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Sensory Quality and Consumer Perception of Wheat Bread

*Towards Sustainable Production and Consumption.
Effects of Farming System, Year, Technology,
Information and Values*

BY

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Abstract

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In order to study the *effect of production systems* aimed at sustainability on *product quality* and of sensory and non-sensory factors on product acceptance – the effect of farming system, year, milling and baking techniques on the sensory qualities of wheat bread as a model product was investigated using a descriptive test, and the effect of information and values on liking of bread using consumer tests.

Whole wheat and white breads were baked with wheat grown in six lots in established conventional and organic farming systems in field trials, in two subsequent years for the white bread.

Milling technique influenced flours' rheology and had greater impact on the sensory qualities of whole wheat bread and on the slice area than did *farming system* and *baking technique*. Bread baked with roller-milled wheat was characterized by sweetness, juiciness, compactness and smaller slice area than bread baked with stone-milled wheat, which was characterized by saltiness, deformity and roasted cereals.

The *effect of year* on the white bread was greater than the effect of *farming system* or *recipe modification*. Bread baked with wheat harvested in 1999 had significantly lower intensities of crumb attributes such as smoothness, juiciness and elasticity, but higher rancid flavour, springiness, compressibility, mastication resistance than bread baked with wheat harvested in 2000. Bread baked with conventional flour had significantly higher juiciness and elasticity than organic bread.

Image analysis did not show differences in slice area between bread baked with conventionally and organically grown wheat harvested in 1999 compared with 2000. *Information* affected liking in relation to the type of provided information. Information on organic origin enhanced most liking of bread, particularly for the less liked samples and frequent consumers of organic food. Significantly different *values* and different specific liking of breads were found among consumer segments. Results linked values and age with "taste".

Keywords: Product quality, Production quality, Sustainability, Organic farming, Wheat, Organic Food, Bread, Milling, Breadmaking, Sensory analysis, Consumers, Information, Values, Food acceptance

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In memory of my parents

Anna and Józef Grochowina

To my sons

Carl, Niklas and Oskar

List of Papers

This thesis is based on the following papers, which will be referred to in the text by their Roman numerals.

- I. Kihlberg, I., Johansson, L., Langsrud, Ø., Risvik, E. (2004) Effects of information on liking of bread. *Food Quality and Preference*, DOI number 10.1016/j.foodqual.2003.12.005: 11
- II. Kihlberg, I., Johansson, L., Kohler, A., Risvik, E. (2004) Sensory qualities of whole wheat pan bread – influence of farming system, milling and baking technique. *Journal of Cereal Science*, 39(1): 67-84
- III. Kihlberg, I., Öström, Å., Johansson, L., Risvik, E. Sensory qualities of plain white pan bread – influence of farming system, year of harvest and baking technique. *Journal of Cereal Science* (accepted)
- IV. Kihlberg, I., Risvik, E. Consumers of organic foods – value segments and liking of bread. *Food Quality and Preference* (submitted)

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Abbreviations

ANOVA	Analysis of Variance
Agenda 21	The Declaration on Environment and Development of the conference in the Rio Janeiro 1992
Cd	Cadmium
dmb	Dry matter basis
E	Extensibility
FOOD 21	Interdisciplinary Research Programme towards Sustainable Production and Consumption
IFOAM	International Federation of Organic Agriculture Movements
KRAV	Key player in the organic market in Sweden and Association for Control of Organic Production in Sweden
KSLA	The Royal Swedish Academy of Agriculture and Forestry
MISTRA	Foundation for Environmental Strategic Research
PCA	Principal Component Analysis
PLS1	Partial Least Squares Regression (models one Y-variable)
PLS2	Partial Least Squares Regression (models several Y-variables)
R	Resistance to extension
SDS	Sodium dodecyl sulphate (used in analyze of sedimentation volume)
S-S	Disulfide bonds
w/w	Weight per weight

Introduction

‘To eat or not to eat a particular food’ has become the question, as ”Food progresses from being a source of nutrition and sensory pleasure to being a social marker, an aesthetic experience, a source of meaning, and metaphor, and, often, a moral entity” (Rozin, 1996). About fifty percent of consumers in the Nordic countries wish to have more information on ethical issues, environmental concerns and animal welfare, and 70% feel that they should demonstrate their attitudes through food choice (Hansen *et al.*, 2001). The intensive technical and industrial development of the past five decades supplied agriculture with effective machines, pesticides and artificial fertilizers. This not only greatly increased the crop yield, but also the environmental problems. Globally, between 1965 and 1989, the wheat cultivation area increased slightly, while wheat production doubled (Kent and Evers, 1994a). Sweden followed this trend, with decreased wheat cultivation area and increased wheat yield, although the changes were not so extreme as they were globally (SCB, 1975; SCB, 1980; SCB, 1986). The agribusiness was born with effectiveness as one main goal, but environmental consciousness as well emerged as a separate phenomenon. Agriculture has been confronted with the challenge of sustainability. Sustainable agriculture, supported by research, attempts to find production methods in line with environmentally friendly goals. Even small improvements can make large differences in the long run. Consider, for example, that on average one Swede will consume seven tons of bread and cereals products during his/her lifetime (Statistics Sweden, 2004a). As all food production entails detriments to the environment (Ford, 2000a), it is a challenge to produce high quality food, which is accepted by consumers, using methods that decrease the negative impact on the environment.

A vision of sustainable agricultural production

Agriculture is one of the most important sectors of societies, as agricultural products are essential for people’s health, well-being and survival. They are no less important than air and water. In sustainable agriculture, not only is yield important, but also the impact of the production system on flora, fauna

and water quality. On the one hand, there are more and more people, including politicians and economists, who understand that our socio-economic system not only affects the environment, but also depends on life-supporting ecosystems. On the other hand, many economists and politicians seem to believe that economic activity can be increased indefinitely (Ebbersten, 1992).

The increasing international environmental consciousness resulted in Agenda 21(1992). Agenda 21 is an action plan of The United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992, and it strives towards sustainable development and a high quality of life. For Sweden and for other consumption societies, changes in individuals' behavioural patterns must play a central role in achieving such a development. Sustainable development assumes sustainable agriculture, and well-known problems in Swedish agriculture, such as leaching of nutrients and use of pesticides, demand changes in the production system towards sustainability. In line with international agreements, the Swedish government raised sustainable development as a political vision, where environmentally friendly methods for agricultural production are in focus. To stimulate the development of alternative farming systems, the government has as a goal that 20% of all arable land should be ecologically cultivated by the year 2005 (Jordbruksdepartementet, 1999). These changes require a high level of acceptance of products from such farming systems on the part of producers and consumers. Consumer demands for organically produced food have to be large enough to give the momentum that will enable development. The Swedish interdisciplinary research program FOOD 21(2003) has been established to focus on sustainability in agricultural production, product quality and consumer demands, along the value chain from growth to consumption. Projects described in this thesis were carried out within the Product Quality Unit of the FOOD 21 (2003) programme, in order to investigate the effects of production system on product quality and the effects of information and values on consumer liking of bread. Wheat processed to bread was followed through all production processes, and product quality, at different steps, was evaluated to obtain a total picture of how variation in grain quality and applied processes affect product quality, and how non-sensory factors can be utilized as a source of knowledge in the process of optimizing liking of food in production systems and consumption aimed at sustainability.

Food production system

The expression "from farm to consumer" explains less scientifically what the food production system is all about. The production chain converts the raw material (wheat) into the designed product (bread). The wheat quality and yield depend on factors such as soil conditions, climate and farm management (Kent and Evers, 1994a). Wheat used for bread production belongs to the species *Triticum aestivum*, and in typical wheat grain 85% is endosperm, 13% bran and 2% germ (Davidson, 1999). Beside yield, resistance to disease and insect attacks, which were always important in wheat breeding programs, the emphasis has been placed during the past five decades on the quality of the grain (Zeleny, 1964). Wheat with 15% water content has on average 65-70% carbohydrates (starch, sugars and cellulose), 10-14% protein, 1.5-2% fat, 2.0-2.5% crude fibre and 1.5-2% minerals. Wheat is used also as feed, and as raw material for ethanol and starch production. Evaluation of the objective quality of wheat includes the functional properties important for the milling and baking industry, the microbiological and nutritional quality, as well as the sensory quality of wheat products. Environmental and immaterial quality are new aspects that extend the notion of quality. Only wheat with good and superior baking quality is good enough for modern bread production (KSLA, 1995). Bread, as the end product of processed wheat, influences not only the well-being and health of the consumer, but also the eco-system in which the wheat was grown. The milling process converts kernel into flour, which is used in the baking process, and bread quality is related to the quality and type of flour. Consumer acceptance and purchase criteria are no longer limited to product attributes, but concern also the type of production system. The traditional monodisciplinary approach to food production did not include the impact of production system on the eco-system or on the product quality perceived by consumers. Food in Sweden is produced mainly in the established conventional farming system, but also in the expanding alternative farming systems, organic (ecological) – controlled by KRAV (2003) and biodynamic governed by Demeter (Swedish Demeter Association, 2003). Not all organic farms are associated with KRAV. Traditionally, conventional farming had a more pragmatic relationship to nature and used easily soluble artificial fertilizers and pesticides guarantying higher yield and more controlled quality. Svenskt Sigill (2003) is an example of new trends towards sustainability within conventional agriculture in Sweden. Traditionally, ecological and biodynamic farming systems had a holistic approach to nature and agricultural production. The modern and concrete principles of organic farming have lately been elaborated in more detail by IFOAM (2004a), an international organization supporting all forms of alternative agriculture

(IFOAM, 2004b). Scientific evaluation of the advantages and disadvantages of different farming systems will provide modern agricultural production with guidelines for further development. Sustainable development focuses on environmentally friendly goals, but also on the situation of farmers/producers (Ljung, 2001) and on consumer demands (Hullberg, 2004; Jonsäll, 2000). Credibility and transparency constitute and bear the organic market. Examples from Denmark have shown what happens when consumers lose their trust in organic foods due to scandals and media attitudes (Thøgersen, 2003). The success or failure of organic farming systems depends largely on the morality and vitality of the market.

Framework of wheat production

The wheat production area is largest both in worldwide cereal production (Kent and Evers, 1994a) and in Sweden (Statistics Sweden, 2004b). Cultivation of wheat in heavy loam and clay, in areas with an annual rainfall of 229-762 mm, more intensive in spring than in summer, and with a mean summer temperature of 13^o C or higher, gives the best results. Nitrogen taken up early in plant development influences the yield, while the uptake after heading improves the nutritional and baking properties of wheat (Kent and Evers, 1994a). In farming practices, the source of nitrogen is one of the fundamental differences between conventional and organic farming, and it was found to affect gluten properties and loaf volume (Pedersen *et al.*, 2003). Agriculture, dominated in Sweden by wheat production, is often mentioned as one of the largest contributors to environmental problems. These accusations are often related to the environmental consequences of using artificial fertilizers and pesticides, and organic farming is considered as the form of farming that is not harmful to the environment, although both systems can decrease these losses and learn from each other (Bergström and Geber, 2003). As organic farming is less nitrogen intensive, a lower total nitrogen loss could be expected. The difficulty in avoiding leaching from manure was the largest disadvantage of the organic system, while the absence of pesticides was found to be the greatest advantage. Furthermore, owing to the lower yield from organic farming, it was calculated that for the production of carrots purée and cereal-based baby foods, the total negative effect on the environment per 1 kg of the product was lower in the conventional farming system, but that the impact per hectare was the same (Mattsson, 1999).

In order to create a scientific basis for discussion of influences of different farming practices, studies concerning nitrite leaching were conducted. At present, experimental data concerning nitrate leaching in different farming systems are scarce (Mølgaard *et al.*, 2003), although it was

shown that changes in crop rotation and increased use of catch crop decreased nitrate leaching in organic farming (Kristensen *et al.*, 2003). The organically manured, legume-based crop rotations utilizing organic fertilizers from the farm were considered an acceptable alternative to the conventional farming system (Mäder *et al.*, 2002). Investigation of factors of importance for phosphorous leaching revealed the importance of, e.g., soil type (clay/sand), high phosphorous concentration in the topsoil and the structure of clay soil (Djodjic, 2001). Phosphate fertilizers are the largest source of cadmium (Lindèn *et al.*, 2001), but also manure (Olsson, 2002) increases the cadmium level in the soil. Thus, longitudinal studies are needed to establish whether cadmium levels in wheat can be related to the farming system. In a Swedish study, it was shown that the cadmium level in wheat increases with increased nitrogen application (Wångstrand *et al.*, 2004). The European Commission has adopted the “European Action Plan for Organic Food and Farming” and put forward 21 actions to boost organic farming in response to the increasing number of organic farms and to consumer demands for organic products (Communities, 2004). According to EU-regulations (Council of the European Communities, 2001), organic farming is a common name for different forms of alternative farming systems, and organic products a common name for the food produced in these systems. Both the ideologically oriented biodynamic farmer and “turbo-ecologist” run their farms as organic farms. Thus, it is difficult to draw general conclusions about the quality of products from organic and conventional farming systems, as the systems are heterogeneous and under continuous development (O’Doherty Jensen *et al.*, 2001). According to the same report, cereals from organic farming were 10-20% lower in protein content. The comparison of breads originating from different farming systems is complex, but the available data confirm reduced protein content and show different baking quality for wheat from organic farming systems (Haglund *et al.*, 1998; Pettersson, 1982). When a suitable variety was selected, the baking quality of wheat from organic farming systems was guaranteed (Woese *et al.*, 1997). Furthermore, the authors pointed out that evaluating the quality of food grown in different farming systems is a complicated task, as it requires detailed information concerning crop rotation, use of pesticides, types of fertilizers, degree of ripeness of the plant samples, etc. Especially in the case of bread, concerning sensory, nutritional or heavy metal tests, it must be kept in mind that differences between samples may be due to factors other than wheat origin, factors such as differences in baking methods or recipe (Woese *et al.*, 1997) or differences in flour extraction rate or ash content. Thus, it is necessary to apply a study design that will keep the investigated factors under control throughout the whole production chain.

Milling techniques

The concept of roller-milling had a revolutionary effect on the milling and baking industry. Introduction of the roller-mill increased the efficiency of the milling process, extraction rate and quality of white flour, due to improved separation of the endosperm material from the bran.

The most often used milling technique in Sweden is roller-milling, but even other techniques, such as stone-milling, are employed. Organic wheat is milled using older techniques in smaller mills, as well as using large modern roller mills.

The roller-mill differs conceptually from the stone-mill. During stone-milling, the whole kernels are ground between stone surfaces so that the endosperm, bran and embryo are ground together (Cornell and Hoveling, 1998). The stone-milled flour extraction rate is 100%, provided sieves are not used for separation of the coarser material. The roller-milled wheat kernels pass through sets of break and reduction rolls. First, the kernel opens and most of the bran is separated from the endosperm, which is crushed and later reduced to the required flour particles on the reduction rolls. A series of sieves separates at every step the ready flour particles from larger endosperm parts, which are moved to the next stage (Ziegler and Greer, 1971).

