame of the breast, saddle and legs. Ross 508 showed significant higher values for chilled carcass, heart (LW>1626.2 g), tail (LW<1907.4 g), breast, fillet and upper back. These findings can be of importance to compare strains in a realistic way under commercial conditions, because economical profitability can be calculated

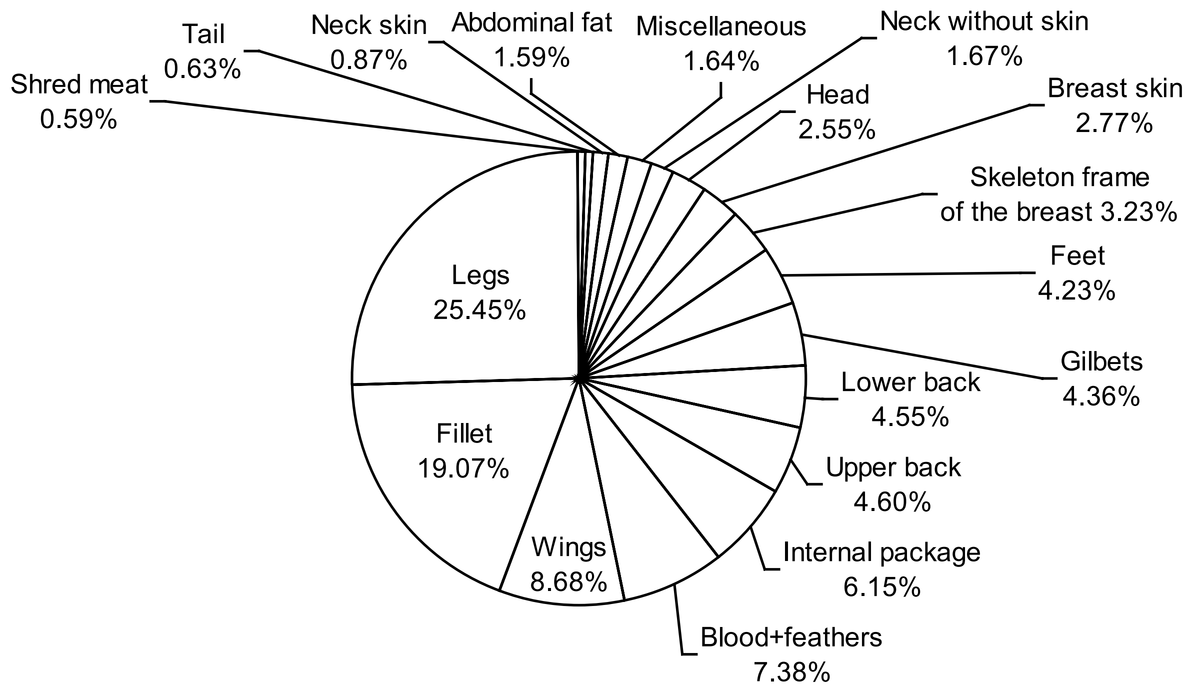

Figure 5.7. Average yield of the parts at an average live weight prior to slaughtering of 1898 g.

when average live weight, raw material costs and selling price per meat part are taken into consideration.

Based on Eq. (5.11) and the regression values of Tables 5.2-5.4 the yield of each part was calculated at an average live weight of 1897 g (overall average of Table 5.1). These results are shown in Figure 5.7. The calculation of the maximum production yield per part can be easily automated by the use of a spreadsheet program. When the average live weight of a flock is measured, the spreadsheet program will calculate the maximum production yield per part. By putting in also the actual yield values the Yield Index per part can be calculated. This makes it possible for a processor to monitor the yield efficiency very closely. Optimisation studies can be started when the Yield Index of the various parts departs from one. Yield Indexes above one can be possible in practice and are often an indication of an ineffective dissection operation, especially when the Yield Index of the less valuable parts is high in comparison of the high valuable parts. When for example the Yield Index of the saddle is 1.0, legs 0.89 and lower back 1.62. The legs are not cut-off efficient, meaning that the dissection operation should be investigated and corrected.

5.4.1. Concluding remarks

For this project, a multi-step approach was followed to implement PYA. This general approach will be extensively discussed in chapter 6. For this poultry case less than 1.5 year for the preliminary tasks (experimental set-up, project meetings etc.), experimental investigation, model building stage and implementing stage were needed. About 1.5 FTE on a yearly average were needed to realise this, including our own efforts. It shows that much work can be done with a straightforward plan. After the implementation stage, we started with the optimisation stage. The Yield Indexes [Eq. (5.8)] that were calculated for the various final products (solid boxes in Figure 5.1) varied between 0.5 and 1.0 and showed remarkable potentials for yield improvement. The lowest Yield Index was observed for giblets and varied between 0.5 till 0.7. It was found that the corresponding unwanted losses were mainly caused by transport losses during processing and ineffective operating machinery. The Yield Index of the wings varied between 0.91 and 0.97, for the fillet, which is the most valuable product, we observed values of 0.91-0.94. The Yield Index of the saddle (or legs including lower back) was the highest of all and approaches 1.0. Yield improvements were realised by many actions, which can be summarised by:

- Improvements to general housekeeping.
- Training and instructing of employees.
- Problems with ineffective operating machinery were discussed with the supplier to use their particular knowledge and experience.
- Machinery was fine-tuned and adjusted if needed.
- Outdated machinery (or parts of it), which resulted in poor yield efficiency was replaced or will be replaced in the near future.
- The company made a start to expand the PYA-method to other plants to enable a company wide benchmark by comparing Yield Index figures.

This PYA case study showed many opportunities to improve the production yield, especially after the implementation stage these potential improvements were visualised. Many improvements were realised by cheap and simple means. Other opportunities to improve the production yield are longer-term projects that are more complex, because they need additional research and a change of technology to realise them. In general, improvement of the production yield is a never-ending task; it needs continuous attention, supervision and leadership and should be seen as an important management task.

