Food Engineering

Research Developments

Terrance P. Klening
Editor

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FOOD ENGINEERING RESEARCH DEVELOPMENTS

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FOOD ENGINEERING RESEARCH DEVELOPMENTS

PREFACE

Food engineering refers to the engineering aspects of food production and processing. Food engineering includes, but is not limited to, the application of agricultural engineering and chemical engineering principles to food materials. Genetic engineering of plants and animals is not normally the work of a food engineer. Food engineering is a very wide field of activities. Among its domain of knowledge and action are: Design of machinery and processes to produce foods Design and implementation of food safety and preservation measures in the production of foods Biotechnological processes of food production Choice and design of food packaging materials Quality control of food production. This new book deals with food engineering research from around the globe.

Chapter 1 - Food processing is an indiscrete part of the chain from cultivation/catch to consumer. During the last decades the food value chain has grown longer and has become more market oriented, i.e. consumer driven instead of producer driven. New information on the effects of food on the health of the consumers and on the environment will continue to influence the choice of consumers regarding food products.

Emphasis on knowledge has and will continue to increase accordingly when producing and marketing food products. The consumer demands knowledge on the origin of the product, on the environmental effects of the production as well as effects on the communities where the production takes place, i.e. the emphasis is on solicitude. At the same time the product should be convenient to cook, safe and fresh. This calls for consistent research and development where the focus in the next years will be on the following areas:

- Fresh products, cooling instead of freezing - superchilling
- Process optimisation, based on precise measurements (such as NMR) and historical data on raw material.
- New processing methods, aiming at minimum processing while ensuring safety at the same time
- Improved use of byproducts
- Engineered products – functional foods
- Low energy use in production
- Supply chain management, including optimisation of transportation
- Genetic improvements of crops and farmed animals.
- Tracebility

- Verification of sustainable and/or organic production, fair and ethical trade as well as other solicitude matters.
- Marketing differentiation
- Increased dissemination of research results and other information to consumers
- OR
- Statistics

Besides from these areas, merging of research institutes and universities will also characterize the food engineering research environment the next decade, as well as increased cooperation between research parties and industrial companies.

The authors will discuss this development, the focus of leading food engineering researchers in Iceland with regard to this development and what strategic aim Matis ohf and the University of Iceland will take to ensure their competitiveness in this fast developing area.

Chapter 2 - Water is the most important compound of food. It affects chemical reactions, microbial growth and organoleptic quality. Historically, the effects of water on food degradation have been related to its availability but the lack of exact definition of this term has caused contradictory results. Nevertheless, it is well known that through the control of "free" and "bound" water content it is possible to restrict degradation reactions and to improve food quality.

Nowadays different parameters to measure the state of water in food are available but, from industrial point of view, the most important is the water activity (a_w). This term is used to indicate the ratio of the vapour pressure in equilibrium with a food and the vapour pressure of water at the same temperature and pressure. With the recognition of the importance of this parameter, new knowledge and understanding of water-food interaction have led to new methods to obtain shelf-stable food by reduction of water activity. Moreover, the importance of water activity led food scientists to study mathematical models to predict a_w values in complex food.

In this chapter the authors present results about osmodehydration and direct addiction of humectants as treatments to reduce water activity in food. The authors studied, in particular: i) the interactions of different humectants, the influence of process variables and the development of mathematical models to predict a_w values from a statistical and engineering point of view; ii) the optimization of processes with the aim to obtain safe vegetable food with good organoleptic quality. Also, the authors reviewed the new water-food interaction theories based on dynamic rather than thermodynamic. In particular, the authors analyze the glassy transition temperature and translational diffusion coefficients measured by DSC and NMR techniques and present some preliminary results obtained on apple osmodehydrated samples.