Breadmaking

The baking test, as well as the baking process, can be described as a “moment of truth” revealing flour and dough quality that can be related to the wheat baking characteristics. In the breadmaking process, there are two stages that are critical for bread texture: proofing and baking. During these processes, the expanded gas has to be retained until the baking sets the structure. The bread volume and the crumb structure depend on the behaviour of the gas bubbles during these processes. Flour proteins (Schofield, 1985), starch (Blanschard, 1985) and lipids (Larsson, 1985), as well as yeast cells and water, are important for the breadmaking process, although the focus is on the protein content and quality.

Breadmaking is both a chemical (e.g. actions of oxidants) and a physical process (e.g., expansion of the gas bubbles, heat transport), affected not only by material but also by mechanical processing (kneading and moulding) and the baking parameters and recipe (Kokelaar, 1994). It was found that the measured value of strain hardening discriminates between flour with different baking quality (Dobraszczyk, 2002; Dobraszczyk and Morgenstern, 2003; Kokelaar, 1994).

During proofing and baking, the loaf volume continuously increases and after protein polymerization, the polar lipids determine the stabilization of

surfaces (Eliasson, 1991; Li *et al.*, 2004), while the gelatinized starch granules stabilize the new structures in the last stage of breadmaking.

Food quality

Scientists and philosophers in ancient and modern times have tried to capture the essence of the notion of “quality” and five principal approaches have been identified: the transcendent, product-based, user-based, manufacturing-based and values-based (Garvin, 1988; Pickel, 1989). In the past, the different approaches to the notion of quality described, on the one hand, scientific and societal development and, on the other hand, how the notion influences our understanding of quality. Because quality is connected with human cognition and perception, it is linked to knowledge and variable in nature. During recent years, and not only in Sweden, the emphasis has been on expanding the notion of food quality, which besides product attributes should also include production methods. Foodstuffs are no longer seen as merely static products, but as part of a production process (Pickel, 1989). For example, fruit production can include the tree nursery, cultivation, trade registration, processing, wholesale trade, retail trade and consumers. The classical differentiation between subjective and objective food quality was inherited by natural science from ancient times, and the Age of Enlightenment and the notion of objective quality still influence trade standards (Pickel, 1989). One example is the quality classification of, e.g., fruits according to size. As size was measurable, it constituted an “objective” attribute, even in the past. The objective quality is still present in the modern and expanded product quality definition, incorporating production methods and product origin (KSLA, 1998). According to this report, the nutritional, microbiological and sensory qualities are objective, as they are directly measurable. In consumer science, objective quality is attached to the product and describes, “what a product is,” while subjective quality derives from the consumer’s point of view and describes how the product is perceived by individuals (Bech *et al.*, 2001). The same approach to the concept of quality is used in sensory science (Rødbotten, 1997).

The notion of food quality, considered in its full complexity, is crucial for liking of food, food choice and food purchase. Among all quality aspects, the sensory quality of food, expressed often by consumers as “taste”, is reported to be the most important criterion (Schifferstein and Oude Ophuis, 1998; Torjusen *et al.*, 2001; Wandel and Bugge, 1997). Consumers are a heterogeneous group, and in order to better understand their needs, the quality of food from the consumer’s point of view has to be investigated.

Besides the sensory aspects, consumer product perception also includes non-sensory aspects and depends on the individual's values, experience and perception of the world. This is crucial for the liking of food, as the consumer's lack of acceptance of the non-sensory context may lead to the rejection of food with a high "objective" quality.

The several hundred years old locution "Animals feed: man eats: only the man of intellect knows how to eat" (Brillat-Savarin, 1970) became a challenge for both consumers and scientists evaluating the quality of products in our complex reality. Despite scientific developments, we still have more questions than answers (Pettersson, 2003). It may be easier to avoid than to choose among different food alternatives, due to, e.g., products' various advantages and disadvantages for consumer health and the environment.

Dough quality

Dough quality evaluation is the next step in wheat/flour quality control. This is traditionally investigated by means of the Farinograph, Extensograph, Zeleny test and SDS volume measurements or with modern methods examining the value of strain hardening (Dobraszczyk, 2002; Dobraszczyk and Morgenstern 2003; Kokelaar, 1994). The results of a rheological test, conducted before the baking test, indicate flour baking quality, but only the loaf characteristics are the final evidence of baking performance. Rheological measurements revealing the nature of the flours also enable a comparison between doughs. The dough is a dynamic and complex system. It can be described as a continuous water phase of flour's proteins, lipids, soluble carbohydrates in which starch, yeast cells and gas cells are dispersed (Bloksma, 1990). Dough is a foam, because of the gas bubbles dispersed in the continuous liquid dough mass. The area of the surface layers between gas (in gas bubbles) and water (in gluten) in the dough is large (1m^2 for 1gram dough). These surfaces have to be stabilized by proteins characterized by sufficiently large resistance against overpressure during proofing and baking and by elasticity good enough for dough rising (Eliasson, 1991). Not only the surface layer, but also the dough around the bubbles should have a certain resistance against the expansion, which is decisive for bubble growth and stability (Kokelaar, 1994). Proteins are not the main flour constituents, but they are most important for the quality of the dough, due to the ability of the protein fractions of gliadins and glutenins to build the gluten complex, unique for leavened bread. The gluten complex network is created with the help of intermolecular disulphite bonds (Schofield, 1985). Thus, the dough quality and bread texture depend largely on protein content and quality, even if the functions of lipids (Li *et al.*, 2004) and carbohydrates (Bloksma, 1985)

are important. As the requirement of large dough viscosity is met by virtually all doughs, the only rheological property required for satisfactory baking performance is high extensibility of the dough, which depends on the level of the glutenins enhancing extensibility (Bloksma, 1990). The dough evaluation focuses primarily on dough resistance and extensibility, crucial for gas retention as well as texture and loaf volume.

Ascorbic acid is used in Sweden as an oxidative flour enhancer and its role is to modify the dough system. Ascorbic acid is a more effective and more exact substitute for the natural flour maturing by atmospheric oxygen during storage (Bloksma, 1974). Addition of ascorbic acid and emulsifiers to wholemeal flour improves the loaf volume and softness of wholemeal bread. The character of dough made with flour with 100% extraction rate in contrast to dough made with white flour is affected also by the bran, the embryo and by interaction between these constituents (Galliard, 1985).

Sensory quality of bread

It is well known that flour composition has a strong impact on bread quality. Bread baked with flour from whole wheat, compared with bread baked with the same wheat sample, but with white flour, results in products that are perceived as very different in terms of comparable quality attributes such as colour, aroma, flavour and texture. Thus, flour's extraction rate and its ash content influence the sensory quality of bread.

The sensory quality is an important dimension of the total product quality and is registered by the human senses of sight, smell, taste, hearing and touch (Meilgaard *et al.*, 1991b). In leavened bread, texture is important for quality perception. It is mainly influenced by protein content and quality (Finney and Barmore, 1948) and used in evaluation as an indicator of food quality (Lawless and Heyman, 1999a). The bread crumb is described by textural properties and attributes such as softness and strength. Thus, bread quality depends in part on textural properties and flour possessing extra strong dough mixing characteristics gave a strong bread crumb (Scanlon *et al.*, 2000). Just as protein and lipids are decisive for gas holding capacity, starch is important for the structure of the crumb during fermentation (e.g., nutrition to the yeast, stability for the foam lamellae of dough) baking (water absorption, colour of the crust), and at the end of baking, as a factor stabilizing the bread structure (Eliasson and Larsson, 1993).

Investigations of the sensory quality of bread produced with wheat from alternative farming systems and of consumer acceptance of these products are not well known, but are decisive for acceptance and for purchase decisions. For consumers, the sensory quality, especially "taste", is reported to be the most important purchase criterion. A Swedish investigation

revealed that consumers believe that organic bread quality is not necessarily superior to that of conventional bread (Magnusson *et al.*, 2001). In the sensory test, attributes such as higher dryness and lower elasticity were found for organic bread as compared with conventional (Haglund *et al.*, 1998). Evaluating the sensory quality of bread from production systems directed towards sustainability requires longitudinal investigations designed so that sensory attributes can be related to specific factors in the production systems. The results from descriptive sensory tests, compared with results from consumer tests, can contribute to the evaluation of wheat grown in different farming systems and to better use of wheat from organic production for human consumption. This can be seen as a part of collaborative learning, where different actors on the market (producers, consumers) communicate in order to direct production and consumption towards sustainability (Ljung, 2001).

Sensory quality can be evaluated by analytical (objective) methods, represented in this thesis by descriptive sensory analyses, and by affective (subjective) methods, represented in this thesis by an acceptance test (Lawless and Heyman, 1999b; Rødbotten, 1997). In the descriptive test, a trained panel evaluates the products. The selected and trained sensory panel describes qualitatively and quantitatively the product in terms of appearance, aroma, flavour and texture. This creates a sensory profile of the product (Stone and Sidel, 1993). The consumer acceptance test of, e.g., bread involves hedonic evaluation. In the acceptance test, the consumer is asked “how much do you like this bread?” (Meilgaard *et al.*, 1991a) and the naïve consumer states the degree of his liking of the product. The sensory quality is the most important dimension of quality evaluation even for buyers of organic products (Torjusen *et al.*, 2001; Wandel and Bugge, 1997).

Health aspects of wheat and bread

In a typical wheat grain, 85% is endosperm, 13% bran and 2% germ, and wheat is a rich protein source compared with other staple foods. Moreover, the wheat protein supplies all amino acids (including essential amino acids) with some limitation for lysine, methionine and tryptophan (Davidson, 1999). Bread is a staple food in Sweden and an important source of carbohydrates, protein, fibre and minerals. The quantity of minerals decreases in order $K > P > Mg > Ca > Fe > Zn = Mn > Cu$ (Chaudri *et al.*, 1993). As a large part of minerals and fibre are found in the outer part of the wheat kernel, bread baked with whole wheat possesses wheat’s qualitative and quantitative attributes. A nation-wide investigation showed that, in Sweden, fibre consumption is below the recommended 3 grams/MJ (1.8g/MJ for men and 2.1g/MJ for women, respectively) (Becker and Pearson, 2002).

Moreover, bread was the only foodstuff eaten by all men and women in Sweden. The majority of consumers (92%) ate white bread, but as much as 76% ate leavened coarse, dark bread. White and dark bread contain on average 3g fibre/100g bread and 8g fibre/100g bread, respectively (Barbieri and Lindvall, 2003). White bread is still, however, a good source of energy, and in addition to carbohydrates it contains protein as well as pentosans and other hemicelluloses and B-glucans (Hoseney, 1990; Meuser and Suckow, 1985). The fruit coat (pericarp) comprises only 5% of the kernel, and besides pentosans, it consists of about 6% protein, 2% ash (high level of minerals) and 20% cellulose. The aleurone layer is relatively high in protein, total phosphorus, fat, niacin, thiamine and riboflavin, while the germ is mostly high in oil, proteins, and E and B vitamins (Hoseney, 1990), which have consequences both for the baking process, bread sensory and nutritional qualities and for consumer health. During extraction of white flour, the outer part of a kernel's fruit and seed coats and the aleurone layer are collected as bran, and together with germ excluded. Deficient diets are found not only in developing countries, but also in the developed world, where lack of energy is not a problem, but rather inadequate composition of the diet. Iron and zinc deficiency occur also in Sweden in some population groups (Barbieri *et al.*, 2003; Becker and Pearson, 2002), and whole wheat products are a rich source of both these minerals. The presence of whole wheat products in the consumer's everyday diets ensures a better balanced intake of minerals and vitamins than do highly processed foods, which are fortified with individual vitamins and minerals (Ford, 2000b).

Bread is not only a source of nutrients and energy. There is a safety risk associated with the presence of harmful substances such as mycotoxin, heavy metals (cadmium) or pesticides residues (Reijnders, 2004). Bread is the largest source of cadmium, compared with different food groups (Olsson *et al.*, 2002). Investigations conducted during the period 1983-1997 show mean values for white flour 0.029 mg Cd/kg and for wheat bran 0.15 mg/kg (Jorhem *et al.*, 2001). There are differences between geographic areas, and cadmium levels in wheat are correlated with cadmium levels in the soil.

Food acceptance

Enjoyment of food, which is a combination of sensory sensations and cognitive and emotional processes, improves everyday quality of life. "The pleasure of table belongs to all times and all ages, to every country and every day; they go hand in hand with all our other pleasures, outlast them, and remain to console us for their loss" (Brillat-Savarin, 1970). So it is not surprising that sensory attributes of food are reported as superior for food

acceptance, food choice and food purchase (Grankvist and Biel, 2001; Magnusson *et al.*, 2001), as they are memories and promises of sensory sensation (Lyman, 1989a). Hedonic pleasure is reported to be one of the strongest motivators behind repeated food choices (Arvola *et al.*, 1999).

Food acceptance depends both on sensory and non-sensory factors. Consumers consistently stress the priority of sensory factors such as appearance and taste for product acceptance, although the influence of the non-sensory factors is great. The non-sensory factors include not only aspects such as price, convenience of preparation and production methods, but primarily values and product beliefs.

Consumers' awareness of health, the environment and animal welfare exemplifies how production aspects influence food acceptance. The environmental and health aspects seem to be prioritized differently by different consumer groups. Younger consumers of organic products are more concerned about the environment and older consumers about their own health (Schifferstein and Qude Ophuis, 1998; Torjusen *et al.*, 2001; Wandel and Bugge, 1997). Aaron *et al.* (1994) stated that rated liking (degree of acceptance) for full- and reduced-fat spreads was influenced by information and followed the individual's beliefs with regard to these products. The information on the product's (tomatoes) organic origin enhanced consumers' acceptance of the product (Johansson *et al.*, 1999), mostly for those consumers who most frequently consumed organic products. In the blind consumer test, preferences for meat were not related to the organic or conventional production system (Jonsäll, 2000). Personal motivation and absence of chemical additives were reported to be the main reasons for demand of organic foods (Ekelund and Fröman, 1991). The most important food purchase criterion for consumers was "taste" and the least or next to the least important criterion was product origin from organic farming system or the environmental consequences (Grankvist and Biel, 2001; Magnusson *et al.*, 2001; Sjöberg, 1996). Interestingly, in a German investigation, a production aspect such as regional production was also the least important (Wirthgen *et al.*, 1998).

Acceptance of coarse (dark) bread has increased, and the good taste of such bread and beliefs in its health promoting attributes are pointed out by consumers (Idétidskriften C, 2004). The consumption trend of eating dark and coarse bread resulted in the largest increase in leavened bread sale volume on the bread market (Butikensvärld, 2003). The Swedish diet, like diets in other developed countries, is characterized by high fat and sugar, but low carbohydrates and fibre content (Becker, 1999a). In order to promote consumer health, an increase in consumption of bread should improve the balance between different food groups and nutrients.

Attitudes and values

Attitudes can be conceptualized in several ways. According to three schools of thought, attitudes can be seen as a function of: i) affective components alone (Thurstone, 1946), ii) both affective and cognitive components (Worchel and Cooper, 1979) and iii) affective, cognitive and behavioural components (Kretch and Crutchfield, 1948). The three-factors view of attitudes includes, besides a value or feeling component, a belief or a cognitive component as well as a behavioural component or a so-called demand of action. These factors interact to form an attitude. Despite different approaches or views, an attitude includes an affective component (Worchel and Cooper, 1979) and an evaluative dimension: liking or disliking (Lyman, 1989b).

