Concepts for modelling the quality of perishable products

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It is generally accepted that the quality of perishable products depends on three factors: the product, the user and the market situation. It is therefore difficult to define what quality is and how to control it. Decomposition of the effects of these factors on quality leads to a distinction between the assigned quality and the acceptability of a product. Assigned quality is the quality notion a consumer has of a product, and results from evaluating that product with respect to the consumer's specific criteria. Acceptability defines whether the consumer in a particular situation is willing to buy a particular product, and is the result of relating the product's assigned quality to other products and to extrinsic factors such as the price. Product and consumer research focus on assigned quality, whereas market research focuses on product acceptability. Changes in assigned quality can be simulated with quality change models that consist of separate models for the quality assignment, for the product behaviour and for the product environment.

From the moment of harvest, agricultural products have a limited life because of loss of quality during the period between harvest and consumption, even when optimal conditions are used during distribution. This loss of quality may be great if products are not treated optimally.

Quality is becoming an increasingly important marketing factor, both for producers and for consumers. So, during the distribution of agricultural products, the management of quality is very important. Because of this increasing importance, definitions for quality have been developed within various areas of research. These approaches to quality are reviewed in the next section.

Based on these approaches, a conceptual model of quality is presented, which incorporates an explicit decomposition of the factors that affect quality: the user of the product, the product itself and the environmental conditions to which the product is subjected. Next, a quality change model is defined as a composition of separate submodels for each of the quality-determining factors. Finally, the advantages of this approach are described for the analysis and modelling of the quality and the quality change of agricultural products.

Approaches to quality

Quality is a very elusive concept, which depends on many factors. In the first place, quality depends on the product itself. Quality also depends on the preferences of the user. The preferences may arise from the intended use of the product (e.g. ripe tomatoes for soup, hard tomatoes for salads), and from socio-psychological factors such as the user's attitude towards the product. For example, one person may be status conscious and prefer plum tomatoes from Italy, another may be environmentally aware and prefer organically grown tomatoes. A third aspect that may affect quality is the market situation: the quality of a product depends on its price (a higher price is often taken to indicate higher quality) and on the availability of other, competing, products (a product of moderate quality will be assigned a higher quality if it is surrounded by products of poor quality than if it is surrounded by products of high quality).

Several approaches to defining quality that reflect these different aspects have been described by Garvin[1] and by Steenkamp [J-B.E.M. Steenkamp (1989) *Product Quality: An Investigation into the Concept and How it is Perceived by Consumers* (PhD thesis), Agricultural University Wageningen, The Netherlands]. These approaches stem from the areas of philosophy, production management, economics and consumer research.

Philosophy

The metaphysical or transcendent approach views quality as an unanalysable property that a user can only learn to recognize through experience. Because people acquire different experiences, their quality evaluations are bound to be different. This approach serves more as background knowledge to the concept of quality rather than as a practical method to handle quality.

Production management

The production management approach is concerned with maintaining quality during production, and uses technical specifications to objectify product quality; thus, a product that conforms to the technical specifications has a high quality. Production starts with product design, includes manufacture and distribution, and extends to maintenance and after-sales services. For each stage in the production process, specific quality criteria are used to monitor and control that production stage[2].

Although this approach was developed for nonperishable products, the concepts relating to the design and the production stages can also be applied to agricultural

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products. Breeding new cultivars with properties such as a better resistance to certain diseases or a better taste can be regarded as improving the quality of design. The production of agricultural products consists of a growth phase and a distribution phase. Examples of maintaining quality during production are control of the growth conditions, and use of packaging throughout a complete distribution chain.

Economics

Economic theories of producer and consumer behaviour in markets containing products of differing quality use a product-based definition of quality. In this case, quality is the composite of product characteristics.

Theories about producer behaviour describe how producers use quality to maximize their profits by differentiating their products from competing products. Differentiation can be achieved (1) by changing the value of a quantitative characteristic, for example by increasing the amount of vitamins in a food product; (2) by making the product more appealing to a specific group of consumers, for example by harvesting fruit at different time points, so that consumers can choose between ripe and unripe fruit; or (3) by introducing a new quality attribute that eventually may make existing quality grades obsolete, for example using organic growing methods instead of using mineral fertilizers.