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PART 4

General system approach and final discussion and conclusions

CHAPTER 6

General system approach to execute a production yield analysis

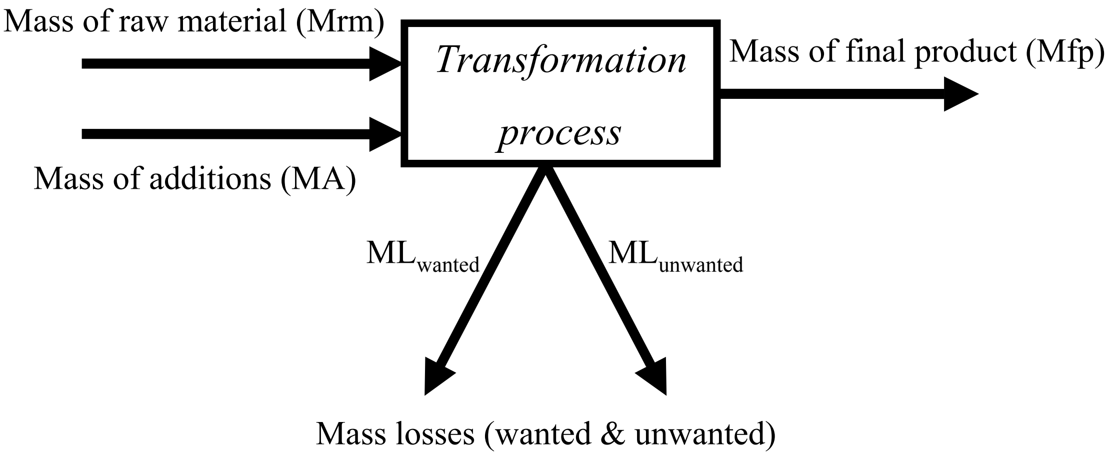
Abstract
Production Yield Analysis (PYA) is a structured system approach to optimise the production yield of production processes. The paper outlines the developed method and the 10 basic steps of the PYA. The PYA-method makes it possible to calculate the Yield Index of a process. This dimensionless figure can be used in balanced scorecards; it visualises the true raw material efficiency of the production process and enables fact-based management, which is the key for yield improvement, cost cutting, waste reduction and saving raw materials.

6.1. Introduction

The objective of the food industry should be to produce their products in a sustainable way, not spoiling nature's resources. In addition, from an economic point of view it is essential to produce yield efficiently. Spoiling nature's resources means an inefficient way of transforming raw materials into final products, resulting in large amounts of waste. In Europe about 330 million tons per year of industrial waste are produced, for the USA this is about 400 million tons. Roughly, 20% of this amount can be attributed to the food, drink and tobacco industries (Twigg, Cresswell, & Buchdahl, 2002). In literature, many studies are presented to reduce waste (Lorton, Fromm, & Freeman, 1988; Smith & Petela, 1991; Kerns & Brennan, 1992; Zaror, 1992; Mans & Swientek, 1993; Anon., 1994; Jenner, 1994; Bateman, 1995; Dunstone & Cefaratti, 1995; Van Berkel, 1995; ETBPP, 1996b; Woods, 1997; Bates & Phillips, 1999; Zechendorf; 1999; Barnard, 2000; Hyde, Smith, Smith, & Henningsson, 2000; Henningsson, Smith, & Hyde, 2001). These waste minimisation or cleaner production programs are unanimous about the following facts:

- A significant percentage of the waste from any food processing plant is avoidable.
- The best solution to minimise waste is to avoid its production at source.
- Minimising waste is essential to maintain business competitiveness.
- Commitment by management is the single most significant factor in any waste minimisation program.
- All savings of a waste minimisation project can be expressed as savings in raw materials, manpower, energy consumption, packaging, consumables, water and effluent. However, raw material savings carry by far the greatest potential for financial savings.
- The clearer a manager can picture improvements in effectiveness to himself and his subordinates the higher the probability that significant changes will occur (Shipper & White, 1983).

These facts together with the key problems that were outlined in the introduction of chapter 5 (Somsen, Capelle, & Tramper, 2004d) were the driving force of the authors to develop a method to increase the raw material yield efficiency of food processing by a more extensive theoretical approach. This Production Yield Analysis (PYA) method was developed during the early nineties and is nowadays implemented at many French-fries production lines (Somsen et al., 2004a; 2004b; 2004c) and one poultry-processing line (Somsen et al., 2004d).



$Mfp=Mrm-ML_{wanted}-ML_{unwanted}+MA$ (6.1)
$PY = 100\ Mfp/Mrm$ = *production yield (%)* (6.2)
Maximum production yield (PY_{max}) *is realised when* $ML_{unwanted}=0$
$PY_{max} = 100\ Mfp_{max}/Mrm$ (6.3)
$YI = PY/PY_{max}$ = *Yield Index* (6.4)

Figure 6.1. Generic presentation of the mass balance of food processing.

The PYA-method is primarily looking at the raw material efficiency of the transformation process. For that reason the term "losses" is used instead of "waste". Unwanted losses will influence the Yield Index [Eq. (6.4) in Figure 6.1] of the process negatively and a wanted loss does not (Somsen & Capelle, 2002; Somsen et al., 2004b). Wanted losses are necessary to transform the raw material into the desired final product(s). A good distinction between both types of losses is essential to understand the transformation process (Figure 6.1). Traditional methods such as "waste minimisation" and "cleaner production" do not make this distinction and emphasise the effects of waste on the environment. Originally, these methods were primarily environmental-driven, but nowadays these methods become increasingly business-driven. "Lean production" is another methodology that has a strong focus on waste reduction. In the lean concept, waste should be seen as non-value-added activities towards the customer that should be eliminated through continuous improvement (Womack & Jones, 1996; Mascitelli, 2002; Shah & Ward, 2003). This lean concept is strictly business-driven. The PYA-method is also strictly business-driven and can be used standalone or as a powerful expansion of existing methods.

Characteristic for the PYA-method is the use of a model to predict the maximum possible production yield with respect to raw material parameters, additions and final product specifications (Somsen et al., 2004c; 2004d). This makes it possible to compare the current production yield with the maximum production yield. Differences between the current [Eq. (6.2) in Figure 6.1] and maximum production yield [Eq. (6.3) in Figure 6.1] are an indication for a more or less inefficient transformation process, resulting in a Yield Index below 1. This Yield Index can be used to quantify and monitor the true raw material efficiency of the transformation process. Based on the Yield Index mass losses can be mathematically divided in wanted and unwanted losses (Somsen & Capelle, 2002; Somsen et al., 2004b). In this way, more rigorous and more powerful mass balances can be formulated, which are of great benefit for food processing, as we found out during practical case studies (Somsen et al., 2004c; 2004d) in the last decade.

Production processes often run in a certain way for a long time because that is how they were designed in the past and nobody has thought to question this. By monitoring only the current production yield without knowing the true maximum, food processors can have a impression that they work yield efficient, although that is often not the actual situation. This impression may be strengthened by small year-over-year improvements, often underlined by the statement "we are doing well, because we improve". In fact, they benchmark them-self by historical (yield inefficient) data. Ultimately, they like to have a cookbook "how to innovate to improve the yield efficiency". In author’s opinion, a company has to be made aware that they process yield inefficiently. Then they will explore opportunities to minimise unwanted mass losses at source. They will start to think about new and powerful concepts that can lead to improvements in process technology to solve current yield obstacles.