Chapter 3 - This chapter is aimed to underline the increasing importance that natural antioxidants have been gaining in the last years. Antioxidants are naturally present in many foods, so that they can be seen as potential recovery sources: oilseeds, nuts, cereals, legumes, vegetables, fruits, herbs, spices and teas. Besides these, antioxidants are often present in food processing by-products and wastes, so that the employment of low-cost industrial wastes could greatly reduce the production costs and increase the margin profit of the products. The introductive section summarises the classes of antioxidant compounds (mainly focusing on phenolic compounds), their potential food and no-food applications, and the main problems you have to account for when recovering antioxidants from residual sources, such as selection of a suitable agriculture by-product, choice and optimisation of the extraction procedure, analytical characterisation and evaluation of antioxidant activity of the obtained extracts, evaluation of potential applications of the isolated substances.

The second part of the chapter presents an experimental work dealing with recovery of phenolic compounds from wine-making wastes through a simple solvent extraction process. Trials were carried out in order to evaluate the feasibility of using different by-products (grape stalks, grape marcs before and after distillation), the influence of grape variety, of different sample pre-treatments, type of solvent, extraction temperature and time (extraction kinetics) on extracts yield and quality in terms of phenolics content and antioxidant power. Food applications of the obtained compounds to inhibit oil oxidation and to extend shelf-life of fresh fruits were also investigated.

Chapter 4 - Mathematical modeling represents a very important and effective tool for a proper design and control of industrial processes. A model reliably predicting a particular transformation process can, in fact, be used to investigate how the outputs may change with time under the influence of changes of the external disturbances and manipulated variables. In this way, it is possible to optimize the process, thus improving the quality and the safety of the final product. A mathematical model is, generally, based on a relationship, expressed in form of an equation (or a system of equations), whose solution yields the dynamic or static behavior of the process under examination. Both finite element method (FEM) and finite difference (FD) modeling have been utilized in food engineering research. A detailed analysis of the literature in the last 15 years shows that FEM applied to heat transfer dominates the publications, followed by diffusion calculations and drying process simulations. It is to be remarked, however, that a widespread use of mathematical modeling in food engineering is far from being well assessed.

The main aim of the present chapter is to analyze the transport phenomena involved in food drying process, performed in a convective drier. The formulation of two different theoretical models will be presented, focusing the attention on the differences that may be obtained if a simplified or a more complete analysis of the same transport problem is adopted. Both the models describe the simultaneous transfer of heat and moisture occurring during drying process. Actually, the first approach is much simpler, even though it could be considered a very important advance with respect to the theoretical analyses that are currently available in the literature. On developing the "simple" model, only food domain has been taken into consideration; moreover, heat and mass transfers occurring at the food surface exposed to the drying air have been estimated on the basis of a set of semi-empirical correlations available in the literature. The second model, instead, takes into account also the behavior of the drying air flowing, in turbulent conditions, about the food sample. This approach is, therefore, more general since it describes the simultaneous transfer of momentum (for air only), of heat and mass (for both air and food) occurring in a convective drier and does not need the specification of any heat and mass transfer coefficient at the food-air interface that, indeed, is one of the results of the proposed model.

Both the models receive - as inputs - only the initial conditions, the geometrical characteristics of both food and drying chamber and the relationships expressing physical and transport properties of food and air in terms of the local values of temperature and moisture content. The resulting system of non-linear, unsteady-state partial differential equations has been solved by means of the Finite Elements Method. The comparison between two possible different approaches may suggest if a significant increase of computation effort is actually required or, instead, if the utilization of a much simpler and faster method is capable of giving a proper description of the process under consideration. The main objective of the present work is to show how an accurate transport model can be used to determine the influence of operating conditions on drying process. In this way, it might be possible to minimize expensive pilot test-runs and have good indications on the characteristics and the quality of dried products.