Economic theories about consumer behaviour assume that consumers try to buy those goods that have the highest quality. Lancaster[3] defines quality as 'those objectively measurable, technical properties of goods that are relevant to consumer choice'. Different consumers may perceive these properties differently. In Lancaster's model, the differences in perception are captured in individual preference functions.

Many economic theories assume that consumers are completely informed about the price and quality of the products available on the market. This assumption is, however, unrealistic. Most of the time, consumers are imperfectly informed and, therefore, use various strategies to evaluate the quality of available alternatives. Depending on how the quality of a product is determined, three types of strategies can be distinguished. The first is to search for a product with the highest quality by inspecting available products before purchase. An example of this search strategy is to compare available wines by using the descriptions of their bouquets. The second strategy that can be used to evaluate the quality of product alternatives is by experience: by trying different alternatives and selecting the one that provides the largest benefit. An example is to buy and taste different wines, until a wine with the most favourable bouquet is found. Some attributes cannot be evaluated from actual experience of the product. In the case of these so-called credence attributes, consumers must rely on information from external sources. An example of a credence attribute is the percentage alcohol in wine.

Consumer research

The user-based or perceived-quality approach puts the user in the central position. In this approach, quality is considered to be subjective: it depends on the perceptions, needs and goals of the individual user. The terms 'perceived quality' and 'fitness for use'[2] emphasize this.

Several definitions for perceived quality have been proposed. Kramer and Twigg[4] define quality as 'the composite of those characteristics that differentiate individual units of a product, and have significance in determining the degree of acceptability of that unit by the buyer'. The difference between user-based and product-based definitions of quality is that the product characteristics no longer need to be measurable; thus, a user-based definition may refer to product characteristics that in reality do not exist, but that the user believes to be important.

Steenkamp[5] distinguishes between quality cues and quality attributes. Quality cues are those product-related characteristics that are ascertained before consumption. Quality cues are similar to the search attributes of Lancaster[3], and can be either intrinsic or extrinsic[6]. Intrinsic quality cues are part of the product, and cannot be changed without also changing the nature of the product. Examples are firmness and colour. Extrinsic quality cues are related to, but not part of, the product. Examples are brand name and price. Quality attributes are observable only during or after consumption. Two types of quality attributes are distinguished: experience attributes and credence attributes, which have the same meaning as used in Lancaster's economic model of consumer behaviour[3].

A conceptual model of quality and quality change

In the approaches described in the previous section, the quality of a product depends on both intrinsic and extrinsic product properties. The intrinsic product properties define the state of the product, which is evaluated with respect to quality criteria imposed by a producer (product management approach) or a user (consumer research approach). Extrinsic product properties, such as the price and the quality–price ratios of the product and of other products, are used as additional information in the decision whether or not to purchase the product.

The distinction in the use of intrinsic and extrinsic product properties can be extended into a distinction between the assigned quality of a product and the acceptability of a product. This is illustrated in Fig. 1.

Assigned quality is the result of an evaluation of a product only with respect to the intrinsic product properties. Assigned quality specifies the suitability of the individual product to the needs and goals of a user, without referring to extrinsic properties of the product, or to other products. The needs and goals of the user are reflected in the criteria that the user imposes on the intrinsic product properties, when assigning quality to the product. As an example, a different criterion will be applied to the firmness of a tomato according to whether it will be used to make soup or in a salad: only ripe tomatoes are suitable for soup, whereas only hard tomatoes are appropriate for salads. Therefore, ripe tomatoes will have a high assigned quality if the user wants to make

tomato soup, but the same tomatoes will have a low assigned quality if the user wants to use them in a salad.

The combination of the assigned quality, the extrinsic product properties and the market situation yields the acceptability of a product: an assessment of the product in relation to its price and to other products. Independent of the assigned quality of the product, the acceptability will decrease or increase if other products available are assigned a better or worse quality, respectively. The acceptability of a product corresponds to its 'affordable excellence'[1], that is, its quality in terms of costs and price. This value-based approach to quality is often difficult to apply, as it combines a measure of excellence (quality) with a measure of value (price).

From this perspective, the approaches reviewed in the previous sections describe strategies used by consumers in deciding whether to accept a product (the economic theories about consumer behaviour and the consumer research approach), and strategies used by producers to increase the acceptability of their products (the economic theories about producer behaviour and the production management approach). The concept of perceived quality used in consumer research differs from assigned quality; the perceived quality depends on extrinsic product properties and on the market situation, whereas the assigned quality depends solely on intrinsic product properties.