The PYA-method can be seen as a stepwise procedure to guide companies through a visualising and increasing awareness stage, showing them the yield potential of the transformation process. However, a considerable research effort and the development of a computer model are needed. In part 2 and 3, two case studies were presented that gave examples of such models for French-fries production (Somsen et al., 2004c) and poultry-processing (Somsen et al., 2004d). During these case studies, a methodology was developed to effectively implement PYA in a food processing company. This PYA-methodology was developed during the last decade and fine-tuned based on practical experiences. This resulted in a multi-step approach that should be widely applicable in food processing. This general multi-step approach will be the main topic of this final chapter. The results obtained with PYA are significant in economic terms and resulted in a continuous year-over-year improvement of the raw material efficiency. These results will also be summarised in this final chapter.

6.2. Methodology - system approach to execute a PYA

Implementation of the PYA-method should be done via a defined procedure. For a process of which the maximum production yield is unknown, a multi-step approach is followed. The procedure can be divided into 10 basic steps, which are explained in this paragraph.

Step 1: Determination of current production yield

First, the current production yield needs to be measured by recording processed raw material quantities (exclusive tare) and produced final product(s). It is important to measure the initial situation to be able to visualise progress. Companies that never monitored the production yield before will already benefit from this first action alone, because production yield will become automatically an issue by monitoring it.

Step 2: Raw material characterisation

All raw material parameters that may affect production yield have to be described. Literature research, interviews with specialists, brainstorm sessions, company information and specific additional research may be necessary. However, it is essential to choose only parameters that will be measurable under factory conditions as was expressed in previous work (Somsen et

Box 6.1. Examples of possible raw material parameters that may affect production yield.

- Age
- Average cell size
- Average dimensions, shape
- Average weight
- Chemical composition
- Density
- Number of objects per unit of weight
- Percentage defects
- Peelability
- Variety

al., 2004a). If this condition is not met, a final model will be created that is not useful under practical circumstances! Box 6.1 gives some examples of possible parameters that can be used to characterise the raw material. Information that is more detailed can be found in previous work (Somsen et al., 2004a; 2004c; 2004d).

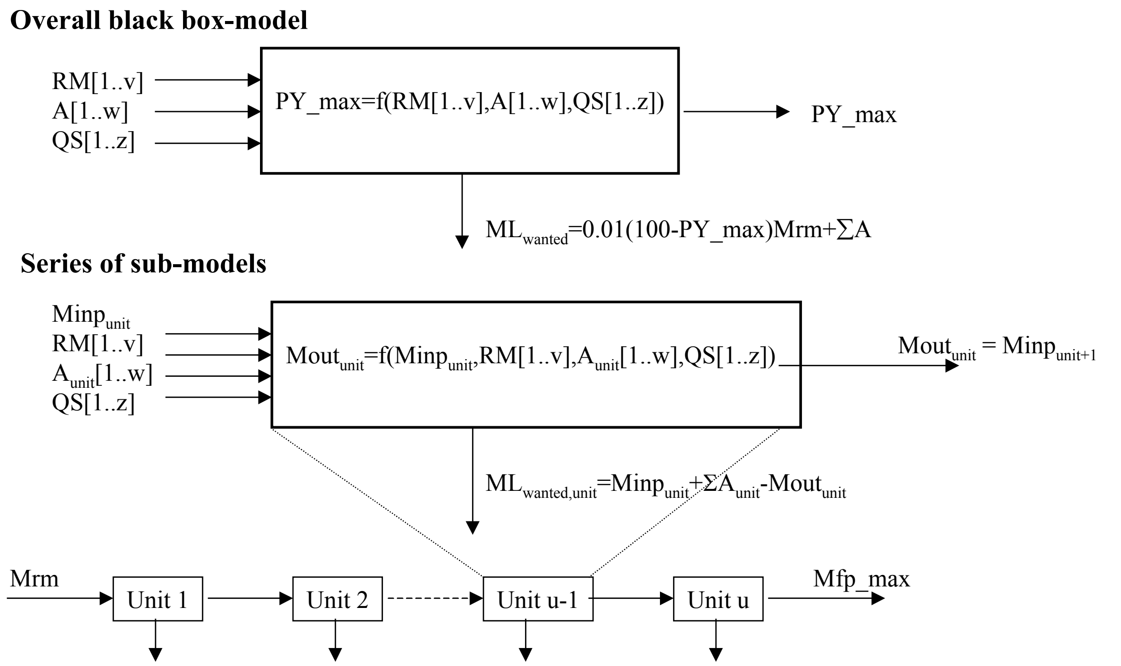
Step 3: Characterisation of the optimum process
The most efficient way to transform the raw material into final product(s) without any unwanted mass losses has to be determined and described in an experimental operating procedure. Each company has to define the definition of the term "most efficient way", but this should be done with an open mind without taking into account current procedures (out of box thinking). Such a procedure describes what has to be done to transform raw material into final products by using all kinds of tools and laboratory and pilot plant equipment. Sometimes a part of an existing production line can also be used. Box 6.2 addresses some typical questions and remarks that can be of help at finding the optimum process. Additionally, all materials and methods have to be described, including the forms that will be used during the experiments to gather all data. An estimation of the costs of the research including labour needs and project time can be presented also. Examples of such experimental operating procedures can be found in the materials and methods section of chapters 4 and 5 (Somsen et al., 2004c; 2004d).

Step 4: Experimental investigation
During this stage, data are collected, which will be used to build the model. During the experimental study, samples of raw materials must be transformed into the final product(s) under optimum conditions according to the experimental operating procedure of stage 3.

Box 6.2. Typical questions and remarks that can be helpful in finding the optimum transformation process.

- Do we understand the difference between wanted and unwanted mass losses?
- Which mass losses are really wanted or unavoidable in our transformation process?
- Is the order in which unit operations are aligned really logical?
- Can we find a (manual) way of transforming the raw material into final products with only wanted mass losses?
- To find the true unwanted mass loss it may be necessary to reuse lost mass in the same process where it comes from.
- Brainstorm sessions together with external specialists can be of help.

Box 6.3. Schematic presentation of two maximum yield models.



A=addition (w/w %); Mfp_max=maximum amount of final product (kg); Minp=input of material (kg); ML=mass loss (kg); Mout=output of material (kg); Mrm=mass of raw material (kg); PY_max=maximum production yield (w/w %); RM=raw material variables that influence production yield; QS=specifications of the final product that influence production yield; u=number of unit operations; v=number of raw material parameters that influence production yield; w=number of added ingredients; z=number of specifications that influence the production yield

Subscripts: Wanted =indicates a wanted or unavoidable mass loss; Unit=indicates a unit operation

Based on practical experiences at least the following data should be recorded:

- Relevant raw material data (described during stage 2) including origin and variety.
- Mass of raw material (clean without any tare).
- Mass of the product after each unit operation.
- The mass loss during each unit operation.
- The mass of the individual additions per unit operation.
- The mass of direct reused components per unit operation. In some processes it is possible to reduce losses by reusing some specific components.
- Mass of the final product(s).
- Quality parameters of the final product(s).