Values represent the non-sensory factors influencing food acceptance. They are criteria for, e.g., selection rather than a quality inherent in the object and have the function of “a guiding principle in people’s life” (Schwartz, 1992). Attitudes depend on values (Worchel and Copper, 1979). According to Lyman (1989b), attitudes are predominant in food acceptance and are not limited to the sensory attributes of the product. Thus, they also include attitudes towards all possible non-sensory factors incorporated in the production process. Information concerning the impact of production methods on the environment or concerning product beliefs are examples of two possible influences on consumer attitudes towards a product (Aaron *et al.*, 1994; Grankvist, 2002). On the other hand, a general positive attitude towards an organically produced product does not imply the choice or purchase of that product (Magnusson *et al.*, 2001), but it is a prerequisite for purchase. This is not surprising, as many other factors influence decision-making. With regard to organic foods, consumers report factors such as higher prices, low availability, and uncertainty as to whether the products are organic (Magnusson *et al.*, 2001).

Product beliefs and attitudes are stored in memory as a network of associative knowledge utilized when needed (Schifferstein, 2001). Such knowledge serves our orientation in practical life. It also allows market researchers or psychologists to investigate consumer attitudes towards food (Magnusson *et al.*, 2001) or determinants of choice of eco-labelled products (Grankvist, 2002) without testing the food samples, because values, beliefs and attitudes are important non-sensory factors for food acceptance, preference and food choice. Positive eco-label information had the greatest effect on consumers with strong environmental values. Furthermore, consumers converting to ecological products revealed the importance of environmental factors in the initial phase of conversion and beliefs about products in the next phase (Grankvist, 2002). Because the product is the

focus of sensory science, samples are always served to the consumer for tasting, even when, e.g., the effect of non-sensory factors is being investigated (Johansson *et al.*, 1999).

Liking of food

Liking of food influences both food choice and food purchase. The terms liking and preference should not be used interchangeably, as a preference expresses a consumer's choice (Mela, 2001) when he/she is asked, "Which sample do you prefer?" (Meilgaard *et al.*, 1991a). In an acceptance test the subject is asked, "How much do you like this product?" and he/she expresses the degree of liking or disliking of the sample on the proposed scale. Specially designed acceptance tests allow us to investigate the impact of relevant factors related, e.g., to the production system, product quality or consumer values and their interactions with taste.

Liking of food is not a function of the pleasantness or unpleasantness of the sensory properties alone. The perception of total food quality depends largely on consumer attitudes towards the product. "More than anything else, food meanings and associations represent attitudes toward the food itself, toward its sensory qualities, or toward the physical and social context in which it is served, including other individuals who serve or eat it" (Lyman, 1989b). Because values are decisive for attitude formation (Rosenberg *et al.*, 1960; Worchel and Cooper, 1979), the values of consumers are of importance in a society working towards the sustainable development of agricultural production.

Consumers and the market

Sustainable development has to be re-negotiated, re-defined and practiced in the society, and the requirements of sustainable development of the agricultural production system must be met through collaborative learning in which different actors are involved (Ljung, 2001). The consumers have a key role on the market, and the consumer test is one way of promoting effective communication, in a real-life situation. On the one hand, consumers are used to making a food choice on the basis of a product's physical attributes, where priority is given to appearance and taste. On the other hand, there are consumers for whom production quality (ethical and environmental aspects) is becoming increasingly important. The majority (70%) of consumers in the Nordic countries feel that they should demonstrate their attitudes through their food choice (Hansen *et al.*, 2001). Concerning general preferences for a food product, Swedish consumers wish for "pure" and "natural" products. "Pure" indicates the highest possible content of the main ingredients, e.g.

high meat content in the meatballs, and “natural” products should be free from additives such as preservatives, thickeners (SJFR, 1986). Consumers believe that bread baked with organic wheat contains fewer preservatives than does bread baked with conventional wheat (Magnusson *et al.*, 2001). In Sweden, during the 1980s, white bread lost its high status to preferences for fibre-rich dark bread (Fjällström, 1991). This was a result of health education concerning the positive effects of fibre. Moreover, the total consumption of bread has increased over the past 20 years (Eidstedt *et al.*, 2004). Consumers have become aware that all bread is an essential part of a healthy diet, and the new bread varieties contributed to this. The trend of wholemeal and dark bread consumption was not only typical of Sweden, but also of England. However in England, the consumers have returned to white bread with various added ingredients, such as multigrains and fibre (Federation of Bakers, 2004). In Sweden, the dark and coarse bread trend is growing stronger (Butikensvärld, 2003).

Consumers demand not only different types of bread, but also breads from alternative production systems. Organic bread consumption is low, and only 8% of consumers reported that they buy organic bread “always” and “often” (Magnusson *et al.*, 2001). The reported perceived accessibility of organic bread by consumers in 2001 was significantly higher than in 1998 (Sjödén, 2003), and consumers stated the importance of bread taste in their choice between organic and conventional products (Grankvist and Biel, 2001; Magnusson *et al.*, 2001). For the majority of consumers, product sensory quality seems to be more important than production quality (Grankvist, 2002; Magnusson *et al.*, 2001).

Aim

The overall aim of this thesis was to study the effects of production systems aimed at sustainability on product quality along the value chain from wheat to bread as well as the effects of sensory and non-sensory factors on bread acceptance in order to understand how variation in wheat quality, different steps in production and provided information can be utilized as a source of knowledge.

The specific aims were:

- to investigate the sensory quality of whole wheat and white bread baked with conventional and organic wheat grown in field trials and to study the effects of farming system, year of harvest, milling and baking techniques on bread characteristics (Papers II and III)
- to investigate the effect of information and consumers' values on liking of bread (Papers I and IV)

Materials and Methods

Experimental overview

Overview of the whole study.

The study was designed in accordance with one of the main objectives of the FOOD 21 program, which was to investigate the effect of production system on product quality and to study consumers' perception of the products (Fig.1).

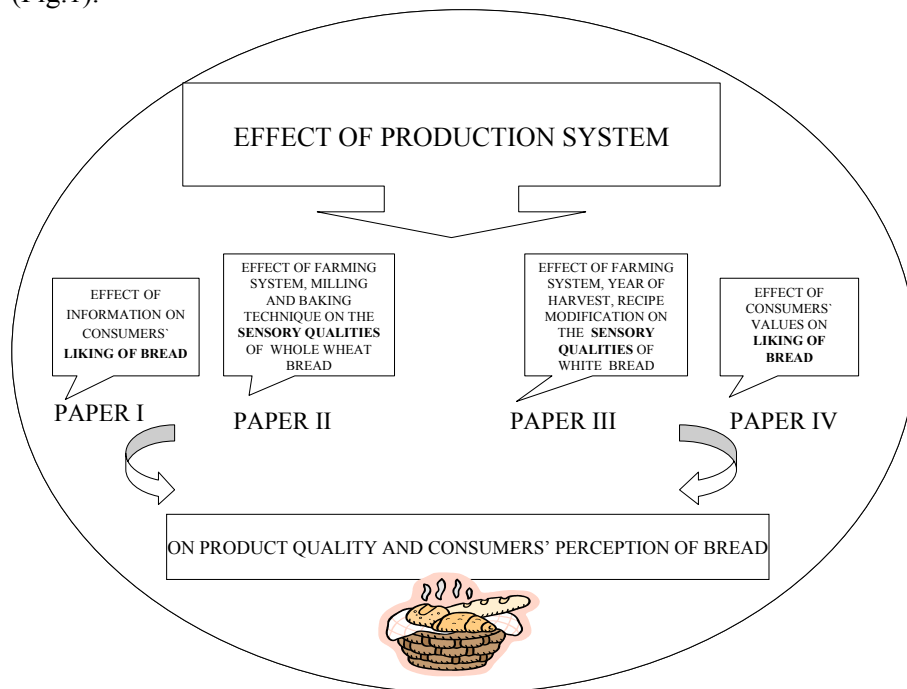


Figure 1. Project design.

In order to achieve this, the baking quality of wheat grown in different farming systems in field trials was investigated (Papers II and III) and the sensory qualities of whole wheat bread (Paper II) and white bread (Papers I

and III) were established by a selected and trained panel. Consumer acceptance of breads (originating from different farming systems) was studied as a function of provided information and consumer values (Papers I and IV). The Swedish winter wheat varieties Kosack and Ebi were used in experiments described in Papers I, II and Papers III, IV, respectively (Table1). Though studies described in Papers I-III, a trained panel carried out a descriptive sensory analysis of the bread. Wheat used in experiments described in Papers II-IV was grown in field trials. Image analysis was used to calculate the bread slice area (Papers II and III).

Wheat was selected as an experimental material, as this cereal is produced in the largest scale in Sweden, both in conventional and organic farming systems. Bread is an important everyday food for the Swedish consumers and a good model for investigating the baking quality of wheat and the sensory quality of bread, as well as consumers' acceptance of a product in relation to its sensory quality and production methods.

Table 1. **Experimental material and the sensory methods.** Origin of two wheat varieties, flour and bread samples in conventional (A - B) and organic (C - E) farming system described in Paper I (white bread with and without amaranth "Aztec wheat"), Paper II (whole wheat bread baked with roller-milled (1-24)^a and stone-milled (25-48)^b wheat), Paper III - IV (white bread baked according to Pharinograph data (1-12)^c and modified recipe (13-21)^d).

Paper	Growth location	Year of harvest/ wheat variety/ previous crop	WHEAT, FLOUR AND BREAD SAMPLES						Sensory evaluation			
			FARMING SYSTEM						Descriptive test	Consumer test		
			CONVENTIONAL			ORGANIC ^a						
I	Uppland commercial	1997 Kosack	C-conventional without amaranth			O-organic without amaranth			Yes	Yes		
			CA-conventional with amaranth			OA-organic with amaranth						
II	Bollerup field trials	1998 previous crop Kosack	Lots						Yes	No		
			no livestock		no livestock		with livestock				with livestock	
			A2	A5	B	C	D	E				
III & IV	Bollerup field trials	1999 previous crop Ebi	winter rape	peas	peas/oat	peas/oat	peas/oat	peas	Yes	Yes*		
			1-4 ^a	5-8 ^a	9-12 ^a	13-16 ^a	17-20 ^a	21-24 ^a				
			25-28 ^b	29-32 ^b	33-36 ^b	37-40 ^b	41-44 ^b	45-48 ^b				
III & IV	Bollerup field trials	2000 previous crop Ebi	A199	A499	B99	C99	D99	E99	Yes	Yes*		
			winter rape	peas	peas/oat	peas/oat	peas/oat	peas				
			1 ^c	2 ^c	3 ^c	4 ^c	5 ^c	6 ^c				
III & IV	Bollerup field trials	2000 previous crop Ebi	A600	A300	B00	C00	D00	E00	Yes	Yes*		
			winter rape	peas	peas/oat	peas/oat	peas/oat	peas				
			7 ^c	8 ^c	9 ^c	10 ^c	11 ^c	12 ^c				
			13 ^d	14 ^d	15 ^d	16 ^d	17 ^d	18 ^d				

^a "organic" is a common name for biodynamic (C) and ecological (D, E) farming system * chosen samples

Paper I. Four bread types were baked for a descriptive sensory analysis, and in a consumer test the same bread types were scored for liking by 480 consumers, when information was provided concerning: flour (origin from conventional versus organic farming system), health effects (cholesterol reducing effect versus no information), and information meant to create a neophobic reaction (admixed amaranth /"Aztec wheat"/ versus no information). The consumers also answered a questionnaire related to the relevant issues.

Paper II. Whole wheat pan breads (48 types) were baked with six samples of winter wheat Kosack, originating from different farming systems in field trials, roller-milled versus stone-milled, with two kneading and flour levels, and evaluated in the descriptive test by a trained sensory panel (Paper II).

Table 2. *Experimental design for whole wheat breads (n=48) baked with roller-milled wheat (breads 1-24) and with stone-milled wheat (breads 25-48), two flour levels (low and high) and two kneading levels (low and high), A2 - A5 conventional wheat^a, C - E organic wheat^a.*

WHEAT SAMPLE	MILLING TECHNIQUE							
	ROLLER-MILLING				STONE-MILLING			
	FLOUR LEVEL ^b				FLOUR LEVEL ^b			
	low		high		low		high	
	KNEADING LEVEL ^c							
	low	high	low	high	low	high	low	high
	Bread numbers							
A2	1	2	3	4	25	26	27	28
A5	5	6	7	8	29	30	31	32
B	9	10	11	12	33	34	35	36
C	13	14	15	16	37	38	39	40
D	17	18	19	20	41	42	43	44
E	21	22	23	24	45	46	47	48

^a For description of farming systems see Table 1

^b Flour levels, *low*: 1477.2 g flour /1000g water and *high*: 1612.8 g flour /1000g water

^c Kneading levels, *low*: 0.5 min (30%), 1min (40%), 1min (50%), 2 min (70%), where 100% is 311rpm and *high*: 0.5 min (30%), 1min (40%), 1min (50%), 4 min (70%), 0.17 min (100%)

Paper III. White pan plain breads (21 types) were baked in accordance with Farinograph data (12) and in accordance with the modified recipes (9), with six samples of winter wheat Ebi, harvested in two subsequent years in the same field trials as the wheat in Paper II, and evaluated as in Paper II.

Paper IV. White breads (five types) described in Paper III were scored for liking in the acceptance test by organic consumers in two age groups. At the same time, the questionnaires concerning consumer values and food-related issues were completed in order to investigate the relation between consumers' liking of bread and their values (Paper IV).

Wheat origin

Paper I. The Swedish winter wheat (*Triticum aestivum*) variety Kosack was grown conventionally and organically in commercial wheat production, in Uppland, Sweden. Amaranth (*Amaranthus cruentus*) was grown in a commercial plantation in the neighbourhood of the city of Łomża in Poland.

Papers II, III and IV. Winter wheat (*Triticum aestivum*) variety Kosack (Paper II) and Ebi (Papers III and IV) were grown conventionally in lots A – B and organically (biodynamically in lot C and ecologically in lots D and E) in field trials (L4-3410), run in Bollерup southeast of Scania, Sweden since 1987 by the Agricultural Society in Kristianstad, Sweden (Gunnarsson and Haslund, 1995; Ivarson *et al.*, 2001) (Table I). The soil in Bollерup has yielded in good return and the type of soil is loam (humus rich, sandy, light clay). The pH measured in the beginning of the project was 6.5 and the mean annual precipitation was 654 mm (measured during the period 1961-1990). Seed for sowing was conventional, and in lots A-B it was treated with pesticides.

Name of samples and farming systems

Paper I. Wheat, flour and breads baked with conventional wheat were named C and with admixed amaranth CA. Wheat, flour and breads baked with organic wheat were named O and with admixed amaranth, OA.

Paper II. The samples of wheat harvested in 1998 and respective flour and bread samples have been named according to their origin, using the symbols for lots A-E (lot A comprised crop rotation A1, represented in this study by the experimental wheat sample from lot A2 and crop rotation A2, represented by the experimental wheat sample from lot A5; see Table 1). In addition, each bread type, baked with wheat harvested in 1998 and roller-milled (1-24) versus stone-milled (25– 48), has been assigned numbers from 1-48, in accordance with the experimental design, to distinguish the individual samples (Table 2).