Chapter 5 - Drying food is an extremely sensitive operation that requires the proper monitoring and control of the heating medium temperature as well as the length of time that the product is exposed to this temperature. Since the different food products have different heat sensitivity the heat load tolerance during drying cannot be generalized if loss of quality is to be avoided. On the other hand the drying process is a very high energy consuming operation and energy usage must be minimized without necessarily compromising on product quality. Optimization of a drying process requires that the authors consider the heat and mass transfer dynamics, product quality indices and production costs. Different control strategies and objective functions must be tried because it would not make business sense to produce a very high valued product at astronomical costs to the producer and nor would a low quality product sell simply because it is produced at minimum cost or energy consumption. This Chapter reviews first the research trends on modeling of the drying process based a heat and mass transfer, cost of dying and product quality. The strategic logistics that have been used over the years in attempts to optimize the drying operation have also been reviewed. Last but not least, the performance of these dryer control strategies in the practical optimization of the drying process have been discussed since it is how well a control strategies works that can make the entire optimization process either a success or a failure.

Chapter 6 - Canned foods are a significant component of the diet of most people in both developed and developing countries, offering a wider choice of nutritious, good quality foods in a convenient form all-year-round. During canning, both desirable and undesirable changes occur in nutritional and sensory properties of foods, resulting from heat treatment employed for the destruction of microorganisms to achieve the desired commercial sterility. The extent of thermal processing, in terms of both temperature and duration of the treatment, is dependent upon the chemical and physical composition of the product, the canning medium and the conditions of storage, determining the product quality in terms of its sensory properties and nutrient content. This chapter reviews the major principles and operations used during food canning, identifies the nutritional and sensory changes occurring during the process and their effect on the quality of canned foods. In addition, it explains the use of response surface methodology (RSM) as modelling and optimization techniques used in the canning industry in recent times to manipulate canning processes to maintain the nutritional and sensory qualities of canned foods, using two recent studies where RSM was used to study the effect of pre-canning processes including blanching time, soaking time and sodium hexametaphosphate [$(NaPO_3)_6$] salt concentration on moisture, minerals, leached solids, phytates, tannins and hardness (texture) of cowpeas (*Vigna unguiculata*) and bambara groundnut (*Voandzei subterranea*). Regression models were developed to predict the pre-canning parameters that yield the best quality products, with minimal effects on the nutritional and textural properties of the products. The optimal conditions found to achieve the optimum quality of the canned cowpeas were blanching time of 5 min, soaking time of 12 h and [$(NaPO_3)_6$] salt concentration of 0.5%, and for the bambara groundnut; blanching time of 8 min, soaking time of 12 h and [$(NaPO_3)_6$] salt concentration of 0.5%. The combination of blanching, soaking and [$(NaPO_3)_6$] salt were modeled using RSM to retain the nutritional (mineral) content of products while reducing the anti-nutritional factors and the hardness of the canned products with acceptable quality characteristics, indicating that as recent advances in canning technology, modelling techniques could be used to control canning operations while retaining desirable product quality characteristics.

Chapter 7 - Starch and proteins processed as individual components offer a wide range of functional properties. Unique blends can be prepared by the extrusion process with a synergistic effect inducing cross-linking sites that contribute to the protein three-dimensional network stability after extrusion, affecting nutritional and functional properties of the new biopolymer to be used in diverse food systems. The aim of this work was to study the effects of extrusion variables such as barrel temperature, feed moisture, alkaline and acidic pH, different proportions of corn starch (CS) and whey protein concentrate (WPC) on protein surface hydrophobicity (S_o), degree of denaturation, rheology, and physicochemical properties of the functional blends. The extrusion variables were barrel temperature (BT 70-180°C), feed moisture (FM 18-30%), pH (3-8) and the ratio of WPC to CS. The physicochemical characterization showed that FM and pH had significant effect on expansion index (EI); EI increased with lower values of FM and higher pH. An interaction of BT and FM had an effect on water absorption index (WAI); at lower FM, the BT effect was nonexistent, whereas at higher BT and higher FM, the WAI increased. PH had a significant effect on WSI, showing high WSI when low pH levels were used. Color analysis showed that higher protein content and pH generated color difference values (ΔE); low FM and low pH resulted in gel syneresis. The highest *in vitro* digestibility was obtained when a higher WPC proportion and pH were used. Surface hydrophobicity (S_o) is a good indicator of the hydrophobic side groups available for interactions in food systems. S_o was affected by the extrusion parameters; this information was used to monitor the interaction between proteins and carbohydrates present in the blends. Reversed-phase chromatography was used to evaluate denaturation of protein after extrusion. Although in extrusion denatured protein, S_o values for the blends were lower than those of the individual components. Rheology reinforced these results. The extruded blends of starch-WPC have potential to be utilized in milk-based new food products such as Oaxaca-type cheese analogues and drinking yoghurt-like.