After some experiments, it is recommendable to screen the data to detect potential problems in an early stage. In this way, corrective actions are possible, without collecting many unusable data. If it is expected that raw material quality will be influenced by seasonal variations, the duration of the experiments must be at least one year. If necessary, the experiments should be repeated after some time.

Step 5: Modelling

Based on the experimental data gathered in stage 4, several scenarios are possible to develop a maximum yield model. One possibility is an overall black box-model for each final product. The second is a more detailed model, which is built-up of a series of sub-models, one for each unit operation. Box 6.3 portrays both scenarios. An overall black box-model was used in our poultry case study (Somsen et al., 2004d) and a series of sub-models was used in the French-

Box 6.4. Some questions that should be answered during the optimisation stage.

Which unwanted mass losses are the biggest?
What are the true costs of the unwanted mass losses?
Which unwanted mass losses are influenced by poor practice?
What do the factory operators need to know?
How does planning influence the production yield?
Which Yield Index will be maximally possible with currently used process?
Is the current process state of the art?
Which engineering changes are necessary?
Which research is necessary to solve the obstacles for further yield optimisation?

fries case study (Somsen et al., 2004c). Statistical techniques such as multiple regression analysis are suitable to develop these kind of models. Statistical textbooks as Myers (1990) and Neter, Kutner, Nachtsheim, and Wasserman (1996) explain how to apply these techniques and describe essential issues as data preparation, variables reduction, model selection, refinement and validation, which are outside the scope of this paper.

Step 6: Programming
The developed model should be made convenient for practical use. This can be done by the development of computer software. This can be a sophisticated computer program or just a simple spreadsheet. The software has to be developed product and company specific and adequate to predict the maximum possible yield and wanted mass losses. The Yield Index and amount of unwanted mass losses can be calculated by the model when processed mass of raw material and produced final product(s) are specified. The software should be carefully tested and debugged. Two example flow sheets of such models can be found in paragraphs 4.2 and 5.2 (Somsen et al., 2004c; 2004d).

Step 7: Implementing
During this stage, the developed software model will be used in practice. Before actually using the system, employees that are involved have to be trained and supplied with adequate background information. The PYA-program should be formalised by corporate management. They should not only approve, but also actively support it. This is essential, when later on the method will be used as a benchmark tool throughout the whole company.

Per batch of received raw material, all relevant characteristics have to be measured. In general, this should be done during raw material intake control. Depending on the needs of the company the Yield Index can be calculated on a batch, shift, daily or weekly basis. The Yield Index may be made part of a balanced scorecard. It is also advisable to use a graphical presentation in which the Yield Index is plotted versus time (Figure 6.2).

Step 8: Optimisation
Acquiring knowledge and understanding of the process, particularly regarding unwanted mass losses, should always be the first step when PYA is implemented. In many practical situations, mass losses can be measured. They can be separated in wanted and unwanted mass losses based on the developed model. A full understanding of all mass losses that may arise in practice can also be of importance. Therefore, a complete overview of all mass losses that may arise in practice was provided in chapter 1 (Somsen & Capelle, 2002).

Box 6.5. Examples of a realistic benchmark of two French-fries factories and two broiler processing factories.

	Par-fried French-fries		Fillet of broiler chickens	
	Factory 1	Factory 2	Factory A	Factory B
Current production yield	54.5 %	58.6 %	18.1 %	18.1 %
Maximum production yield	60.5 %	73.3 %	19.3 %	18.6 %
Yield Index	0.90	0.80	0.94	0.97

Box 6.4 gives some basic questions that should be answered during the optimisation stage. Once started with the optimisation stage the actions should concentrate on the biggest unwanted mass losses. According to the 80/20-rule of Pareto, 80% of the unwanted losses is influenced by 20% of the shortcomings. Wrong handling routines, incorrect process settings and "factory blindness" can be solved by training and coaching of employees and can often establish the most direct improvements without big investments. The optimisation stage is a continuous process in which yield maximisation is the major goal. Successes should be reported frequently to maximise understanding and support from the employees. The objective is to reach a Yield Index equal to 1, but only when the profits of saving raw material are in balance with the costs of realising that!

Step 9: Benchmarking (optional)
For companies with more than one production line the method can be implemented at each production line. This will give added value, because employees that are working at lines that are performing less can learn from the better ones.

A realistic comparison of the production efficiency of production lines throughout the company is nearly impossible with traditional methods (only looking at the production yield instead of the Yield Index, as shown by Box 6.5). For example: production locations of the same company in other countries work with another crop of raw material or with other product specifications. Comparison of the Yield Index per production line will automatically compensate for different raw material quality and final product specifications, which enables a realistic benchmark. Due to differences in size and under-water-weight of the potatoes and different final product specifications (cut size and moisture content), the production yield in Box 6.5 of factory 2 should be much higher than factory 1. The Yield Index makes clear that the yield efficiency of factory 1 is much better than of factory 2. This realistic comparison is impossible by only looking at the current production yield.

Factory A (Box 6.5) processes Ross 508 broilers with an average live weight of 1935 g. Factory B processes Ross 308 with an average live weight of 1897 g. The main cause of the higher Yield Index of factory B is because Ross 308 yields normally less fillet than Ross 508 (Somsen et al., 2004d).

Step 10: Building more advanced models (optional)
In principle, the model can also be used for yield forecasting and as a raw material decision support system. If adequate information from the farms about the quality of the upcoming crop is available, the production yield for the coming season can be predicted using model predictions and adjusting them with the average Yield Index of the preceding year.

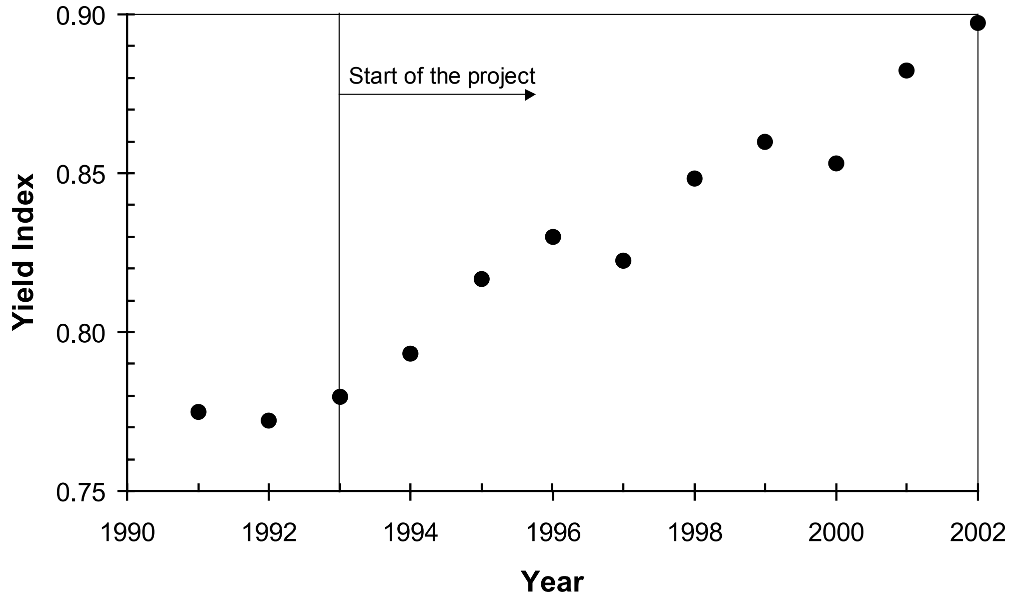


Figure 6.2. Yield Index of par-fried French-fries production over the years after starting up PYA in 1993.