Papers III and IV: For the samples of wheat harvested in 1999 and 2000, respective flour and bread samples have been named according to the symbols for lots A-E as in Paper II (Table 1) and year, i.e. samples originating from lot E and year 1999 were named “E99”, and those from lot E and year 2000 were named “E00”, etc. Lot A comprised both crop rotation A1 and A2. Crop rotation A1 was represented in 1999 by the wheat sample from lot A1 (named A199) and in 2000 by the sample from lot A6 (named A600). Crop rotation A2, in 1999, was represented by the wheat sample from lot A4 (named A499), and in 2000, by the sample from lot A3 (named

A300). In addition, each bread type bake with wheat A-E harvested in 1999 and 2000 has been assigned numbers from 1-21. Breads numbered 1 to 12 were baked in accordance with Farinograph data. Additionally, bread types 13-19, baked in accordance with the modified (m) recipe, were marked with “m” in addition to lot symbol and year, i.e. E99m. Breads number 20 and 21, baked according to the extreme modified (me) recipe, were called A600me and E00me (Paper III, Table III). In this thesis, only the lot symbols A, B, C, D, E will be used when information concerns samples from all years of harvest 1998-2000. When information concerns all samples from each year, the symbols A98-E98, A99-E99 and A00-E00 will be used, respectively.

Date of sowing and harvest: Paper II. The date of sowing was the 19th of September 1997 and the date of harvest was the 7th of September 1998. One cycle of six years of crop rotation (including winter wheat) had been used continually in each lot (A-E) with the exception of lot A, where two crop rotations were applied.

Papers III and IV. The date of sowing was the 19th of September 1998 and the date of harvest the 30th of August 1999. In 2000, the date of harvest was the 15th of August for lots C-E and the 16th of August for lots A-B.

The different cycles of crop rotation in lots A-E were described in detail by Ivarsson *et al.*, (2001). The main criteria for the second cycle of crop rotation (1993-1998) and for the third (1999-2004), as well as changes for lot B-E, are described in Papers II and III, respectively. Changes in the previous crop for wheat concerned lots B-D (Table 1).

Wheat and dough analysis

Wheat samples used for baking of whole wheat and white breads, evaluated in Papers II-IV, were analyzed for protein content (N x 5.7 Kjeldahl, ICC 105/2, dmb), ash content (ICC 104/1), volume weight (SJVFS 1991,23), phosphorous and potassium (NMKL 161Nordic Committee on Food Analysis and Determination ICP-AES; see Paper II, Table 1; Paper III, Table 1).

Whole wheat flours and white flours were analysed for protein content (Nx6.25 Kjeldahl AOAC 979.09, dmb), Falling No. (ICC 107/1) and by means of Farinograph and Extensograph. Flour of whole wheat was analysed for SDS (ICC 116/1). The gluten content was investigated in the white flours (ICC 137/1) and gluten quality was analysed by Glutograph according to Sietz and by means of the Zeleny test (ICC 116/1). The analyses were conducted at accredited laboratories: Swedish Cereals Laboratory AB, Svalöv, Sweden; Analycen Nordic AB, Uppsala, Sweden; AgroLab Scandinavia AB, Kristanstad, Sweden and Nord Mills AB, Uppsala, Sweden (Paper II, Table 2; Paper III, Table 2).

Baking

Baking of all experimental samples was conducted according to experimental design, in the experimental bakery in Nord Mills AB, Uppsala, Sweden, by the their test baker and the author.

On the basis of a pilot baking test, the four bread types (Paper I) were selected for the consumer test according to the criterion that differences should be large enough to be perceived by consumers, but not so large that samples could be perceived as belonging to different classes of breads. In order to achieve this, the choice was made to balance the effect of admixed amaranth for perceived sensory quality by addition of whole wheat flour to bread baked without amaranth. Doughs for the four bread types were made with 25% (w/w white flour) whole wheat flour or 25% (w/w white flour) amaranth seeds. For close description of the baking process, see Paper I, 2.2.2. Baking, Table 1.

The baking of whole wheat breads (Paper II) was conducted according to the experimental design presented in Table 2 in order to reveal the quality of whole wheat bread baked with wheat grown in different farming systems where different milling and baking techniques were applied. For close description of the baking process, see Paper II, 2.4. *Baking*, Table 4. White breads numbered 1-21 were baked with six wheat samples grown in different farming systems in Bollrup and harvested during two consecutive years (Papers III and IV). Baking of breads 1-12 was adapted to Farinograph data of the individual flour and breads numbered 13-21 were baked in accordance with modified recipes. For close description of baking process, see Paper III, 2.2.4. *Baking*, Table 3.

Sample preparation

The loaves were thawed in sealed polyethylene bags for three hours at room temperature, sliced (13 mm thick slices) on an industrial slicing machine (Rose Forgrove at Skogaholms Bröd AB, Uppsala, Sweden) and returned to their original bags. The samples were transported by car (15 min) to the sensory laboratory, where they were placed in separate covered Petri dishes ($\varnothing = 90$ mm; labelled with 3-digit random numbers) and presented to the panel/consumers for descriptive sensory/consumer tests.

Paper I. The crust was cut off and a half slice was served to the consumers and to the descriptive panel. The trained assessors also received a whole slice with crust for evaluation of the texture attribute.

Paper II. A whole slice with crust was presented to the panel for descriptive sensory analysis.

Paper III. A whole slice without crust was presented to the panel. The crust was cut off with scissors, placed separately in a Petri dish, labelled with a three-digit number and evaluated separately.

Paper IV. A whole slice with crust was served to the consumers.

Sensory evaluation

The sensory evaluation of bread was conducted both by selected (ISO, 1993) and trained assessors (Papers I-III) by means of a descriptive test (ISO, 1985; Stone and Sidel, 1993) (sensory profiling), describing the objective quality of bread, and by untrained consumers (Papers I and IV) in a consumer test (acceptance test) (Meilgaard *et al.*, 1991a; Resurreccion, 1998), describing the subjective quality of bread. The sensory descriptive test belongs to the group of “analytic” type tests and was conducted in the sensory laboratory. The consumer test is a “hedonic” (affective) type of test (Lawless and Heyman, 1999b) and was conducted in supermarkets and university campus areas. After training sessions, during the descriptive test, each member of the sensory panel, working in a standardized, neutral environment, assessed individually the bread samples using the earlier-defined attributes (Table 3). The samples were marked with randomly chosen three-digit numbers, in two (Paper II) and three replicates (Papers I and III). The intensity of the specific attributes was assessed on a continuous unstructured scale from 0 to 100 on a computer screen. The product received a sensory profile, describing qualitatively and quantitatively the products’ appearance, aroma, flavour and the texture of the breads.

Conceptually different is the acceptance test, which was conducted among untrained consumers. In this test, the consumers scored bread for liking and additionally completed the questionnaire containing questions relevant to the investigation. The scale was unstructured, 150 mm long and had a frowning face on one end (and anchor “I dislike it very much”) and a smiling face on the other (and anchor “I like it very much”) (Risvik, 1996). The consumer tests were conducted among 480 consumers in order to observe the variations in liking of bread as a function of information (Paper I) and among 184 consumers to investigate the specific liking of bread in relation to the consumers’ values (Paper IV).

Table 3. *The sensory attributes constituted breads sensory profiles (Papers I - III). Breads baked with conventional and organic wheat, with and without amaranth (Paper I), with whole wheat flour (Paper II) and with white flour (Paper III)*

PAPER I	PAPER II	PAPER III
<i>Appearance</i>	<i>Appearance of slice (crumb)</i>	<i>Appearance (crust)</i>
Colour	Colour tone (yellow/red) Whiteness/blackness	Colour intensity
<i>Aroma</i>	Colour intensity	<i>Aroma (crumb)</i>
Wheat	Raw streak	Wheat
Cereals		Whey
Earthy	<i>Aroma (crumb)</i> Wheat	Rancid
	Cereals	Overall aroma
<i>Texture (by finger)</i>	Hay	<i>Texture (crumb) /by finger</i>
Elasticity	Overall aroma	Compressibility
Compressibility		Springiness
Deformability	<i>Aroma (crust)</i> Roasted cereals	Deformability
<i>Texture (mouth feel)</i>		Elasticity
Juciness	<i>Texture (crumb) /by finger</i> Deformability	<i>Texture (crumb) /mouth feel</i> Smoothness
<i>Flavour</i>		Mastication resistance
Wheat		Juiciness
Cereals	<i>Texture (crumb) /mouth feel</i> Juiciness	
Earthy	Compactness	<i>Texture (crust) /mouth feel</i> Toughness
Astringent	<i>Texture (crust) /mouth feel</i> Crispiness	<i>Flavour (crumb)</i> Wheat
	<i>Flavour (crumb)</i> Sweetness	Sour
	Saltiness	Rancid
	Cereals	Overall flavour
	Nuts	
	Aftertaste	
	<i>Flavour (crust)</i> Aftertaste	

Values

An instrument to measure all value types and test hypotheses that relate value priorities to consequences, developed by Schwartz (1992), was used in the study described in Paper IV. The set of 56 universal value types (Schwartz, 1992) was included in the questionnaire and rated by organic consumers who subsequently scored the bread samples for liking. The experiment was conducted to observe differences between people with regard to their specific value priorities and bread acceptance.

Statistical analysis

The sensory data were subjected to ANOVA (Papers I and III), PCA (Papers I-IV) and PLS1 and PLS2 (Papers II and IV).

Paper I. The data from the descriptive test were analysed in a mixed ANOVA model, with assessors as a random factor. Two different models were considered. Model I had *bread* as a fixed factor with four levels (*bread*: C, O, CA, OA) (3df). This model contained the terms: *assessor*, *bread*, *assessor*bread* and *replicate* (block variable). In Model II, the bread factor was replaced by *farming system* (1df), *amaranth* (1df) and *farming system*amaranth* (1df). And consequently, the term *assessor*bread* (5df) was replaced by *assessor*farming system* (5df), *assessor*amaranth* (5df) and *assessor*farming system*amaranth* (5df). In principle, these two models are equivalent. In the latter model, the *bread* term was decomposed into three orthogonal terms. Apart from that there were no differences. The data from the descriptive test were analysed in MINITAB (Minitab, 1996).

A Principal Component Analysis (PCA) was conducted to study the relationship between sensory attributes of the breads and to describe the sensory profiles of the four bread types: C, CA, O, and OA. The PCA makes it possible to overview the data by extracting the most important information and finding dominating patterns among samples. This is possible by projecting the information from the original variables into the reduced space dimensionality to derive the new variables called principal components. PCA was performed using the Unscrambler statistical package (Unscrambler, 1996).

In the consumer test, each consumer was served four samples combined with four information types. The whole study involved $2^3=8$ information types, which were divided into two groups of four types (half-fractions). These groupings were made according to fractional-factorial-design theory (Box *et al.*, 1978). Considering the first half-fraction, there are 24 different ways to combine these four information types with the four bread types and all these combinations were used. Furthermore, according to the second half-fraction, we have 24 additional combinations. Therefore, 48 consumers were needed to carry out all these combinations of samples and information. In our study, the total design consisted of ten such groups of 48 consumers.

In a traditional ANOVA analysis of consumer data, the consumers would be regarded as a random factor. In our complex design, *group* (480 consumers) was regarded as the random variable (consumers were regarded as a fixed factor). The resulting tests are still statistically correct. More specifically, all models contain the factors *flour*, *health*, *neophobia*, *bread*, *sex*, *age*, *education*, *group* and all possible two-factor interactions between them. To investigate the first question (q1), the following terms were added

to the model: $q1$, $q1*flour$, $q1*health$, $q1*neophobia$ and $q1*bread$. As *group* was treated as a random factor, all interactions involving *group* were also treated as random. The results from the health-related questions were also added to the model (one question at a time). When the question variable has several levels, it is best to treat it as a continuous variable, but the categorical variant was also tried. The significance testing was based on Type II sums of squares, and *proc mixed* (SAS, 1999) was used for computation. To illustrate the various effects, average scores were calculated according to least-squares means.

The data obtained from sensory analysis (Paper III) were subjected to analysis of variance by General Linear Models (GLM) procedure, using a statistical program package (SAS, 1999). The experiment contained an unbalanced factorial design, with two fixed factors (farming system and year of harvest) and one random factor (assessor). An overall test was first performed with main factors and interaction terms. When random interaction terms were significant (or when the F-ratio exceeded 2), the resulting model was analysed with a random statement. When there was significant interaction between the main factors, the results were interpreted with reference to each of these factors. If there was no such interaction, conclusions were drawn regarding each main factor on its own. A 5% level of significance was chosen.

Papers II-IV. Principal Component Analysis (PCA) was performed in the statistical package (Unscrambler, 1996). PCA was applied to discover the relationships between the perceived sensory attributes of the breads and to investigate whether there were specific patterns in the material.

Furthermore, PLS1 was applied to study which sensory attributes were important for the individual design variables and to relate the specific significant sensory variables to the effect of roller-mill versus stone-mill, to the effect of conventional farming system versus ecological farming system, and to the effect of low versus high flour level. The sensory variables were weighted, full cross-validation was applied and significant sensory variables were found using the Jack-knife uncertainty test. PLS2 analysis was conducted to study further interpretation of interactions between design variables (milling technique, farming system, flour level, level of kneading intensity) and their relationships to the sensory variables (Paper II).

Papers IV. PCA was performed in a statistical package (Unscrambler, 1996) to describe the relationships between the consumer values and liking of the five tasted samples of bread. In order to see whether the collected information on the Schwartz set of values provides a representative space, a PCA was performed. To understand the relationships between samples, sample characteristics and consumer values, a preference-map-like procedure was used. PLS1 and PLS2 were used for predictive modelling of

age groups ($30 \leq$ and $30 >$) and responses to the additional statements parallel to the Schwartz values.

Image analysis

Image analysis was applied for the calculating of area of the bread slice. For the whole wheat bread, the method of choice for segmentation of the bread slices from the background was a texture method (Paper II). The images used in analysis were RGB (colour) images. In order to measure texture in these images, a modified form of neighbourhood standard variation described by Pratt (1991) was applied.

For the white bread, the images were segmented separately using a procedure based on colour tubes that were defined individually for each image (Image Pro-Plus 4.5 Media Cybernetics, 2001) (Paper III).

Results

In this section, a summary of the results is presented for each article separately.

Paper I. Results of the consumer test showed that the information concerning *flour origin* (farming system) significantly affected liking of bread. The variable *health effect* was a significant factor, as it was involved in a significant interaction with the variable *flour*, but *health* did not show a significant effect as such. The *health* statement (information concerning cholesterol reducing effect) increased liking for samples said to be baked with *flour* with origin in conventional farming, but not for samples said to be baked with *flour* with origin in organic farming. There was also a significant interaction ($p=0.0113$) between the *health* statement and the type of *bread*. The health statement increased liking scores for three *breads* (*C*, *CA*, *OA* – the conventional without and with amaranth and the organic with amaranth), but not for the *bread O* (*organic*). Finally, the information concerning admixed *amaranth* (neophobic factor) did not result in significant differences in liking. There were no significant differences in liking of bread between men and women or between consumer groups representing different education levels.