Chapter 8 - In order to guarantee and optimize the quality of a good cup of coffee, roasting is a key step in the process. In this roasting step the green beans are heated at high temperatures (over 190 °C), initiating a series of complex chemical reactions, which lead to the formation of essentials substances to give among other, the sensory quality of the cup of coffee. Consequently, roasting is essential to control a large number of factors. Today's, robust sensors and algorithms are used to measure and on-line analyze essential factors such as color, surface, temperature, weight,... In this work, a control strategy is applied to on-line estimate the quality of roasted coffee. Coffee beans were roasted using hot air as heating medium. Bean temperature, weight, color and surface were measured on-line during roasting. These experiences allow better understanding of the phenomena that appear during roasting. A dynamical model was used to describe the heat and mass transfer of the beans while the gray values and expansion kinetics of the beans were estimated by an artificial neural network. The neural network considers the simulated temperature of bean and roasting time during the process. This strategy allowed us to estimate the quality of roasted coffee, when the roasting degree wished is similar to the gray value obtained by the model. These results were in good agreement since the roasted coffee was evaluated experimentally. Therefore, it is possible to apply this strategy in the industry to guarantee the quality of coffee roasting.

Chapter 9 - The selection of appropriate fibres is determined by the required values of the stiffness and tensile strength of a biodegradable material. Further criteria for the selection of suitable reinforcing fibres are, for example, elongation at failure, thermal stability, and adhesion of fibres at the matrix (starch), dynamic and long-term behaviour, price and processing costs. The fibres can impart synergistic properties to the thermoplastic starch composition. The aim of this research was to study the effects of extrusion variables: feed moisture, barrel temperature and content of sugar cane fibre, starch and plasticizer on the mechanical properties of traction of films that can be used for the manufacturing of disposable bags. Sugar cane fibre (250 μm) and native starch (25% amylose) were used as starting materials. An experimental laboratory single screw extruder with an L/D ratio of 20:1, designed and manufactured by Cinvestav-IPN, México.

A screw compression ratio of 1:1, and a rectangular die-nozzle of dimensions 40 mm X 0.75 mm were used. Feeding and die zones temperatures were kept constant at 60 and 75°C respectively; whereas the temperature of the transition zone (zone 2) was set according to the experimental design (110-140°C). The screw speed was kept constant at 40 rpm. The extruded films were stored for 40 h under controlled temperature and humidity (23±2°C and 50± 5%) for further analysis. The evaluated properties of traction were: Maximum resistance to the traction (σmax), Elongation at fracture (εf): and Modulus of elasticity (E) according to standard ASTM-D882-00. It was found that high plasticizer content (>30%) decreased the σmax. On the other hand, intermediate fibre content (5-15%) increased the σmax; high barrel temperatures (130°C) and intermediate fibre contents favored the εf and therefore resulted in thinner films. Also, high fibre contents (>15%) and low feed moisture (18.25%) decreased E which resulted in a less flexible film. The best conditions for thermoplastic extrusion were found to be: Barrel temperature (110-130°C), feed moisture (20.5-22.75%), fibre content (5-15%) and plasticizer (22-30%) as shown in assays 3, 5, 7, 8, 11, 12, 15, 16, 25, 30. In summary, fibres can impart more strength to the starch-bound matrix without adding significantly bulk or mass to the matrix. Sugar cane fibre in blends with native starch improved the strength and other mechanical properties of the films, and it has strong potential for the production of disposable bags.