Until now, equations were developed to predict the wanted mass loss per unit operation. However, this will not always give enough information about they exact origin of unwanted mass losses. A simulation program of a current unit operation can be an outstanding tool to understand how unwanted mass losses arise. This gives additional possibilities to reduce them. Developing such a simulation model requires often much effort and has only to be considered if the Yield Index of the process or typical unit operation is still too low without understanding why. An example of such a model was given in chapter 3 (Somsen et al., 2004b) for the steam peeling operation of potatoes.

6.3. Results and discussion

6.3.1. French-fries production

In Figure 6.2 the overall results over the last 12 years are given for several French-fries production lines. The PYA-project was started in 1993 resulting in a significant and continuous raw material efficiency improvement. The realised raw material savings were about 2.2% of the turnover. These improvements were mainly realised by:

- Improvements in general housekeeping.
- Specific training and instruction sessions for employees based on the typical knowledge that was gathered during the whole project. Many important issues were translated into financial terms to establish maximum understanding of the employees.
- Discovered knowledge gaps that were highlighted during the PYA-project were filled-up by research projects.
- Changes in technology.

Table 6.1. Realised yield efficiency improvements during the first 1.5 year of the project for the most valuable final products

Final product	Initial Yield Index	Yield Index after 1.5 years
Fillet	0.86	0.92
Legs	0.94	0.99
Wings	0.92	0.94
Giblets	0.63	0.82

- Collaborations with manufacturers to increase the yield efficiency of typical process equipment.
- A company-wide benchmark was established.

Nevertheless, currently available technology is not efficient enough to achieve Yield Index figures much higher than 0.9 as can be seen in Figure 6.2. The French-fries industry needs a new and powerful process technology that should lead to revolutionary improvements. The major drawbacks are the unit operations peeling and defect sorting. Somsen et al. (2004b) pointed out that the current way of peeling potatoes is rather yield inefficient. The Yield Index of this unit operation is about 0.92. Defect sorting is another critical unit operation (Somsen et al., 2004c) that has potential for improvement. When these major drawbacks can be solved by innovative technological changes, additionally 1.7% of the turnover can be saved by reduced raw material costs. By knowing this substantial potential, the company's research-force can be more precisely directed to solve the current yield obstacles.

6.3.2. Poultry-processing

In 2001, a second PYA-project was started at a poultry-processing line, processing 9000 broiler chickens per hour (Somsen et al., 2004d). The process was deliberately chosen because it is a totally different production process than the manufacturing of French-fries. An additional challenge to test the generic model equations (Somsen & Capelle, 2002) was the use of living animals. The systematic approach guided the authors (including other team members from the company itself) through a knowledge-gathering phase, although the authors had no experience with poultry-processing. It resulted in new essential information to improve the yield efficiency. Within 1.5 year, PYA was implemented in this broiler processing company. During this project, the Yield Indexes of the most valuable final products were significantly improved as shown by Table 6.1.

In the case study paper about poultry-processing (Somsen et al., 2004d), more detailed information can be found about the actions that were taken to realise these results. In fact most of the improvements were realised by similar actions as mentioned in the French-fries case study. Because this project was started-up recently, no historical data about long-time progress can be given. However, the Yield Indexes for the particular final products that are reported in Table 6.1 show a major potential for further improvements.

6.3.3. Final discussion and general conclusions

According to Bates and Phillips (1999):

- The amount of waste we produce is a consequence of how efficiently raw materials are transformed into final products.
- Once waste has been produced, dealing with it has an impact on the environment.

Besides having sustainable aspects, the creation of waste costs money. Studies in the UK estimated the true costs of waste at approximately 4.5% of the business turnover (ETBPP, 1996a; 1998). In spite of this the generation of waste continues to increase in the European Union and seems to be closely linked to economic growth (EEA, 2001). These problems are consequences of the overall scale of raw material use. Higher efficiencies in the use of raw materials are necessary to improve sustainability and profitability of food processing. Additionally waste minimisation can also help to raise the environmental image of a company.

Traditionally, waste was seen as a disposal issue and companies started to reduce waste because of regulatory reasons. These waste reduction programs where end of pipe solutions. The characteristic driving force behind it was waste reduction because of legislative pressure. Current methods like waste minimisation, cleaner production and lean production, which were successfully applied in food processing and other types of industry, showed that waste should be prevented at source (Smith & Petela, 1991; Zaror, 1992; Van Berkel, 1995; ETBPP, 1996b; Zechendorf, 1999; Henningsson et al., 2001; Steger, 2000; Cuatrecasas, 2002). This means that transformation processes should be carefully examined and re-evaluated. Many food process operations are still seen as an artisanal activity but it should be seen as a technology that is based on chemical and physical phenomena. Therefore, our PYA-methodology starts with a rigorous re-evaluation of the transformation process (stages 1-5). By using the maximum yield model the sources of mass losses can be identified and separated in wanted and unwanted losses. Subsequently the causes of the unwanted mass losses should be carefully evaluated and options need to be developed to reduce these unwanted losses. The PYA-methodology was developed from a process engineering perspective. The driving force behind it is maximising the raw material yield efficiency. An advantage of the PYA-method in relation to others is that potential improvements are made clear before the actual optimisation (stage 8) starts. Equations to calculate the potential raw material savings, in both quantitative and financial terms can be found in chapter 1 (Somsen & Capelle, 2002). The development of a predictive model to estimate the maximum yield with respect to raw material parameters, additions and final product specifications is a new concept in applying mass balances. In fact the true yield efficiency can only be calculated, when the real maximum is known! Additionally, the development of a maximum yield model will ensure that a food processor will gather enough knowledge to really understand the transformation process. In our opinion large food processors need a more thorough understanding of the efficiency of the transformation process. This knowledge boost will stimulate innovations and more rigorous changes in a company as was stated by Shipper and White (1983) also. By using the Yield Index potential raw material savings can be calculated. For managers it is important to know these potentials because they will feel a need to actively support it. In the introduction of this paper it was already stated that commitment by management is a key condition. Another advantage is that the Yield Index is a dimensionless performance indicator. Therefore it can be used in balanced scorecards to monitor the yield efficiency of production lines. Also using the Yield Index can realistically benchmark plants within one company that uses different varieties of raw materials or use other product specifications. This enables fact-based management.