There was a significant interaction between *flour origin* and the question “When you buy food, how often do you think about food safety (presence of pesticide residues, antibiotics or the like)?” Consumers who “always” thought about it showed the greatest increase in liking of bread when the information stated that the flour had originated from organic farming.

The interaction between *flour* and the question “How often do you eat organically produced food?” tended to be significant at the 5% level ($p=0.0521$). Those consumers who ate organically produced food every day showed the greatest increase in liking of bread as an effect of information that flour originated from organic farming. Similarly, the interaction between information on admixed amaranth and the question “Are you a vegetarian, semi-vegetarian or not a vegetarian?” tended also to be significant ($p = 0.0509$).

Descriptive test. Bread samples showed significant differences between the following sensory attributes: colour, wheat, cereals and earthy aromas, wheat, cereals and astringent flavour and juiciness. Up to 89% of the total

sensory variation was explained by PC1 describing the aroma and flavour attributes dimension. Bread with admixed amaranth had a significantly higher intensity of earthy aroma, astringent and earthy flavour, but a lower intensity of colour, cereals aroma and flavour than bread without admixed amaranth.

Paper II. The main finding from the descriptive test was that the variation caused by milling technique had a greater impact on the sensory qualities of the whole wheat pan bread than did the variation caused by the farming systems, amount of flour in the formulation or kneading intensity. According to the partial least squares regression model (PLS1), the design variables *milling technique* and *farming system* were explained by the sensory variables up to 91% and 62%, respectively, in two principal components PC1, PC2. Sweetness, juiciness, compactness and raw streak of the crumb were significant sensory variables of importance for the roller-mill, whereas deformity and saltiness of the crumb and crispiness of the crust, as well as the intensity of roasted cereals, were significant sensory variables related to the stone-mill. Flavours of nuts and cereals, whiteness/blackness, yellow-red tone, colour intensity, compactness, raw streak and aftertaste of the crumb were important sensory variables for explaining the effect of organic farming system, while wheat aroma of the crumb and roasted cereals as well as crispiness of the crust were significant sensory variables related to conventional farming system. We stated that conventionally grown wheat dominated breads with endosperm attributes. Those breads were perceived as high in wheat aroma, crispiness and roasted cereals, whereas the organically grown wheat contributed most with bran attributes such as darker colour, stronger cereal flavour and aftertaste. The experimental variable, high *level of flour*, affected the bread sensory attributes of crispiness of the crust and compactness of the crumb. The *level of kneading* (the fourth design variable) did not significantly affect any of the sensory attributes. The group of breads representing organic farming systems (biodynamic C and ecological: D and E) showed larger sensory quality variations than did the group of breads baked with flour from conventionally grown wheat (A2, A5, B). Regarding the influences of the variable *farming system* across the experimental material, it is necessary to keep in the mind the complexity of the notion farming systems and the variation within the conventional group, lots: A2, A5, B and within the organic group, lots C, D and E.

The image analysis showed that milling technique had the greatest impact on baking performance, followed by farming system, flour level and kneading level. Baking performance, measured as the area of the middle slice of the loaves, was greater for the stone-milled samples than for the roller-milled. The slice area of stone-milled samples baked with flour from

organically grown wheat C, D, E, despite higher protein content (Paper II Table 2), was smaller than that of respective breads baked with flour from conventionally grown wheat A2, A5, B (Paper II Table 3). High ash content and low volume weight characterized organic samples (Paper II Table 1). The flour level had a stronger effect on the roller-milled samples, whereas kneading level had a greater impact on the baking performance of stone-milled samples. High flour level for roller-milled samples and high kneading level for stone-milled samples decreased the area of respective bread slice independent of wheat origin.

The SDS value and degree of damaged starch, Extensograph resistance and Farinograph data were higher for the roller-milled samples than for the stone-milled. Higher protein content in the conventional wheat than in the organic was not confirmed by the experimental material.

Paper III. The sensory quality differences dominating the white breads were related to the texture attributes. The effect of year of harvest was greater than the effect of farming system or recipe modification. Adaptation of the baking process to the flour characteristics (baking according to Pharinograph data) gave bread with highest intensities of attributes such as smoothness, elasticity and juiciness (samples such as A300, A600, D00). Adaptation of the flour to the process (recipe modification) decreased intensities of smoothness, elasticity and juiciness and increased the intensities of attributes such as mastication resistance, compressibility for modified samples such as A300m, A600m and D00m (Paper III Fig. 1a and b).

The Principal Component Analysis revealed the relationships between the sensory attributes and the specific patterns in the material. The total variation among all experimental samples in the sensory data was explained up to 91% by PC1 (63%) and PC2 (28%). The PC1 described attributes related to the texture of the crumb, such as compressibility, springiness and mastication resistance (mostly related to samples from 1999) versus texture attributes such as elasticity, smoothness and juiciness (mostly related to samples from 2000). PC2 described attributes related to the aroma and flavour such as wheat aroma and wheat flavour, versus attributes such as rancid aroma and rancid flavour (Paper III Fig. 1a and b).

The Analysis of Variance showed significant differences for eleven of the seventeen sensory attributes. Toughness of the crust scored higher ($p=0.0047$) for breads baked with wheat harvested in 1999, while the overall aroma of the crumb ($p=0.0047$) and deformability ($p=0.0001$) scored lower than in breads baked with wheat harvested in 2000. Attributes such as overall aroma, deformability, and toughness of the crust were affected only by year, while there was no attribute only affected by farming system. In conclusion, breads baked with wheat harvested in 1999 compared with bread

baked with wheat harvested in 2000 scored lower for colour intensity, higher for crust toughness, lower for crumb attributes such as overall aroma, deformability, elasticity, smoothness and juiciness, but higher for rancid flavour, springiness, compressibility and mastication resistance.

The effect of farming system never appeared alone, but followed the effect of year and resulted in interactions displayed for samples representing conventional farming system: A199, A499, B99, A600, A300, B00 and organic farming system: C99, D99, E99, C00, D00, E00 (Paper III Tables 5 and 7).

Attributes such as springiness, juiciness and rancid flavour were affected both by farming system and year, although no interactions between the two for these attributes were found (Paper III Table 6). Springiness scored significantly higher for the organic compared with the conventional bread, with the exception of samples B and E, for which no significant differences were displayed. Rancid flavour of organic bread C and E scored significantly higher than that of the conventional breads and the organic bread D. Juiciness in organic bread scored significantly lowest.

The effects of year of harvest, farming system and the interactions between these two were found for the attributes: smoothness, compressibility, elasticity, mastication resistance of the crumb, and colour intensity of the crust (Paper III Table 7).

Smoothness in breads baked with wheat harvested in 2000 was significantly higher in breads baked with conventional wheat than in breads baked with organic wheat. Also among breads baked with conventional wheat harvested in 2000, breads A600 and A300 had significantly higher smoothness than did bread B00. Among breads baked with organic wheat harvested in 2000, bread D00 had significantly higher smoothness than did bread baked with wheat C00 and E00. For comparison, bread A199, baked with wheat harvested in 1999, had the highest smoothness among breads baked with conventional wheat, while among organic breads, bread C99 had significantly lower smoothness than did bread E99.

Compressibility for breads baked with wheat from 2000 was significantly lower for those baked with conventional wheat than for those baked with organic wheat, and there were no significant differences within the conventional or within the organic group for 2000, whereas such differences were shown for wheat from 1999 (Paper III Table 7).

Elasticity was significantly higher in breads baked with conventional wheat than in breads baked with organic wheat, independent of harvest year. Nevertheless, the interactions between farming system and year revealed different patterns in both years (Paper III Table 7).

For mastication resistance and colour intensity, there were some interactions between farming system and year (Paper III Table 7). Among

breads baked with wheat harvested in 1999 versus 2000, bread A199 (conventional) had the lowest, and bread C00 (organic) the highest mastication resistance, but this pattern was not the same the other year for the respective samples (Paper III Table 7).

Colour intensity for wheat harvested in 1999 was significantly highest in bread A199 (conventional wheat), while for wheat harvested in 2000, this attribute was significantly highest in breads A600, A300, B00 (conventional wheat) (Paper III Table 7).

It can be concluded that in the experimental material, two attributes – juiciness and elasticity – were significantly higher in all conventional white breads than in all organic breads, for both years.

Paper IV. The Principal Components Analysis (PCA) of the rated Schwartz set values explained 25% of the variation in the material by two principal components PC1 (18%) and PC2 (7%) (Paper IV Fig. 2a). The largest differences among the consumers' values concerned those described by PC1: "pleasure", "enjoying life" and "daring" versus "respect for tradition", "devout", "honouring parents", and "politeness". Principal component two (PC2) described values such as "preserving public image", "social power" versus "spiritual life", "world of beauty". Translating to Schwartz's set of values, the largest differences were described by "hedonism", "stimulation" and "self-direction", versus "tradition"/"conformity" and "security". Values below PC1 "intelligent", "influential", "ambitious", "successful" (according to Schwartz "achievement") and "social power", "wealth", "preserving public image" (according to Schwartz "power") are opposite to the values above PC1 "spiritual life", "meaning in life", "forgiving" (according to Schwartz "benevolence") and to the "world of beauty", "unity with nature", "protecting the environment" (according to Schwartz "universalism"). Values below PC1 describe in large part a world of material values, power, and wealth as important for the individual, while the values above PC1 represent the world of ideal values concerning nature/environment and people. The modern or go-ahead values ("daring", "exciting life") versus traditional values are found on each side of PC1, close to its extreme points. The younger consumers tended towards modern and materialistic values, while the older consumers tended towards traditional values. Both idealistic and materialistic values are present in both groups, although to a different degree, and the consumer groups were influenced largely by the PC1 dimension, which describes modern/go-ahead values versus traditional values.

According to PLS1, significantly different values were found to be guiding principles in the lives of the two age groups. For consumers over thirty years of age, "freedom", "accepting life", "wisdom", "meaning in

life”, “national security”, “devout” and “spiritual life” were the guiding principles in their lives. The younger consumers had “true friendship”, “enjoying life”, “exciting life” (related to hedonism according to Schwartz), “capable”, “reciprocation of favours” and “successful” as a guiding principles.

There was also a significant difference in liking of breads between age groups. The bread A300 was scored significantly higher by the younger than by the older consumers (87.3 versus 76.5 on the scale from 0-150 mm). The most liked bread in the older group was A199 (77.8). The highest liking scores amongst all consumers were given to breads A300, A199, D99 (81.9, 81.8 and 79.1, respectively), while the lowest liking scores were given to breads C99 and E00 (68.1 and 74.5, respectively).

The Partial Least Square Analysis (PLS1) of 56 values by Schwartz scored by men and women showed significant differences in relation to sex concerning only the three values: “world of beauty”, “world of peace” and “equality”, which were found as guiding principles in women’s lives.

The Partial Least Square Analysis (PLS2) revealed relationships between ten additional statements and the 56 rated Schwartz values. Statements 1 to 9, related to food issues, were found close to the values by Schwartz, such as “world of peace”, “a world of beauty”, “social justice”, “spiritual life”, “unity with nature”, “equality”, “curious” and “protecting the environment”. The last statement (10) was related to price for organic versus conventional products, and was located close to the value “wealth” and negative on PC1, opposite to the other statements.

According to PLS1, the lowest frequency of organic product consumption was related to values such as “honouring of parents”, “authority”, “wealth”, “clean”, “ambitious” and “respect for traditions”, while the highest frequency was related to the “spiritual life”, “curious”, “world of beauty”, “unity with nature”. Values important for the lowest frequency belong, according to Schwartz, to values: achievement, power, security, conformity and are related to conservation and self-enhancement, while values important for the highest frequency belong, according to Schwartz, to values: self-direction, benevolence, universalism and are related to openness to changes and self-transcendence.

The majority of consumers in the younger group (64.1%) and in the older group (68.5%) agreed that organic food tastes better than conventional. A positive response to statement number five (“The consumption of organic bread should increase”) was given by 92.4% of younger consumers and by 91.3% of older consumers. There were 45.6% in the younger group and 46.7% in the older group who stated that they would not buy organic food if the price were noticeably higher.

Discussion

A vision of sustainable agriculture

The political goal in Sweden to increase ecological agricultural production to 20% of all arable land by 2005 constitutes, according to Pettersson (2003), is an attempt to apply an overall solution to environmental problems. Moreover, he argued that the traditional political involvement of Swedish citizens seemed to move to the market, where consumers act “correctly” to promote a better environment and animal welfare. Values found in the present study (Paper IV): “respect for tradition”, “ambitious”, “clean”, “wealth”, “authority” and “honouring of parents”, were reported as important for *consumers with the lowest frequency* of organic food consumption, which is associated with social/political correctness. These consumers were guided largely by the external world and social norms, as compared to *participants with the highest frequency* of organic consumption. The latter group was guided by internal values: “spiritual life”, “curious”, “world of beauty” and “unity with nature”, which belong to “universalism” and “self-direction”, according to Schwartz (1992), and these values are associated with individual cultures.

Values influence not only consumers’ food choices on the market, but also scientists’, politicians’ and producers’ views on the production system as well as their perception of the environment (Agenda21, 1992; FOOD21, 2003; IFOAM, 2004a,b). The challenge of sustainability with which agriculture is confronted as well as the expanding notion of product quality along with aspects of production (KSLA, 1998; Pickel, 1989) indicates the presence of new values and the possibilities of a paradigm shift. In the “drama” that often follows a paradigm shift, there are different trends in science, economy, ecology, e.g. towards an ecological economy (Colby, 1990; Salomonsson and Rydberg, 2000) versus streamlined production. Ljung (2001) argued that in order to retain shared beliefs in society, sustainable development has to be re-defined and practiced and that collaborative learning, involving different actors such as farmers and consumers, must take place to meet the requirements of a sustainable food

production system (Ljung, 2001). Extended knowledge concerning the effect of information and values on consumers' food acceptance (Papers I and IV) is one step towards collective learning. Results of field experiments (Paper I) investigating the effect of providing information show the practical consequences of activating environmental values in a real-life situation (Grankvist and Biel 2001). These results underline the importance of sensory science as a sensitive tool in consumer studies, e.g. for investigating liking of bread and how it is affected by "taste" and provided information (Paper I). The experiments described in Papers I and IV showed how consumers view product quality, and consumer views (Bech *et al.*, 2001) should be used in creating a sustainable market. The lower yield of organic than of conventional wheat in Bollerup's field trials, which produced our experimental material (Gunnarsson *et al.*, 1995; Ivarson *et al.*, 2001), can be seen in light of the advantages of an increased product acceptance of bread of organic origin (Paper I) and market attempts to meet consumers' positive attitudes towards organic food (Magnusson *et al.*, 2001). Swedish consumers perceive organic bread as healthier than the conventional (Magnusson *et al.*, 2001) and organic labelled products as better for the environment, health and as having better taste and quality than conventional products (Grankvist and Biel, 2001).

Asian consumers, in accordance with the Swedish, think that organic food is healthier, due to the absence of pesticides and artificial fertilizers. Experience from Asia shows that it is difficult to find a balance between sustainability and productivity in a world where the focus is on economic growth in a competitive economic environment. Sustainable agriculture for most Asian countries will not involve organic farming, but rather using a minimum of fertilizer with increased efficiency, supplemented with organic matter, as sustainable food production means sustainable profitability as well as ecological and social sustainability (Bay-Petersen, 1995).