Chapter 10 - Diverse formulations of thermoplastic biopolymers have been developed in an attempt to at least partially replace non-degradable petroleum-based products with biodegradable components which can be used for the manufacture of extruded and/or moulded articles such as films, utensils, containers, electric appliances and automobile interior materials. Several of these materials have been formulated of blends of starch and other components. In general, such thermoplastic biopolymers that have been developed primarily for the packaging industry do not have the mechanical characteristics of conventional polymers. In particular, the high rigidity and fracturability are disadvantageous for this projected usage. In addition, these materials tend to interact among them, this causes that the materials loss their dimensional stability, and tear or collapse. In an attempt to improve the structural stability of articles made from starch-based compositions, the authors experimental research have shown the viability of the use of natural fibres as reinforced materials in blends with native corn starch. The use of starch blended with agricultural fibres result attractive because the final products have the advantages of low cost, low density, acceptable specific strength properties, and biodegradability. Also, in many Latin American countries there are available high volumes of agricultural residues that can be used as raw materials to fabricate biodegradable materials. In this work, the effect of fibre and glycerol contents in blends with native corn starch on structural and mechanical properties of extruded injected-moulded plates was evaluated. Mechanical properties (elasticity modulus), structural properties (X-ray diffraction, viscosity profiles, infrared spectroscopy, scanning electronic microscopy) and biodegradable properties were evaluated in extruded injected-moulded plates. These plates showed better mechanical properties when increasing the fibre content, improving their resistance. Also, increasing the glycerol content improved the elongation and processability in plates. Structural properties (X-ray diffraction), viscosity profiles, infrared spectroscopy and scanning electronic microscopy (SEM) showed some changes in the physical structure of the materials as well as the possible interaction of fibres with the polymeric starch matrix. Studies of biodegradation showed that the fabricated plates were completely biodegradable. The best mechanical properties of the plates were those that had a formulation of 10% of fibre and 10% of glycerol with starch. It becomes clear that some of these natural fibres can potentially be used as reinforced material in blends with native starch with similar characteristics to those fabricated with conventional polymers.

Chapter 11 - Commercial food flavors in liquid form are difficult to handle or incorporate into foods. Flavors are volatile and thus would readily evaporate from a food matrix during storage. Encapsulation provides a better retention of flavors and protection against light-induced reactions and oxidation. Various forms of modified starches are used for flavor encapsulation which includes emulsifying starches and starch hydrolysis products. The aim of this work was to prepare phosphorylated waxy maize starch by melting extrusion with sodium tripolyphosphate using a single-screw extruder, and its evaluation as shell material for encapsulation of orange peel oil using spray drying. Starches were hydrolyzed with hydrochloric acid before they were esterified (3.4% HCl, 6 h, 50ºC). The viscosity of the modified starch was reduced as the hydrolysis products had smaller molecular weights than the native starch, while the water solubility index increased, making the modified starches appropriate for the encapsulation process using spray drying. Emulsions were prepared with 30% (w/w) of shell material and 20% of orange oil (w/w) by weight, based on the total weight of solids. The phosphorylated starch had a total oil retention of 55.7%. The addition of 2% (w/w) of whey protein concentrate (WPC) improved the emulsification process and oil retention to 66.8%. Encapsulated orange peel oil showed a good stability through 28 days of storage at room temperature and 50°C (50% HR) with an oil retention of 86% and 68% with respect of the starting oil in the capsules. The use of blends of starch-WPC improved the emulsification process and oil retention during spray-drying. Phosphorylated starches are a good alternative of shell material of low cost for flavor encapsulation.