The PYA-methodology is most suitable for more complex food processes, where the relationship between raw material(s) and final product(s) is hard to understand. For that reason we selected French-fries and poultry-processing. The case studies proved that much new knowledge was gathered. A unique feature of our series of papers is that transformation processes were discussed in a comprehensive way. Existing literature on waste minimisation, cleaner production and lean production shows no reported examples with a thorough explanation of the investigated food processes. PYA emphasises the need to really understand the transformation process based on wanted and unwanted mass losses. For relatively simple processes the PYA-approach is less useful, because the maximum yield is often already known, including all influencing parameters. Traditional techniques, as reported by many waste minimisation and cleaner production programs, are then still useful. The ETBPP (1996b) for example provides a list with 200 tips to reduce waste.

During both case studies it was proven that useful raw material parameters to predict the maximum production yield could be found. In fact, surprisingly simple parameters were found, like average number of potato tubers per kilogram (Somsen et al., 2004a) and the average live-weight of the broiler chickens (Somsen et al., 2004d). These raw material parameters should be seriously measured to keep track of the Yield Index of the transformation process. Knowledge of the relationship between raw material parameters and production yield can also be used to assure a reasonable price making of the raw material at the farm level as a function of its quality parameters. For potatoes as example, Hekkert (2003a) proved that differences in potato quality currently are disproportionately rewarded in the price making of the potatoes. There is a need for a new raw material paying system that is more based on real quality differences (Hekkert, 2003a; 2003b). Another important relationship is the relationship between product specifications and production yield. By knowing this relationship, specifications of the final product can sometimes be re-evaluated and modified to make a higher production yield possible. This can be an additional advantage of having a yield model, because effects can be simulated.

Maximising the yield efficiency means minimising unwanted mass losses. However, wanted mass losses will still arise, but must be seen as a resource out of place. Ideally food processes will generate only wanted mass losses that would be completely and yield efficiently reused in other processes. From a mathematical point of view this means maximising the Yield Indexes of subsequent processes in the chain. However in real life this objective should be always in balance with the costs of realising that. Raw material yield efficiency models should become an essential component to improve economics and sustainable aspects in modern food processing. Often it is believed that efficiency and environmental aspects are contradictory. We have shown here that increasing the raw material yield efficiency will lead to a mixture of improvements that help both its bottom line and its environmental impacts at the same time. The challenge is there!

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Summary

In the past food was processed batch wise at low capacity and highly labour intensive, often on a seasonal basis. Nowadays most food processes are continuous at high capacity all year round. This means that food processing is much more efficient than a few decades ago, but according to the author of this thesis there is still plenty of room for improvements. The thesis demonstrates how smart-monitoring techniques can lead to those improvements. Interviews were carried out with specialists from large food processing industries manufacturing beer, cheese, sugar, French-fries and chicken products. For each industry a general overview is given of the factors that influence production yield, for example the quality of the raw material, losses prior to processing, contaminants and foreign bodies, internal and surface losses during processing, packaging or storage. If these factors are monitored properly it is possible to identify where losses could be minimised or resources could be used more efficiently. With this fact-based management it is outlined how it is possible to develop a production Yield Index that enables companies to predict the maximum possible production yield for a particular process.

From a general perspective, food processors face increasing demands to improve their raw material yield, because the raw material costs are a considerable part of the overall business costs. Improvement of the raw material yield will therefore result in a substantial and immediate reduction of the production costs. Additionally this leads to waste reduction end of pipe. The basic approach to increase the raw material yield efficiency is to minimise unwanted mass losses at source. The thesis points out that there are two types of mass losses, respectively unwanted and wanted mass losses. Wanted mass losses are necessary to transform the raw material into desired final products and unwanted mass losses are not. Unwanted mass losses will therefore put the company's profit under pressure. The Yield Index makes it possible to mathematically divide mass losses in unwanted and wanted ones.

From a raw material yield perspective, many food processors are facing some or more of the following key problems:

- Food processes are often seen as an artisanal activity instead of a technology.
- Raw materials and final products are complex products, indicating that the relationship between them is often poorly understood or unknown. This knowledge gap forms a weak foundation for process optimisation to improve the production yield.
- Many unwanted mass losses are hidden and nobody seems to be concerned about the true costs of these losses.
- Poor practice is often not classified as poor but as common practice.
- In most companies, there is a gap between the work floor and the management.
- Management is often not convinced of the fact that unwanted mass losses are significant in economic terms and that these can be reduced by corrective management actions.
- The "technology push" is often absent because of the above-mentioned problems.

These findings are the conclusions of the author based on experience over the last two decades, personal conversations with specialists from other large food processing companies and literature research. The author found a way to improve the raw material yield by a structured approach, called Production Yield Analysis (PYA). PYA was developed to solve the above-mentioned key problems by realising three essential goals:

- Filling up the existing knowledge gap of production yield in a company. For that goal, experiments are carried out which form the basis for the development of a computer

model to predict the maximum production yield.
- Showing a company the true yield efficiency of the current transformation process (raw material into final product(s)) to convince the management about the necessity to reduce unwanted losses. For that goal the actual production yield is compared with the maximum production yield.
- Applying a suitable performance indicator in a company to monitor and benchmark the yield efficiency, because what gets measured gets managed. For that goal the Yield Index was developed.

Two PYA's were executed for two totally different food processes: French-fries production and poultry-processing (broiler chickens into meat parts). The French-fries case study proved that the maximum production yield of French-fries depends on 11 variables. These variables can be grouped into: raw material parameters (under-water-weight, number of tubers per kilogram, average cell size, skin appearance and defect load), additions (fat) and product specifications (cut size, target defect load and target moisture and fat content). It was shown that the number of tubers per kilogram shows a good relationship with the average principal dimensions of the tubers and the average surface area. A new technique to predict the surface area of the tubers was developed to prove this. Based on the developed maximum yield model, the Yield Index of French-fries production was calculated. Unwanted mass losses were reduced by actions like:
- Improvements in general housekeeping.
- Specific training and instruction sessions for employees based on the typical knowledge that was gathered during the whole project. Important issues were translated into financial terms to establish maximum understanding of the employees.
- Discovered knowledge gaps that were highlighted during the PYA-project were filled-up by research projects.
- Changes in technology.
- Collaborations with manufacturers to increase the yield efficiency of typical process equipment.
- Establishing a company-wide benchmark.

These actions resulted in a major improvement of the raw material yield efficiency. Further improvements in the yield efficiency of French-fries processing are possible, but innovative technological changes are necessary to realise this. The thesis points out that the peeling and sorting (defect removal) operation show potentials to realise this improvements. An extensive study about the peeling operation made clear that currently about six times the peel thickness is removed. This means that much more good potato tissue is removed than skin.