The emphasis of Swedish scientists active within economic ecology is on holistic solutions for sustainable development (Ebbersten, 2001; Salomonsson and Rydberg, 2000).

Food production system

Different links in the production chain influence product quality. Factors of importance in the production system – year of harvest, farming systems, milling and baking techniques – affected the sensory quality of bread in a specific way (Papers II and III). Johansson and Svensson (1998) showed that the variation in breadmaking quality from different years of harvest is

complex for the winter wheat and depend on temperature and precipitation in different stage of plant development.

The use of manure, stale, chemicals, and artificial fertilizers are examples of factors of importance both for plant development and for consumer product acceptance (Paper I), and these factors influence consumer attitudes towards food products (Magnusson *et al.*, 2001; Schifferstein and Qude Ophuis, 1998). The production system affects the microbiological status, chemical, sensory and nutritional qualities of wheat, and breads can be baked with or without addition of improvers. Most of these factors or qualities have credence value, contrary to the sensory qualities of bread, which are manifested as a loaf and accessible for the consumer evaluation. Immaterial values (Paper I) are credence values and consumers' belief that such values are attached to the product when it is labelled as "organic" and when the price is perceived as higher (Grankvist and Biel, 2001). Besides a product's "taste", factors such as credibility and transparency determine the organic market success or failure (Thøgersen, 2003). Both agriculture and the market are influenced by different factors and stakeholders. Results of the present study concerned liking of bread baked with wheat grown in different farming systems, influenced by additional information and consumer values, and confirmed the complexity of the product quality evaluation and the need for a multidisciplinary approach to food choice behaviour (Frewer and Risvik, 2001), system ecology (Ebbertsen, 2001), economy/ecological economy (Salomonsson and Rydberg, 2000) and for the introduction of collaborative learning for sustainable development (Ljung, 2001).

Framework of wheat production

The results from a review of relevant literature showed that conventionally grown wheat had a higher protein content and a superior protein quality in comparison with organically grown wheat (KSLA, 1995; O'Doherty Jensen *et al.*, 2001). In the present study, wheat harvested in three subsequent years did not show the same quality pattern (Paper II Table 2; Paper III Table 2). The rheological analysis on white flours revealed, especially for samples harvested in 2000, differences between those extracted from conventional and organic wheat. The conventional samples had quality parameters associated with better baking performance than did the organic samples (Paper III Table 2). This is in line with the bulk of the results from a previous study from the same field trials (Gunnarsson *et al.*, 1995), however this report also contained contradictory results showing higher protein content and loaf volume in some samples representing organic farming system. Bread characteristics indirectly describe wheat baking quality. In general, our results concerned the wheat and flour qualities, area of the slice,

sensory attributes of whole wheat (Paper II) and white breads (Paper III) as well as consumer liking of breads (Paper IV) and did not describe one system as superior in comparison with the other system. According to the consumer test, among the most liked samples were two conventional breads and one organic, baked with wheat with a protein content of 12%, 10.6% and 9.3%, respectively (Paper IV). Significantly higher juiciness and elasticity of the white bread baked with conventional wheat compared with bread baked with organic wheat are important results, which can be linked to protein content and gluten quality, the bakery's required specification and consumer perceptions. The protein content and quality are dependent on the nitrogen (KSLA, 1995) and sulphur supply (Schung *et al.*, 1993) and on the nitrogen source (Pedersen *et al.*, 2003). Different protein contents of the same wheat variety grown in the same location in field trials, representing different farming systems (Papers II and III), were related to the farming system to the lesser degree than to the year of harvest (Papers I, II and III). Highest protein content needed for the industrial baking (KSLA, 1995) was found in organic wheat E, harvested in 1998 and all conventional samples harvested in 2000.

In the present study, the farming system influenced the quality of whole wheat bread to a lesser degree than did the milling technique and the quality of white bread to a lesser degree than did year of harvest (Paper II). Interestingly, for the white breads baked with wheat harvested in 1999 and grown conventionally and organically, respectively, there were no differences between the slice areas, though there were differences in the slice areas of the respective samples baked with wheat harvested in 2000.

A decrease in the negative impact of wheat production on the environment is one goal of the sustainable production system. The effects of nitrogen losses during transition to ecological farming and the results of investigating conventional and organic cultivation systems in Bollerup (the site of the experimental material field trials) generally did not indicate differences related to the cultivation system (Torstensson, 2000). Other factors were of importance, such as individual cropping system, cultivation strategies, use of livestock waste and farmers' knowledge and practices. For example, the nitrogen concentration of drainage water from the lighter soils was too high in all cases, and better practices supported by research on both farming systems are needed (Torstensson *et al.*, 2000).

Great differences in the Zeleny sedimentation values found in the experimental material between samples representing different farming systems indicated differences in gluten proteins, which can be related to different growing conditions such as the availability of nutrients for plants in different farming systems. A gliadins and glutenins ratio as well as amino acid composition was shown to depend on the nitrogen content in the grain (Triboi and Branlard, 1990.) The quantity of nitrogen per grain is different in

conventional and organic farming systems, though it is normally not possible to apply soluble nitrogen fertilizers during the growing season in organic farming (Starling and Richard, 1990). Nitrogen content is related to protein content and the lowest nitrogen content for wheat harvested in 1998 was found in conventional sample A5, containing less protein. Contrary to this, in wheat harvested in 1999 and 2000, the lowest protein content was found in the organic wheat. Dahlstedt and Dlouhý (1995) showed that conventionally grown wheat had significantly higher content of amino acids such as lysine, treonin, and amino acids containing sulphur such as cystine, and methionine than did organically grown wheat. Cysteine and cystine residues account for 2-3% of gluten's total amino acids residues, which during formation of dough undergo sulfhydryl-disulfide interchange reactions resulting in extensive polymerization of gluten proteins. The intermolecular disulphide bonds, cross-linking gluten protein, allow building of the network of protein films in the leavened dough (Damodaran, 1996), which is decisive for the loaf volume. Differences in Zeleny values and area of slice for samples A300 and C 99 are related to the protein content and quality.

Milling technique and breadmaking

Flours of roller-milled versus stone-milled wheat samples differed the most in particle size distribution, degree of damaged starch, SDS volume and also in the Extensograph and Farinograph data (Paper II Tables 2, 3 and 6). Evidently, milling technique affected the flour quality. Doughs made with stone-milled flours had the shortest development times and thereby, practical production consequences. Higher water absorption and higher SDS, which characterized the roller-milled samples (Paper II Table 2), are associated with larger loaf volume (Kent and Evers, 1994b; Pratt, 1971). According to Bloksma (1990), the most important factor for baking performance is the extensibility of the dough. The highest Extensograph extensibility characterized dough made with stone-milled flour. Bread baked with those flours showed the largest slice area, despite the lower SDS and water absorption. Thus, our results confirmed that superior extensibility gives superior baking performance. Owing to the sensory analysis, the question of whether there are any sensory differences between breads baked with roller-milled versus stone-milled wheat was answered (see: Results section and Paper II), but new questions arise concerning the dietary characteristics. What possible effect for human health does the consumption of the bread baked with roller-milled versus stone-milled flour may have, considering that the Falling number and damaged starch differ? The investigation of the

effects of milling techniques on the quality and dietary characteristics of the carbohydrates should be taken into consideration.

The higher SDS volume for roller-milled flour is not surprising given the different concept underlying this milling technique. The roller-mill carefully separates the bran from the endosperm material and the breaking and reduction rolls contribute the largest fraction of the smallest flour particles, which is favourable for the building of the protein aggregate in the sedimentation test (SDS volume). These procedures of bran separation from the endosperm did not occur during the stone-milling.

The extensibility is governed by protein fractions (Bloksma, 1990). The results of the present investigation showed that milling technique also affects extensibility and could possibly shed some light on an investigation in which flours with higher SDS surprisingly resulted in lower loaf volume (Salovaara, 1986). Besides the Extensograph extensibility, resistance was affected by milling technique, and both are important for gas retention in the bubble and dough expansion, due to production of carbon dioxide, and finally decisive for bread texture and loaf volume. According to Bloksma (1990), virtually all doughs fulfil the demand for resistance. In light of this, lower resistance of stone-milled flours should not imply disadvantages. Different development times for the dough explain, on the one hand, the improved baking performance of the roller-milled samples and, on the other hand, the decreased baking performance of the stone-milled samples when kneading time was increased (“high level of kneading”) (Paper II Table 3).

The dominant effect of milling techniques on the rheological characteristics of whole wheat flours is an interesting result inviting further investigation of flours’ functional and nutritional properties as a function of milling. Different sensory qualities of breads baked with the same sample of roller-milled versus stone-milled wheat (Results section and Paper II Fig. 2a, b, c and d) show the need for whole wheat products development and for consumer tests to map preferences for these products. The larger effect of milling technique than farming system on bread qualities revealed that technology can be used as a tool to turn the same material into different products in accordance with raw material advantages (Paper II).

Adaptation of wheat to the baking process demands well-defined wheat quality parameters in large-scale industrial baking (KSLA, 1995), but optimal use of the technological processes and bakers’ skills can result in high quality products in which variation in material can be seen as an advantage. As ethical values and environmental consciousness are of growing importance among Nordic consumers (Hansen *et al.*, 2001) and as different values are significant for different consumer segments (Paper IV), different concepts of bread qualities can contribute to higher quality of life (Agenda 21, 1992), because food (bread) is not only essential as nutrition,

but also for achieving such basic values as self-fulfilment and recognition (Grunert *et al.*, 2001).

Food quality

The data processing from the sensory descriptive test resulted in a description of objective bread qualities. Appearance, aroma, flavour and texture were described qualitatively and quantitatively and resulted in bread sensory profiles (Papers II and III). Significantly higher intensity of attributes such as smoothness, springiness, elasticity and mastication resistance provide important product information, but only the consumer test can reveal the subjective quality of bread seen from the consumer's point of view (Bech *et al.*, 2001), which was expressed as liking of bread in the acceptance test. Information from both tests makes it easier to understand consumer preferences in relation to the bread's objective attributes, as for example significantly higher acceptance of bread A300 by a group of younger consumers (Paper III Tables 6 and 7; Paper IV). The sensory quality is an important dimension of the total quality, but not the only one. Health or nutritional quality is another factor motivating consumers' food choice (Magnusson *et al.*, 2001; Schifferstein and Qude Ophuis 1998). An adequate intake of fibre-rich food, such as cereal products made with flour of the highest extraction rate, has a positive effect on the blood glucose level, protects against constipation and obesity and is thought to protect against cancer of the large intestine (Becker, 1999b). The consumers perceive the organic bread as healthier and as having more fibre than the conventional bread (Magnusson *et al.*, 2001). In the present investigation, more bran was found in relation to endosperm in two (C and D) out of three organic samples of wheat harvested in 1998 (unpublished results). This was illustrated in the sensory profile of breads (Paper II).

Information concerning the effect of fibre omits its disadvantages: the harmful effect of cadmium on human health and the highest cadmium content in cereals as compared with other food products (Olsson *et al.*, 2002). A higher cadmium level in blood among Swedish teenagers was associated with university-educated mothers and a significantly higher consumption of vegetables in this group was suggested as a possible explanation (Bàràny *et al.*, 2002). When the trend of dark and whole wheat bread consumption increases, the risk of high-level intake of cadmium from everyday food must be limited in the sustainable food production system. Bread and cereal products are staple foods and it is important that cadmium levels are kept low through sustainable improvement of food safety (DuPont Nordic, 2004) and that wheat with the lowest cadmium content is selected

for whole wheat food production. Furthermore, phytase from wheat and from Baker's yeast, as well as low pH, influenced the level of phytate, which is related to mineral absorption (Türk, 1999). Thus, priority should be put on investigating the effects of different methods of breadmaking on human cadmium absorption.

Given that the cadmium content of wheat increases with increased nitrogen fertilizing (Wångstrand *et al.*, 2004), applied to produce high protein wheat for industrial use, a question arises: "How does this coincide with sustainability and improved quality of life?" (Agenda 21, 1992). Is there a need to adapt food production to the demands of industry or vice versa? (Möller and Salomonsson, 1992). Both objective and immaterial quality aspects (KSLA, 1998), related to the entire chain of the production system, are important from the consumer's point of view and, as such, are linked to product acceptance (Paper I).

Dough quality

The effect of milling techniques on the flour (dough) characteristics, such as degree of damaged starch, Falling no, SDS value, Extensograph and Farinograph data, was one of the main findings of the present study. According to the dough quality evaluation, the Farinograph water absorption and SDS values were favourable for the roller-milled flour, while the increased extensibility was favourable for the stone-milled flour (Paper II Table 2). According to Bloksma (1990), extensibility is decisive for baking performance.

It is known that an increase in nitrogen supply increases the protein content in wheat, which has an effect on dough quality (KSLA, 1995). Farinograph water absorption, dough development time, and stability are dependent on protein content (Preston *et al.*, 1992). Our results confirmed (Paper II Table 2; Paper III Table 2) that the rheological dough characteristics were influenced by protein content. The respective values were highest for the conventional samples with the highest protein content, harvested in 2000. All dough samples made with conventional wheat harvested in 1999 and 2000 and one made with organic wheat harvested in 1999 (E99) had Extensograph areas close to what is considered a good quality of bread wheat (Olered, 1982). Interestingly, the similarity of bread sample E99 to the conventional samples from 1999 was also shown in Paper II.

The quality of glutenin or gliadin or the high ratio between glutenins and gliadins is thought to be responsible for low extensibility of dough (Kokelaar, 1994). Thus, the highest extensibility found in conventional samples from 2000 (A600-B00) and in the conventional grown without

added manure from 1999 (A199, A499) indicates qualitative protein differences between those samples and others (both conventional and organic). (Kokelaar, 1994) found that the best baking performance was shown by samples with both highest resistance and highest extensibility. A sample with the highest values of both parameters was not found among our experimental samples, but a positive effect of high extensibility on slice area was shown by samples A600, A300, B00 and A199 (conventional wheat). The largest differences in dough qualities between flours representing conventional and organic farming systems were found for white flours extracted from wheat harvested in 2000 (Paper III Table 2). Providing nitrogen supplement in more than one application increases the gluten content and affects the volume and texture of leavened bread. The nitrogen content explained 80-85% of the variation in grain sulphur content. Wheat grains contained less sulphur-rich proteins important for the formation of disulfide bonds (S-S) in the dough, had higher Extensograph resistance, lower extensibility and resulted in smaller loaves than did wheat grain with more sulphur-rich protein (Moss *et al.*, 1981). In the present study and for white flours, highest extensibility and gluten content characterized samples A600-B00, while lowest values of these parameters characterized samples C00-E00 and C99-E99, respectively (Paper III Table 2).

Sensory quality of bread

Generally, the sensory qualities of bread are affected by the wheat quality and all links in the production chain and in the distribution system. Moreover, each link is influenced by many factors. Owing to the well-described experimental material originating from established field trials and due to the experimental design, the wheat samples were studied with respect to chosen experimental factors such as: farming system, milling and baking techniques and year of harvest.