Assigned quality may change because of changes in intrinsic product properties, or because of changes in the criteria imposed on these product properties. This distinction between changes in product behaviour and in quality criteria can also be found in models of keeping quality[7,8]. Keeping quality is defined as 'the time a product remains acceptable under whatever circumstances and using whatever acceptance limits'. Like assigned quality and perceived quality, keeping quality is a combination of the product behaviour and of the (possibly changing) quality criteria. However, keeping quality differs from assigned quality and perceived quality, because the latter two represent assessments of a product at a particular point in time, whereas keeping quality represents the period that all quality attributes of the product comply with the quality criteria.

Changes in the intrinsic properties of agricultural products may be caused by conditions in the environment to which the products are subjected during postharvest storage and distribution. The environmental conditions themselves can be affected by the product, particularly in the case of packaged products; for example, respiring fruit give off carbon dioxide, thereby changing the environmental conditions. In such a case, a strong bi-directional interaction exists between the product and its environment. For non-packaged products, only a uni-directional interaction is important, because the influence of such a product on its environment is negligible.

From this line of reasoning, the changes in the assigned quality of agricultural products can be decomposed into three quality-determining factors: the assignment of quality to a product by the user, the changes in the intrinsic product properties, and the interaction between the product and its environment.

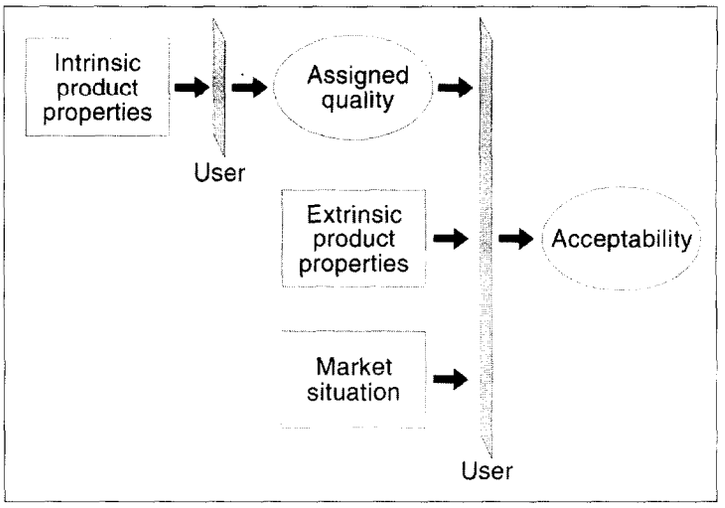


Fig. 1

A user evaluates intrinsic product properties to assign quality to a product. By also taking into account extrinsic product properties and the market situation, the user determines the acceptability of the product.

Quality assignment by the user

Users select certain quality attributes and impose criteria on these attributes to assign quality to a product (see the earlier section 'Approaches to quality'). The quality attributes selected by a user, and the criteria imposed on them, form the quality notion of the user with respect to a certain product. Although each user may in principle have a different notion of quality, groups of users can be identified that use the same quality attributes in their evaluations, and impose more or less equal criteria on these quality attributes. Such groups are said to be homogeneous with respect to the assignment of quality to a certain product. In modelling quality change, quality assignment is defined with respect to such homogeneous groups of users, for example with respect to households that include growing children, rather than with respect to an individual user.

The assignment of quality to a product is a process that, in several steps, transforms the many intrinsic properties of a product into one (subjective) uni-dimensional measure of quality. To arrive at an assignment of quality, a user perceives and evaluates a number of intrinsic product properties, and then carries out an appreciation of these evaluations (see Box 1).

Describing a product state

During the quality assignment, users evaluate and appreciate quality attributes that are perceptions of product properties.

Just as in the consumer research approach, quality cues are described as being intrinsic or extrinsic; thus, product properties can be categorized as being either intrinsic or extrinsic. For example, intrinsic properties of mushrooms are the species, the growing origin and

Box 1. Steps in quality assignment

Perception

The first step in quality assignment (see Figure) is the perception of the intrinsic product properties. Properties of perishable products can be perceived either using instruments (e.g. firmness can be measured by a penetrometer or an Instron, colour by a colour meter) or using human senses (e.g. ripeness can be assessed by pressing a tomato between your fingers). Some properties, such as the vitamin C content, can only be measured using instruments; these are the so-called hidden attributes[4]. Other properties can (to date) best be assessed by human senses (e.g. flavour). Through perception, the intrinsic properties of a product are converted into quality attributes. A single quality attribute can be based on several product properties. A good example is colour, which in most cases is the perception of the combined concentrations of several colour components inside the product.