The second PYA case study was executed at a poultry-slaughtering line, processing 9000 broiler chickens per hour. It was shown that the average live weight (prior to slaughtering) of a flock of broilers was the critical key parameter. Based on the average live weight the maximum production yield of each individual type of final product (fillet, legs, wings etc.) could be predicted. The strains Ross 308 and 508 were investigated in this study and it was shown that maximum yield models could realistically compare these strains. Significant differences between the strains were found. The production yield of the fillet for Ross 508 was for example higher than that of Ross 308. Based on the developed maximum yield model, the Yield Index of the several final products was calculated. Efficiency improvements were realised by about equal actions as described for the French-fries case.

Raw material yield efficiency models should become an essential component to improve economics and sustainability aspects of modern food processing. For large food processors it is necessary to fully understand the transformation process. Therefore the Yield Index should be continuously monitored, not only by specialists but also by management. Based on that fact-based management is possible.

Samenvatting

In het verleden werd de industriële productie van levensmiddelen batch-gewijs uitgevoerd met een lage capaciteit en een hoge arbeidsintensiteit, en vele industrieën werkten op seizoensbasis. Tegenwoordig zijn de meeste processen continu, met een hoge capaciteit, en produceren de bedrijven het hele jaar rond. Dit maakt de verwerking van grondstoffen veel efficiënter dan enkele decennia geleden het geval was. Maar volgens de auteur van dit proefschrift is er nog steeds voldoende ruimte voor verdere verbetering. Het proefschrift maakt duidelijk hoe slimme monitortechnieken een verdere verbetering van de efficiency in het gebruik van grondstoffen mogelijk maken. Interviews werden afgenomen bij specialisten van grote levensmiddelen producerende bedrijven afkomstig uit de bier, kaas, suiker, patat frites en kippenindustrie. Voor elke industrie wordt, volgens een algemene classificatie, een overzicht gegeven van de factoren die het productierendement beïnvloeden. Bijvoorbeeld, de kwaliteit van de grondstof, verliezen voorafgaande aan de productie, verontreinigingen en vreemde bestanddelen, interne en oppervlakte verliezen tijdens productie en verpakkings- en opslagverliezen. Als al deze verliesstromen precies worden bijgehouden, dan wordt het mogelijk om aan te geven waar verliezen nog kunnen worden geminimaliseerd of grondstoffen kunnen worden bespaard. Met deze op feiten gebaseerde aanpak kan zinvolle managementinformatie worden gegenereerd, die in een kengetal genaamd de rendements-index kan worden weergegeven.

In zijn algemeenheid is er in de levensmiddelenindustrie behoefte om de efficiency in het gebruik van grondstoffen verder te verbeteren, omdat de grondstofkosten een zeer belangrijk deel uitmaken van de totale bedrijfskosten. Verbetering van de grondstofefficiency leidt dan ook tot een wezenlijke en ogenblikkelijke reductie van de bedrijfskosten. Tevens resulteert het in een reductie van afval. De basismethode om de grondstofefficiency te verbeteren is het reduceren van ongewilde verliezen direct in het productieproces zelf. Het proefschrift geeft aan dat er twee type massa verliezen zijn, namelijk ongewilde en gewilde verliezen. Gewilde verliezen zijn noodzakelijk bij het omzetten van grondstoffen tot eindproducten, bij ongewilde verliezen is dat niet het geval. Ongewilde verliezen resulteren daarom in een verlaagde winstgevendheid van bedrijven. De ontwikkelde rendementsindex maakt het mogelijk verliezen mathematisch te splitsen in ongewilde en gewilde verliezen.

Als we kijken naar de efficiency in het gebruik van grondstoffen dan hebben veel levens-middelenbedrijven een aantal wezenlijke problemen, namelijk:

- Het produceren van levensmiddelen wordt veelal gezien als een ambacht in plaats van een technologie.
- Grondstoffen en eindproducten zijn complexe producten, hetgeen aangeeft dat de relatie tussen beide veelal slecht wordt begrepen of onbekend is. Dit gebrek aan kennis vormt een zwak fundament voor verdere procesoptimalisatie om het productierendement te verhogen.
- Veel ongewilde verliezen zijn niet direct zichtbaar en tevens lijkt niemand geïnteresseerd in de werkelijke kosten die deze verliezen met zich mee brengen.
- Een slechte bedrijfsvoering op de productievloer wordt meestal niet bestempeld als slecht, maar als een gebruikelijke manier van werken.
- Bij veel bedrijven is een kloof aanwezig tussen de werkvloer en het management.
- Het management is veelal onvoldoende doordrongen van het feit dat ongewilde verliezen een substantieel deel van de bedrijfskosten veroorzaken en dat deze kunnen worden gereduceerd door gerichte acties van het management zelf.
- De innovatiekracht om processen verder te verbeteren is vaak afwezig vanwege de

hierboven genoemde probleempunten.

Dit zijn de bevindingen van de auteur, gebaseerd op zijn werkervaring over de twee laatste decennia, persoonlijke gesprekken met specialisten van andere levensmiddelenbedrijven en literatuuronderzoek. De auteur ontwikkelde een methodiek om de grondstofefficiency via een gestructureerde methode verder te verbeteren, genaamd productie rendement analyse (Engels: Production Yield Analysis of PYA). PYA werd ontwikkeld om de hierboven genoemde probleempunten op te lossen, waarbij de volgende drie doelstellingen een essentieel onderdeel vormen:

- Het opvullen van de kennisleemte binnen een bedrijf op het gebied van het productierendement. Voor dat doel worden experimenten uitgevoerd die als basis dienen voor de ontwikkeling van een computermodel waarmee men het maximaal mogelijke productierendement kan voorspellen.
- Het visualiseren van de werkelijke efficiency in het gebruik van grondstoffen van het huidige transformatie proces (van grondstof naar eindproduct(en)). Dit om het management er van te overtuigen dat het noodzakelijk wordt om ongewilde verliezen verder te reduceren. Voor dat doel wordt het werkelijke productierendement vergeleken met het maximaal haalbare productierendement.
- Het invoeren van een makkelijk te gebruiken kengetal binnen een bedrijf, waarmee de grondstofefficiency kan worden gevolgd en kan worden vergeleken met dat van andere productielijnen van het bedrijf. Dit is wezenlijk omdat zaken die worden gemeten pas kunnen worden gemanaged ("meten is weten"). Voor dat doel werd de rendementsindex ontwikkeld.