Whole wheat bread: Distinctively different sensory profiles found for whole wheat bread baked with the same wheat roller-milled versus stone-milled constitute the main technological result of this study, revealing the power and possibilities of technology for end-product quality. Milling techniques affected bread appearance, aroma, flavour and texture. Bread baked with wheat A-E roller-milled was characterized by wheat aroma, sweetness, juiciness, compactness and raw streak, while stone-milled samples had crispy crust with roasted cereals aroma and darker crumb with more intensive cereals flavour and aftertaste (Paper II Fig. 2a-d). Studying exclusively the significant attributes, we found crispiness, roasted cereals, deformity and saltiness for stone-milled bread and sweetness, juiciness, raw streak and compactness for roller-milled bread. Differences created by the

milling process are related to the raw material characteristics and the concept of the milling. This can be exemplified by the careful separation of bran from the endosperm and the influence of the reduction rolls on flour quality (degree of damage starch), which had consequences for the bread sensory attributes sweetness and juiciness (for description see: milling techniques and Paper II, discussion section). Grinding the whole kernels between stone surfaces on the stone-mill contributed to a specific character of flour, such as bran particle size distribution (Paper II Tables 2 and 6), related to attributes such as deformity, saltiness and cereals character of bread baked with stone-milled samples.

The significant sensory attributes found for the conventional farming system (wheat aroma, crispiness and roasted cereals) and for the organic farming system (compactness, raw streak, nuts flavour, aftertaste of crumb, cereals flavour and higher colour intensities) were related to the wheat kernel characteristics (Paper II Table 2). The wheat from the organic farming system (C, D and E) had a higher ash content and lower volume weight than did the conventional wheat. This dominated the aroma and flavour characteristics, and the rich bran fraction in relation to the endosperm resulted in significant compactness and raw streak of samples (Paper II Fig. 2a and c). The sensory profile of bread E did not differ considerably from the profile of breads baked with conventional samples and was not similar to the other breads baked with flour from organic wheat C and D. Organic wheat sample E had the highest volume weight and nitrogen content among all organic samples and the highest protein content among all experimental samples. Higher ratio between endosperm and bran in the conventional wheat was decisive for the wheat aroma of bread and for the crust crispiness as an effect of heat on the starch and proteins during baking. This revealed the manifold function of starch in breadmaking (Eliasson and Larsson 1993), showing the different effects of roller-milling versus stone-milling on the sensory qualities of breads (Paper II Fig. 2a-d). Different degree of caramelization, polymerization processes and Maillard reactions, during baking in an oven under standardized conditions, were related to the milling techniques and farming system (Paper II).

For whole wheat bread, only the area of the slice was influenced by kneading (Paper II Table 3). The effect of kneading on baking performance, illustrated by image analysis, was not great, but interesting, as the two milling techniques tended to show the opposite patterns. High kneading increased the baking performance for the roller-milled samples, but decreased it for the stone-milled samples. This is in line with rheological data showing higher dough stability and higher development time for the dough made with roller-milled wheat (Paper II Table 2). According to our results (Paper II Table 3), the commonly held opinion that dough made with

organically grown wheat requires less kneading than dough made with conventionally grown wheat was not supported, and the flour kneading demands were related to the milling technique used. It is known that loaf volume or slice area is related to protein content. According to our data, these parameters were mainly related to the milling technique, and stone-milled samples had larger slice area than roller-milled. Intensive mixing (kneading) caused a rise in iso-acids (isovaleric, isobutyric) and resulted in unpleasant olfactory attributes, while gentle mixing and prolonged fermentation gave superior bread characteristics concerning volatile compounds (Richard-Molard *et al.*, 1979), important for the sensory quality and acceptance of bread. It is well known that, e.g., gentle mixing and longer fermentation time are applied in organic bread production, while intensive mixing and short fermentation time are applied in industrial baking with consequences for the bread sensory quality.

White bread: Sensory qualities were influenced to a higher degree by year of harvest than by farming system. The organic and conventional farming systems contributed three samples each in both years. To conclude that samples from one farming system differed from those of the other (during only two subsequent years) requires observation of the same pattern among the three involved samples. Juiciness and elasticity were significantly higher in breads baked with wheat harvested in 2000 than 1999, and these attributes were also significantly higher in the breads originating in conventional than those originating in organic farming systems, and there was an interaction between year of harvest and farming system for the elasticity. Interestingly, the significantly higher juiciness found in the white breads baked with conventional wheat harvested in 1999 and 2000 as compared with bread baked with organic samples from the same years, showing juiciness to be related to the farming system, was not found in breads baked with whole wheat from respective wheat samples harvested in 1998. The juiciness, however, was related to the milling technique and significantly higher for breads baked with roller-milled flour. Juiciness depends on different factors, but protein (gluten) content and degree of damaged starch are of great importance. Organic wheat samples harvested in 1998 did not have a lower protein content than the conventional samples, but all roller-milled samples, despite wheat origin, had higher degree of damaged starch than stone-milled and gave breads that scored significantly higher for juiciness. The conclusion of our result concerning the juiciness of whole wheat bread was that this attribute couldn't have been related to the effect of farming system.

That stronger bread crumb is related to strong dough properties (Scanlon *et al.*, 2000) was confirmed by our results, as breads described by significantly higher mastication resistance and compressibility were baked

with dough characterize by highest Extensograph resistance and area and made with wheat harvested in 1999. However, stronger bread crumb (crumb texture increased in mastication resistance and compressibility) was also a result of recipe modification affected by increased kneading time for sample D00m as compared with kneading time for sample D00 (Paper III Table 3, Fig. 1a). The significantly lower elasticity of organic bread baked with wheat harvested in 1999 and 2000 can be linked to the discussion about the often-mentioned alleged lower baking quality of organic wheat (KSLA, 1995; O'Doherty Jensen *et al.*, 2001). However, also the group of organic wheat differed in elasticity, and wheat sample D00 from 2000 (Paper III Table 7) had significantly higher elasticity than other organic samples. This can be related to the higher Extensograph extensibility for sample D00 than for other organic samples. Our analysis of all experimental samples showed that high elasticity characterized breads with high extensibility (Paper III Table 2), which indicates differences in protein quality between samples. Smoothness seems to be a puzzling attribute, affected both by year of harvest and by the farming system. We observed that samples with the highest smoothness (A600, A300 and A199) were baked with wheat possessing the highest baking quality parameters, but high values of these parameters per se did not result in high smoothness for the sample B00. The main difference between system A, conventional without added manure, and B, conventional with added manure, is the form of nutrient supplement. The source of nitrogen was found to be decisive for baking performance (Pedersen *et al.*, 2003). The specific position of bread A199 on the score plot, showing most similarity to the conventional samples from 2000, corresponded to flour characteristics expressed both by highest ratio between gluten and protein content and by highest extensibility among the 1999 samples. Thus sample A199, despite high resistance, showed good baking performance, as only the lack of accompanying extensibility usually leads to poor baking performance (Bloksma, 1974). In the consumer test, bread D99 baked with organic wheat contained 10.6% protein. Despite having lower elasticity than conventional breads (Paper III Table 2), it belonged to the group of the three most liked breads (Paper IV). This result should influence the criteria and perception of wheat quality for bread production. Alternatively, the use of wheat with these qualities, by small-scale producers, can be taken into consideration. It was shown that certain consumer segments are interested in products cultivated without pesticides (Schifferstein and Qude Ophuis 1998) and prefer bread made with organic wheat to that made with conventional wheat (Paper I).

Food acceptance

The experimental design applied in the first study (Paper I) allowed us to observe the effects of sensory and non-sensory factors on product acceptance. The effect of information with environmental connotations, described in Paper I, is in line with statements that ethical factors became important for food quality evaluation and acceptance as aspects of immaterial quality of food (KSLA, 1995). Positive attitudes towards organic food (Magnusson *et al.*, 2001) confirmed by consumers in the present study (Papers I and IV) do not per se imply purchase of organic food (Magnusson, 2002). People's food choices are not rational and objective, as they are influenced by hedonism and specific liking, cultural and social norms, etc. (Frewer and Risvik, 2001) as well as by prices (Magnusson *et al.*, 2001). Food is not only nutrition, but also consolation, a promise of promoting good health and an expression of lifestyle, related to values and to value conflicts and compatibilities (Schwartz, 1992). Food acceptance is measured by liking of food and the consumer acceptance test is a powerful tool for measuring the degree of liking or disliking (Cardello and Maller, 1982; Resurreccion, 1998). There are different approaches to the investigation of food acceptance. According to Lawless and Heyman (1999c), the most efficient procedure in consumer testing is to use the data from multiproduct acceptance tests for determination of consumer preferences. For the consumer test used in the present study, five samples described by the trained sensory panel were chosen with help of the statistical multivariate method, PCA (Paper IV) and four bread types were baked in accordance with the experimental design (Paper I).

Information, attitudes and liking of bread

The significantly enhanced liking of bread as an effect of information concerning wheat origin (Paper I) showed that consumers have a positive attitude towards the organic bread, which is in line with the findings of Magnusson *et al.*, (2001). Moreover, consumers who ate organic products most often and those who most often thought about pesticide residues, antibiotics or the like, increased their liking of bread the most. The results link both the frequency of organic food consumption and the concern about pesticides residues to higher liking of food and to organic farming. Avoiding pesticides (chemicals) is one of the reasons for consuming organic products and consumers perceive food produced without pesticides as healthier (Bay-Petersen, 1995; Magnusson *et al.*, 2001; Schifferstein and Qude Ophuis, 1998; Torjusen *et al.*, 2001).

Interestingly, in the present study (Paper I), the health statement increased liking of bread said to be baked with flour originating in conventional farming as well as of the less liked bread samples OA, CA and C. The positive effect of information on less liked samples was also found by (Caporale *et al.*, 2001; Johansson *et al.*, 1999). However, the enhanced liking of less liked samples did not reach the level of the most liked bread, which showed that positive information could only partly compensate for the low sensory scores of the product. A decreased acceptance of bread said to contain admixed amaranth (an experimental neophobic factor) among vegetarians is not surprising, as they are restricted in their diet. Lyman (1989b) stated that changing of food preferences (liking) is more a matter of changing attitudes towards food than of changing food sensory attributes.

The superior importance of “taste” for product acceptance (Paper I) is in line with self-reported priority of sensory attributes for product choice or purchase on the part of consumers (Grankvist and Biel, 2001; Lappalainen *et al.*, 1998; Magnusson *et al.*, 2001). The largest enhancement of liking of bread shown by frequently organic food consumers, as an effect of information of bread organic origin, is in line with other investigations in which a larger proportion of “organic” than of “conventional” consumers thought that organic food tasted better (Arvola *et al.*, 2000). The significantly enhanced liking of bread as an effect of information on organic origin of wheat revealed the importance of bread origin for quality perception. Organic bread was perceived as healthier (Magnusson *et al.*, 2001), better for the environment, and as having better taste and quality (Grankvist and Biel, 2001). The same investigation showed that the origin of products from organic farming systems was the least or next to the least important purchase criterion. However, that a criterion is least or next to the least important among a list of criteria does not necessarily mean it is unimportant, particularly not for frequent organic consumers with a specific ideology (Schifferstein and Qude Ophuis, 1998). An increased relative purchase frequency was found to be an effect of activation of environmentally related attitudes. Thus, activation of attitudes (Grankvist, 2002), exposure to and positive sensory experience of organic products (Arvola *et al.*, 1999), as well as information of importance for consumers (Paper I) are possible tools for expanding the organic market.

Values and liking of bread

Significantly different values found for the different consumer segments revealed both the heterogeneity of the organic consumer and distinct differences in values among consumer segments. The largest differences found between segments were explained by “hedonism”, “stimulation” and

“achievement” – according to Schwartz’s nomenclature “individual value” (Schwartz, 1992) (consumers 30 years old and younger), versus “tradition”, “security” and “benevolence” – according to Schwartz’s nomenclature “collective values” (consumers over 30 years). Sjöden (2003) stated that collective values have no tradition in the area of food purchase and that getting consumers to consider such values constitutes a challenge. Interestingly, in our study, individual values characterized the younger consumers and collective values the older consumers. People change values during the course of their life, and age is one of the influencing factors (Schwartz, 1992). Significant differences found in the acceptance test revealed that a specific liking of white bread differed between groups (Paper IV). Bread A300 (Paper III) was scored significantly higher for liking by consumers 30 years of age and younger than by consumers over 30 (Paper IV). This result links age and values to “taste” (specific liking of bread). Bread A300 was most appreciated by consumers for whom “hedonism” (Schwartz’s nomenclature and represented by “enjoying life”) was a guiding principle in their lives. Statistical analyses of the trained panel performance described this bread as the most different in comparison with other breads. This sample, in similarity with A199, was characterized by significantly higher intensity of attributes such as: smoothness, elasticity and juiciness than samples C99, D99 and E00, but what differentiated sample A300 from sample A199 was degree of mastication resistance. It was lowest for A300. To express it unscientifically, bread A300 had the most delicate texture and was easiest to chew. It is not surprising that bread A300 was preferred by a group of consumers for whom “hedonism” was a strongly held value. Thus, the different values functioning as “guiding principles in one’s life” (Schwartz, 1992) in the different consumer segments (Paper IV) were linked to bread acceptance. Because the values influence attitude formation (Worchel and Cooper, 1979) and perception of the world, they also influenced the consumers’ perception of bread (Paper I) and liking (Papers I and IV), in accordance with the values’ importance (Grankvist, 2002).

The degree of value recognition on the market influences consumers’ purchasing behaviour (Sjöden and Magnusson, 2004). Achieving basic values such as self-fulfilment, recognition or security is essential in consumers’ lives (Grunert *et al.*, 2001).

Consumers and the market

Profitability and material values are associated with the market. In order to meet consumer needs (Hansen *et al.*, 2001), the market has to identify and incorporate values that are attractive to consumers into the collaborative learning for sustainability. The experiments conducted as field-experiments

(Papers I and IV) revealed activation of consumer values in real-life situations and the ability of some consumers to discriminate the samples in accordance with the sensory profile established for breads by a selected and trained panel (Papers III and IV). Moreover, they showed different degrees of bread acceptance in relation to the immaterial values attached to the product. This indicates the consumers' ability to play an active role on the market. Not surprisingly, quality/freshness, price and taste were perceived as the strongest factors influencing food choice in all EU member states (Lappalainen *et al.*, 1998). Quality has different definitions (Garvin, 1988; KSLA, 1998; Pickel, 1989), as it is connected with human perception and linked to changes in our life and society. Looking at quality of food from the consumer's point of view (Bech *et al.*, 2001) is one example of how the notion of quality can be expanded. This could be seen as an indicator of a paradigm shift. Due to the surplus of food production, new product varieties, as well as scientific developments, have increased our understanding and the status of sensory sensation, as well as food-related hedonism in the developed countries. Interestingly, in the past (Locke, 1961), colour, taste, smell, sound, warm and cold did not belong to the primary (objective) qualities, as opposed to size and shape. This has greatly influenced food science and is still present in our modern food standards, which are based on size and shape and applied in trade (Pickel, 1989). Introduction of immaterial values to the trade and on the market can be seen as a paradigm shift in the quality perception. In our modern time, the sensory quality or "eating quality" is considered one of the objective qualities of the food product (KSLA, 1998). A paradigm shift includes not only our view of, or approach to the issue of quality and the consumer's role, but also our approach to agricultural production, where maximizing productivity is not the main goal. Animal welfare and environmental protection have been important factors to consumers in the product quality evaluation, and they are examples of the psychological and moral factors affecting the market. These quality aspects can influence food choice only if the food supply is guaranteed by different food groups (Ekman and Ekman, 1995). The interest in ecology was not a temporary trend, but a strong stream among groups of Nordic consumers (Hansen *et al.*, 2001), and the environmental consciousness of these societies is in line with political decisions concerning sustainable development (Agenda 21, 1992; Jordbruksdepartementet, 1999). The origin of the product is an example of the credibility quality dimension. This dimension, in contrast to the search and experience dimensions (e.g. sensory), can most often never be ascertained by the consumer, who has to trust the labelling "organic". This is the most sensitive category of the quality dimension on the market.