Chapter 12 - This paper aimed to make a longer-term forecast analysis on global food nutrition supply and demand. The forecasts of supplies of food calories and proteins for the world and various regions over the period 2010-2030 were given, and food nutrition supply and demand balance in the forecast period was discussed.

If the past pattern continues, the global total food calorie supply would grow at the annual rate of 13.43±0.71 kcal/cap/day and reach 3210.4±67.3 kcal/cap/day in 2030. Total food calorie supplies for all of the regions would grow during the forecast period and, in most regions they are forecast to be greater than 3000 kcal/cap/day from 2015-2020. Total food protein supply for all regions but not Oceania, is forecast to grow during the forecast period. The proportion of animal sourced protein in total food protein supply is in 2030 forecast to increase and reach 35.5%, 61.6%, 56.8%, and 21.7% for Asia, Europe, South America, and Africa.

Food calorie supply in the world is expected to exceed the adequate energy intake after around 2015. Strong focus should be worldwide put on the over-intake of food calorie in the near future. Global food protein supply is not expected to be greater than the adequate range during the period 2010-2030. Food protein supply in Africa and Caribbean would be just a little greater than the basic demand in the forecast period. Food protein intake in these regions should be improved in the coming years.

CONTENTS

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Chapter 1

FOOD ENGINEERING TRENDS – ICELANDIC VIEW

Sveinn Margeirsson[1,2], Gudmundur R. Jonsson[2], Sigurjon Arason[1,3], Gudjon Thorkelsson[1,3], Sjofn Sigurgisladottir[1], Birgir Hrafnkelsson[4] and Páll Jensson[2]

[1]Matis ohf
[2]University of Iceland, Department of Mechanical and Industrial Engineering
[3]University of Iceland, Department of Food science
[4]University of Iceland

Abstract

Food processing is an indiscrete part of the chain from cultivation/catch to consumer. During the last decades the food value chain has grown longer and has become more market oriented, i.e. consumer driven instead of producer driven. New information on the effects of food on the health of the consumers and on the environment will continue to influence the choice of consumers regarding food products.

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Besides from these areas, merging of research institutes and universities will also characterize the food engineering research environment the next decade, as well as increased cooperation between research parties and industrial companies.

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Introduction

Food is a complex phenomena and the food market mirrors this. It is therefore admittedly a simplification, as is done in here, to divide the food market into three segments: low value (low cost), intermediate and high value. This approach is however widely accepted. Living standard in Iceland is high, salaries are high and production cost is generally high. Consequently, the high value food market is the most appealing one to Icelandic food producers. Because of this, and the fact that the high value food market is rapidly growing, the focus of this article is on the trends in food engineering that apply mostly to producers aiming for the high value end of the market.