Twee rendementsanalyses (PYA's) werden uitgevoerd bij twee totaal verschillende bedrijven, namelijk één bedrijf dat patat frites produceert en een ander bedrijf dat slachtkuikens verwerkt tot vleesdelen. De studie uitgevoerd bij het frites bedrijf maakte duidelijk dat het productierendement van frites afhankelijk is van 11 variabelen. Deze variabelen kunnen worden ingedeeld in grondstof parameters (onderwatergewicht, aantal knollen per kilogram, gemiddelde celgrootte, uiterlijk van de schil en het percentage aan defecten), toevoegingen (vet) en product specificaties (snijmaat, gewenste percentage defecten en vocht- en vetgehalte). Daarbij werd aangetoond dat het aantal knollen per kilogram een goede samenhang vertoonde met het gemiddelde knoloppervlak. Een nieuwe wiskundige techniek werd ontwikkeld om het knoloppervlak te kunnen berekenen. De rendementsindex van frites productie kon worden berekend op basis van het ontwikkelde maximale rendementsmodel. Dit gaf de mogelijkheid om ongewilde verliezen te reduceren. Dit kon worden verwezenlijk door:

- Algemene verbeteringen in de bedrijfshuishouding.
- Specifieke trainingen en interne opleidingen voor het bedrijfspersoneel gebaseerd op de typische kennis die werd opgedaan tijdens het invoeren van PYA. Belangrijke verliesstromen werden omgerekend naar de bijbehorende geldstromen om een maximaal begrip te verkrijgen bij het personeel.
- Leemtes in kennis die werden ontdekt tijdens het PYA-project structureel op te vullen door gericht onderzoek.
- Technologische veranderingen.
- Samenwerkingsverbanden met toeleveranciers op te starten om de efficiency in het gebruik van grondstoffen van hun procesapparatuur verder te verbeteren.
- Binnen het hele bedrijf structureel een "benchmark" (vergelijkingen van de efficiency in het gebruik van grondstoffen van diverse dochterbedrijven met elkaar) door te voeren.

Deze acties resulteerden in een beduidende verbetering van de grondstofefficiency. Verdere verbeteringen van de grondstofefficiency zijn nog mogelijk, maar hiertoe zijn zeer innovatieve technologische veranderingen noodzakelijk. Het proefschrift maakt duidelijk dat deze potentiële verbeteringen dienen te worden gezocht in het sorteren (verwijderen van defecten) en het schillen van de aardappelen. Een uitgebreid onderzoek naar het schillen maakte duidelijk dat de huidige schilmethodiek ongeveer een factor 6 maal de schildikte verwijdert. Dat maakt duidelijk dat er meer goed aardappelmateriaal dan schil wordt verwijderd.

Het tweede PYA onderzoek werd uitgevoerd bij een kippenslachterij met een verwerkingscapaciteit van 9000 slachtkuikens per uur. Het werd duidelijk dat het gemiddelde levend gewicht (voorafgaand aan het slachtproces) van een koppel slachtkuikens de kritische parameter is. Gebaseerd op dit gemiddelde levend gewicht kon het maximale productierendement van alle individuele vleesdelen (filet, poten, vleugels etc.) worden voorspeld. De rassen Ross 308 en 508 werden onderzocht en het werd duidelijk dat maximale rendementsmodellen het mogelijk maken om deze rassen reëel met elkaar te vergelijken. Significante verschillen tussen de rassen werden op deze wijze aangetoond. Zo was het productierendement van de filet van Ross 508 als voorbeeld hoger dan dat van Ross 308. Het maximale rendementsmodel werd gebruikt om de rendementsindex van de verschillende eindproducten te berekenen. Op basis daarvan konden rendementsverbeteringen worden doorgevoerd, die qua acties sterk leken op de verbeteracties die bij de frites case werden doorgevoerd.

Modellen om de efficiency in het gebruik van grondstoffen te bepalen, zouden een essentieel onderdeel moeten gaan vormen bij het optimaliseren van processen in de levensmiddelenindustrie, ten einde de winstgevendheid en het duurzaam produceren verder te verbeteren. Daartoe dient de rendementsindex frequent en kritisch te worden gevolgd, niet alleen door specialisten, maar met name door het management zelf. Dat maakt management gebaseerd op feiten mogelijk.

Curriculum vitae

Dirk Johan (Derk) Somsen werd geboren op 7 december 1960 te Eibergen (Gld). Hij studeerde levensmiddelentechnologie, met specialisatie proceskunde aan de destijds Rijks Hogere School voor Levensmiddelentechnologie te Bolsward, alwaar hij in 1985 afstudeerde. Zijn afstudeerwerk omvatte een computermodel waarmee lucht/waterdampsystemen konden worden doorgerekend. Destijds waren er uitsluitend diagrammen waarin men de fysische grootheden van een lucht/waterdampsysteem kon aflezen. Een computermodel van dit diagram gaf verbeterde mogelijkheden tot het modelleren en optimaliseren van droogprocessen.

Direct aansluitend startte hij zijn bedrijfsmatige carrière bij Melkunie Holland te Woerden, dat tegenwoordig onderdeel uitmaakt van Campina. Hij werkte gedurende 4 jaar bij Melkunie op de afdeling "Nieuwe Technologie" die onderdeel uitmaakte van de centrale research afdeling. Hij deed daar onderzoek aan de reologische karakterisering van yoghurt, waarover ook een artikel werd gepubliceerd. Het hoofdonderzoek richtte zich echter op het optimaliseren van continuvla-installaties en de opschaling daarvan richting fabrieksinstallaties. Het samenspel tussen afschuifkrachten welke de structuur van de vla beschadigen, de warmteoverdracht en de vervuilinggevoeligheid van het warmteoverdragend oppervlak waren hierbij de kritische factoren. Verder deed hij veel procesmatig advieswerk bij de verschillende productievestigingen van Melkunie.

In 1989 trad hij in dienst bij Aviko te Steenderen en gaf daarbij invulling aan het procestechnologisch onderzoek van de afdeling Research & Development, die ongeveer gelijktijdig met zijn indiensttreding was opgericht. De eerste jaren werd veel onderzoek gedaan naar de "unit operations": schillen, snijden, sorteren, blancheren, drogen, frituren en vriezen. Aviko expandeerde indertijd enorm, waarbij hij was betrokken bij de bouw van nieuwe productielijnen in binnen- en buitenland. Hij deed ook veel advieswerk voor diverse buitenlandse vestigingen van Aviko. Productierendement kreeg begin jaren negentig grote interesse van Derk, waarbij hij een methode ontwikkelde om de werkelijke effectiviteit van het transformatieproces te kunnen meten. Deze methodiek wordt uitgebreid omschreven in dit proefschrift. Momenteel vervult hij als hoofd procestechnologie een leidinggevende rol binnen de afdeling Research & Development.

Hij volgde een veelheid aan cursussen, waaronder een vijftal internationale cursussen van "The center for professional advancement" op het gebied van de statistiek, modellering-technieken en proceskunde. Verder volgde hij diverse informatica- en management cursussen.

In mei 2001 startte hij als externe promovendus, naast zijn baan bij Aviko, met zijn promotieonderzoek aan de Wageningen Universiteit. Dit onderzoek werd afgerond in maart 2004.

Addendum

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