The food industry's and consumers' demands for product quality may be different. Long shelf life of products is more important for distributors than for consumers (Ekman and Ekman, 1995). Similarly, higher protein content in wheat is required for industrial baking, while the consumer test showed high acceptance of bread baked with wheat containing less than 11% protein (Paper III and IV). There is a need for reflection over the fact that higher nitrogen supplies increase not only the protein content but also the cadmium in wheat (Wångstrand *et al.*, 2004). The security and health aspects of wheat and bread in a sustainable system can be discussed both in terms of feed quality origin, as manure increases the content of cadmium in the arable soil (Lindén *et al.*, 2001; Olsson, 2002), and in terms of local production, as the consumption of locally produced bread saves 20% of the energy expended in comparison with bread transported 20 Swedish miles (Naturvårdsverket, 1998).

Multinational food companies are growing larger and small scale and local production is decreasing, however both need to study what consumers regard as quality in a broad sense (Bech *et al.*, 2001). The ability to understand consumers' perceptions of food and patterns of purchase may be decisive for the success or failure of these companies.

The results (Paper I) revealed the importance of supplied information concerning production method (Paper I) and the effect of consumer values (Paper IV) on product acceptance. Enhanced liking for bread said to have organic origin, particularly for the frequent consumers of organic food, confirms consumers' positive attitudes towards organic products (Magnusson *et al.*, 2001) and the effect of consumption frequency on liking (Paper I). Addressing the significantly different values of different organic consumer segments (Paper IV) is a challenge for the market.

Methodological considerations

The results of the present study contribute to the research puzzle being tackled by the interdisciplinary research programme FOOD 21 (2003). The aspects of bread qualities were also discussed in relation to findings from other theses written within FOOD 21, concerning nutrient leaching (Djordjic, 2001), cadmium levels (Olsson, 2002), consumer attitudes towards organic products (Magnusson, 2004) and choice of eco-labelled products (Grankvist, 2002) – issues important for the sustainable production and consumption of bread, as bread, through consumers' choices, affects both the environment and consumer health in the short- and long-term.

Due to the well-defined material, originating from the established field trials (since 1987) (*Papers* II, III and IV), possible biases related to growing

and harvest conditions were avoided and products could be studied in a value chain from the producer to the consumer under controlled experimental conditions (Table 4).

Table 4. *Factors of importance in the study of sensory qualities of bread related to wheat quality and growth conditions*

Factors	Degree of control
Elaboration of experimental design	a
Cultivation of wheat in establish field trials	b
Harvest	b
Preparation for the storage	b
Chemical analysis	a, b
Transport	b
Storage of wheat	a
Preparing of sensory evaluation	a
Milling	a
Flour and dough analysis	a
Test baking	a
Baking	a
Storage of bread samples	a
Sample preparation	a
Sensory evaluation	a
Data processing	a

^a under control of author

^b under control of The Agricultural Society in Kristianstad

Image analysis was applied for the calculation of bread slice area, as traditional rapeseed replacement for evaluation of baking performance did not give satisfactory repeatability for the loaf volumes.

The same routines and parameters in the breadmaking (Table 5), bread storage and sample preparation (slicing), conducted in an industrial environment, ensured the equal quality of samples in terms of the handling of material.

Table 5. *Parameters related to the baking of breads evaluated in Papers I - IV*

Parameters	Paper I	Paper II	Paper III	Paper IV
Dough temp. (°C)	27.3 - 29.4	28.0 - 29.9	27.5 - 29.0	27.0 - 28.6
Resting time/temp. (min / °C)	30/30	30/30	30/30	30/30
Rising time/temp. (min / °C)	40/38	40/38	40/38	40/38
Baking temp. (°C)	200	200	200	200
Baking time (min.)	20	20	20	20
Steam added (sec.)	20	20	20	20
Centre temp. (°C)	97.2 - 98.3	97.0 - 98.5	98.10 - 98.5	97.8 - 98.6
Approximate cooling time (h)	2	2	2	2

Conclusions

Overall conclusions

Factors related to production (farming system, year of harvest, milling and baking techniques) affected the quality of wheat, flour and bread, respectively, in different steps of production to different degrees, but the effects of milling technique and year of harvest predominated. Consumers' liking of bread was affected by bread sensory qualities and non-sensory factors (provided information and consumers' values). The sensory quality of bread ("taste") was the most important factor for liking, however non-sensory factors ought to be attached to the product in order to optimize consumers' liking of bread, in accordance with values to which some consumers adhere.

The results from the present study link bread quality and liking of bread to the environment, production chain, consumers' attitudes and values.

Related to different steps in production and product quality

Farming system and year

- Wheat harvested in three subsequent years did not show the same quality pattern concerning chemical and rheological data, but parameters such as lower volume weight and higher ash content characterized organic wheat, while higher Zeleny value and dough extensibility characterized conventional wheat.
- Sensory attributes of white breads were more affected by year of harvest than by farming system.
- Generally, the wheat and flour qualities, slice area and sensory attributes of whole wheat and white breads, as well as consumer liking of breads, did not describe unambiguously products from one farming system as superior to products from the other system.
- Among the most liked bread samples, both conventional and organic samples were found. The younger consumers' lower acceptance of some organic samples was related to the rancid flavour found in samples by a trained sensory panel.

Milling techniques and farming system

- Whole wheat flour qualities, such as degree of damaged starch, and rheological characteristics, such as dough development time, were affected by milling technique to a higher degree than by farming system and these values were higher for roller-milled samples than for stone-milled.

Specific conclusions

Related to the bread sensory quality

- The sensory qualities of whole wheat bread and the area of bread slice were influenced more by milling technique than by farming system or moderate recipe changes. The slice areas were larger for breads baked with stone-milled wheat than for respective breads baked with roller-milled wheat.
- Attributes such as juiciness and compactness characterized whole wheat breads baked with roller-milled samples, while saltiness and deformity characterized stone-milled samples. Juiciness in whole wheat breads baked with wheat harvested in 1998 was not related to the conventional farming system but to the milling technique.
- Organic bread samples showed larger variation in the sensory qualities than conventional bread samples baked with wheat harvested in 1998 and 2000, but not in 1999. For example, the whole wheat bread baked with organic wheat E (ecological without livestock) harvested in 1998 differed from other organic breads C (biodynamic with livestock) and D (ecological with livestock), which were dominated by bran attributes such as cereal flavour, whereas bread E, in similarity with bread baked with conventional wheat, was dominated by endosperm character expressed in attributes such as wheat aroma and sweetness.
- For the white bread, more sensory attributes were affected by year of harvest than by farming system. Attributes such as elasticity and juiciness were highest for samples from 2000, and within each year, the significantly highest scores for elasticity and juiciness characterized the conventional samples, which relates to the highest extensibility, gluten content and Zeleny values. Attributes such as compressibility, springiness and mastication resistance were significantly highest for samples from 1999. In 1999, one conventional sample A199 (without livestock) was distinguished as significantly highest in smoothness and significantly lowest in compressibility and mastication resistance, while samples C99 (biodynamic with livestock) and D99 (ecological with livestock) showed similarities concerning lowest smoothness.

Related to liking of bread as an effect of information and consumers' values

- “Taste” was most important for liking of bread and the information provided with samples had an effect related to the type of information. Information about organic origin of flour had a positive effect on liking, largest for the less liked samples and a greater effect for frequent consumers of organic products than for non-users. A health promoting statement affected positively only the conventional samples. Information concerning the unknown ingredient amaranth (neophobic factor) tended to decrease liking of bread for participating vegetarians.
- The organic consumers were not a homogenous group, and different values were adhered to by consumers in different segments. Age groups had different values and showed different specific liking of breads, which linked values and age to the “taste”. The majority of organic consumers thought that organic food tastes better than conventional and that the consumption of organic bread should increase.

Future perspectives

For sustainable production

There are favourable conditions for increased use of organic wheat from extended wheat production, as the results revealed that it was technologically possible to produce breads from all of the conventional and organic wheat samples and that consumers have positive attitudes towards organic wheat bread. In the group of white breads scored highest on liking by consumers were samples representing both the conventional and organic farming systems. Fatty acids composition in conventionally and organically grown wheat should be investigated, as should starch quality as an effect of milling, in order to optimally utilize product characteristics. Longitudinal studies are needed to establish whether cadmium level can be related to the farming system.

The variation found in the sensory profiles of the whole wheat breads, baked with the same wheat samples, showed that technology should take advantage of this material variation, optimizing the quality of bread with respect to the product's objective quality (e.g., wheat characteristics, flour particle size distribution and healthiness), but also with respect to subjective quality (from the consumer's point of view, e.g., origin of wheat, perceived healthiness and food security).

The market has to identify and incorporate values that are attractive to different consumer segments in order to stimulate the development towards sustainability.

For product quality and sustainable consumption

The present findings on flours' and breads' qualities as well as consumers' perception of bread open up new perspectives on wheat utilization for human consumption aimed at sustainability. Information (on food origin and on health effects) and values (recognized on the market by consumers) can be used as tools in communication between the producers/market and different consumer segments, in order to increase the vitality and transparency of a market aimed at sustainability.

Organic wheat (grown without pesticides), which had the lowest volume weight, highest ash content and for two of three years lowest protein content, may be, at present, more suitable for coarse or whole wheat bread production than for white bread.

Substantial improvement in bread healthiness and safety, aimed at sustainable consumption, is needed with respect to factors such as fatty acid composition, starch quality and cadmium content in wheat, which are related to protein content and cadmium content in the soil, artificial fertilizers and manure. Moreover, higher content of harmful cadmium in wheat bran than in white flour should be balanced with respect to the health effect of fibre, particularly in the case of iron deficiency.

The effect of breadmaking methods on cadmium level in bread has to be investigated.

Streszczenie (Summary in Polish)

Celem pracy było zbadanie efektu systemów produkcji zmierzających do racjonalnego i przyrodniczo zrównoważonego systemu gospodarowania (<http://www-mat21.slu.se>) na jakość produktu oraz wpływu zarówno sensorycznych cech produktu, jak i czynników nie-sensorycznych na ocenę hedoniczną żywności przez konsumenta. W tym celu efekt produkcji w rolnictwie konwencjonalnym i organicznym (ekologicznym, biodynamicznym) na jakość pszenicy, technik przemiału na jakość mąki oraz receptury na jakość sensoryczną chleba (jako modelu), został zbadany przy użyciu analiz chemicznych i reologicznych oraz sensorycznej analizy opisowej. Badania przeprowadzono w laboratorium sensorycznym przez wyselekcjonowany i wyćwiczony (wg ISO standardu) zespół oceniający. Efekt czynników nie-sensorycznych (informacji oraz systemu wartości konsumentów) na ocenę smakowitości chleba został zbadany w testach konsumenckich (n= 480; n= 184).

Pszenica pochodząca z systemu organicznego miała wyższą zawartość popiołu oraz niższą gęstość nasypową. Zawartość białka nie dla wszystkich prób i lat była niższa w systemie organicznym niż to miało miejsce w konwencjonalnym.

48 typów chleba z pełnego przemiału ziarna i 21 z białej mąki było wypiekanych z pszenic rosnących w 6 typach upraw (3 konwencjonalne, 1 biodynamiczna, 2 ekologiczne), na poletkach doświadczalnych uprawianych od 1987 roku. Mąka do wypieku białego chleba pochodziła ze zbiorów w dwóch kolejnych latach.

Technika przemiału miała większy wpływ na reologię ciasta, na cechy sensoryczne oraz na objętość chleba niż systemy upraw i zastosowane zmiany w recepturze. Chleb typu graham, wypiekany z pszenicy mielonej w mlewniku walcowym, cechował się bardziej słodkawym smakiem, był bardziej wilgotny (wpływ charakteru skrobi) i miał mniejszą objętość niż chleb pieczony z mąki zmielonej metodą tradycyjną na kamieniach młyńskich (najczęściej stosowana w Szwecji metoda dla pszenicy organicznej). Chleb ów cechował się najbardziej słonym smakiem, nutą smakową prażonych zbóż i konsystencją zdolną do łatwej deformacji.

Wpływ roku zbioru pszenicy na jakość sensoryczną białego chleba był większy niż efekt systemu produkcji i zmodyfikowanej receptury. Mięsz

chleba pieczonego z pszenicy ze zbiorów w 1999 roku miał niższą intensywność cech takich jak: gładkość/aksamitność miąższu, wilgotność i elastyczność, ale za to wyższą sprężystość, opór przy naciskaniu i żuciu oraz wyższą intensywność zjełczałej woni niż chleb pieczony z pszenicy zebranej w roku 2000.

Miąższ chleba pieczonego z pszenicy uprawianej konwencjonalnie, wg danych farninografu, miał wyższą elastyczność i wilgotność niż chleb pieczony z pszenicy uprawianej w systemie organicznym.

Analiza obrazowa nie wykazała różnic w wymiarze przekrojowym chlebów konwencjonalnych w porównaniu z wymiarami przekrojowymi chlebów wypiekanych z pszenic organicznych zebranych w 1999 roku. Było to w przeciwieństwie do przekrojów chlebów pieczonych z pszenic zebranych w roku 2000, gdzie chleby konwencjonalne miały największy wymiar przekroju.

Wpływ informacji na ocenę hedoniczną chleba przez konsumentów zależał od rodzaju informacji dołączonej do próbek chleba. Informacja o organicznym (biodynamicznym, ekologicznym) pochodzeniu chleba najbardziej podwyższyła hedoniczną ocenę, szczególnie wśród tych konsumentów, którzy najczęściej spożywali żywność pochodzenia organicznego oraz dla tych próbek, które były najmniej lubiane i uzyskały najniższą ocenę w teście konsumenckim (bez informacji).

Różne systemy wartości (wg Schwartz'a) zostały zidentyfikowane wśród konsumentów organicznej żywności, tworzących segmenty konsumenckie różniące się w hedonicznej ocenie chleba. Wyniki łączą systemy wartości z wiekiem konsumentów i z preferencjami smakowymi. Większość konsumentów była zdania, że żywność organiczna ma lepszy smak niż konwencjonalna i że konsumpcja chleba wypiekanego z pszenicy uprawianej w systemie organicznym powinna zdecydowanie wzrosnąć.

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I wrote that bread is a complex product, but what then can be said about producing a thesis? There is no bread expert who can mention names for all chemical substances that constitute dough or bread, but it is possible to mention all ingredients. So can I. The main “ingredients” decisive for this thesis were situations created by not really ordinary, but hard working people with strong wills and clear visions. To all these people, unmentioned and mentioned in the following, I wish to express my deepest and most heartfelt thanks:

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