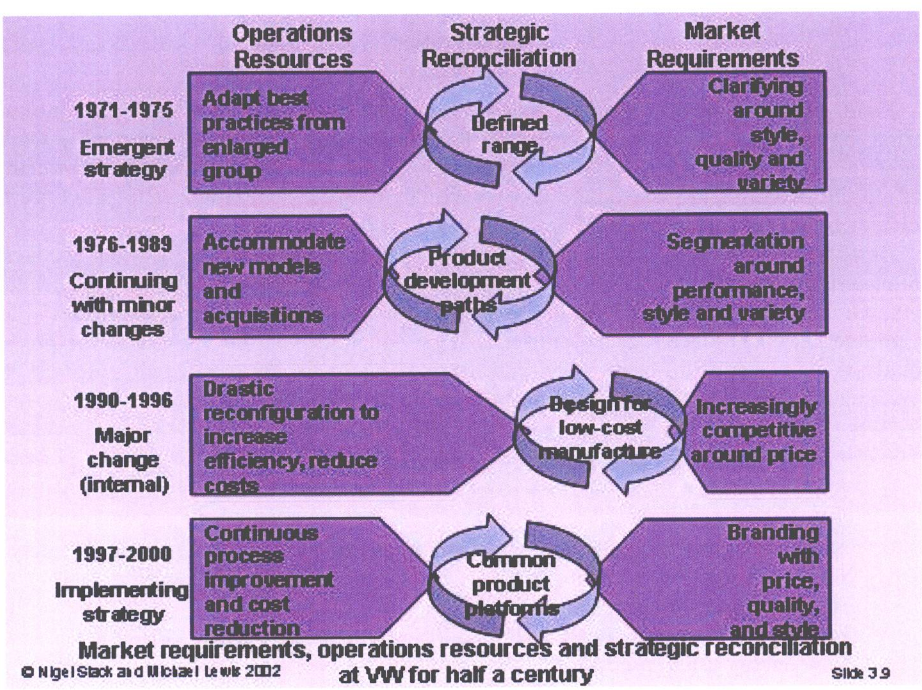

Figure 1. Market requirements, operations resources and strategic reconciliation at VW (Volkswagen) from 1970-2000.

Consumer behaviour has changed considerably over the last 60 years. The post-war shortage was solved with increased capacity in production and simplicity of products. Since then, prosperity has increased which has ment more focus on differentation in one way or another. Today, it is not enough to be able to produce, you must be able to produce something *different*, but also a great quality and cost-competitive product. Figure 1 (Slack and Lewis, 2002) shows how this change in market requirements changed the operations strategy of the car producer Volkswagen from 1970-2000. It is evident from the figure that the weight of cost efficiency, quality and style increased greatly in the last part of the 20th century.

The same market requirement applies to food market requirements. The nature of the food market, as well as development over the last few years has also placed more burden on the shoulders of food producers. Firstly, consumers are concerned about their safety and well-being due to recent unprecedented food scares, as well as positive and negative news on the effects of food on health. Secondly, consumers are concerned about the environment – sustainability is playing an increasingly critical role in marketing of food products. This can e.g. be seen in extended demands for eco-labelled food products. Thirdly, consumers are becoming more and more aware of their power to influence communal development with their purchasing power. The concept of 'fair-trading' (i.e. buying food which is grown, harvested and processed in such a way that 'fair' distribution of the profits made in a supply chain between the links in the chain is ensured) is gaining momentum. The vision of 'fair-trade' is stimulating development of farmers and other raw material suppliers' societies. Summing all this up gives the keyword: solicitude – for yourself, the environment and the society.

Consumers of the 21st century are well informed. The internet provides consumers with access to information on more or less everything they like to know, including health effects of food ingredients and other information affecting consumption. The level of education has, and will be growing and consumers are used to 'filter out' information they find credible and information they find not. This puts pressure on the quality of information delivered with food products – it has to be comprehensive, simple and still be put forth in such a way that consumers find it credible.

The food supply chain has changed greatly over the last two decades. Firstly, growth and merging of retailers has created multi-national companies selling a large part of their wares under their own label. Stiff competition between retailers and profitability demands of share holders put pressure on producers with regard to price. At the same time, quality demands of the retailer are increasing, since quality defects on a retailer labelled product will not only spoil the reputation of the product itself, but the retailer brand as a whole. Secondly, speciality stores (e.g. focusing on ecology, organic food or kosher food) have flourished. These stores (or chains of stores) often request different characteristics of the food products. Style and differentation is the keyword here. Consumers (especially those willing to pay a little extra for their products) are tired of homogeneity and standardisation – they demand a different *experience* when *enjoying* their food.

This development puts both food producers and R&D institutions in the food industry in a difficult, but exciting situation. A decision must be taken: – where shall the focus be? Is it wise to focus wide or narrow? This will not be answered for food producers here, but in our opinion the answer for Icelandic food research is: both! There is a need for specialisation but maintaining overview is also vital. This calls for the same development in R&D as in retailing, i.e. the merging of institutions. In the following chapter a few topics concerning