Sensory perception is complex. Even the mealiness of apples, which is an apparently straightforward quality attribute, does not show a one-to-one relationship with the amount of cell juice, but also depends on how the apple tissue fractures when bitten. Mealiness is enhanced by fracture along cell walls, thereby preventing the perception of the juice and the sugars present in the intact cell. A user would therefore experience a mealy apple as dry, although the apple may contain almost the same amount of juice as a crisp apple.

Evaluation

In the second step, the perceived quality attributes are evaluated to determine their intensities or values. Evaluation can also be conducted both by instruments and by human senses. As perception and evaluation are strongly connected, perception and evaluation of a quality attribute are usually performed with the same 'equipment', that is, using instruments or human senses.

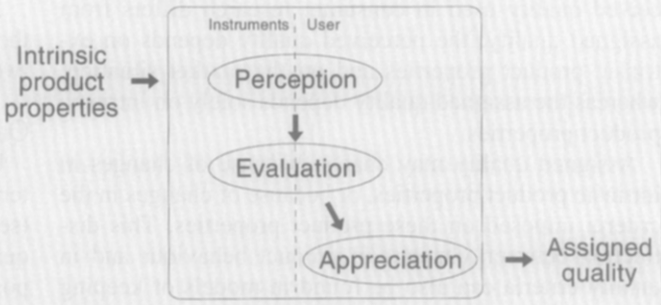
The relationship between a stimulus intensity and the corresponding sensation experienced by the human senses is not a simple linear one. It generally flattens at high intensities owing to saturation of the human senses, whereas intensities below a certain threshold intensity that is specific to the user will not be perceived at all.

Another characteristic of using human senses instead of instruments to evaluate quality attributes is a possible shift in perceived intensity following the evaluation of several products. Thus, a quality attribute may be evaluated differently if it is assessed after a batch of products with low intensities for that attribute rather than after a batch of products with high intensities.

Appreciation

Once the quality aspects have been perceived and evaluated, they can be converted into appreciations. In many cases, the relationship between the evaluation and appreciation of a quality aspect shows a strong optimum: following the first increase in liking with increasing intensity, the curve flattens in a region of no preference, which is followed by a more or less steep decline in liking with increasing intensity. A very weak salt solution is not very agreeable. Neither is a very strong salt solution.

Finally, the appreciations of the individual quality attributes are combined into a uni-dimensional quality measure. In this step, relative weights are assigned to the individual quality attributes and to combinations of quality attributes. These weights reflect the influence of socio-psychological factors, including personal preferences, trends, tradition and status symbols, on the assignment of quality to a product. The socio-psychological factors determine the attributes to be used, and the order of importance of these attributes.



Steps in quality assignment to a product by a user. For the perception and evaluation steps, instruments and/or human senses may be used, whereas appreciation is assessed entirely in the mind of the user.

conditions, the amount of water in the mushrooms, the firmness and the colour, whereas the price, the appearance of the package, and the shop where the mushrooms are bought are extrinsic properties.

Product properties can also be categorized according to whether or not they change during the normal lifetime of the product. Properties that change during the lifetime of the product are called variable product properties; properties that are constant are called fixed product properties. Of the mushroom properties mentioned above, the growing origin and the species are fixed product properties, whereas the amount of water, the firmness and the colour are variable product properties.

A third distinction that can be made is whether the value of the product property can be effectively controlled or manipulated. This issue is more apt for the operational and strategic planning of the distribution of (agricultural) products than for modelling or understanding their postharvest behaviour. Operational planning concerns the performance of activities during distribution and, therefore, concerns only those variable product properties that can be effectively manipulated. Strategic planning, however, involves the (re)design of distribution chains; in this case, properties that are fixed during the postharvest life of the products, such as harvest time, as well as variable properties, can be manipulated.

For the purpose of quality change modelling, only intrinsic product properties are relevant. Of these, the values of the variable product properties at any point in the lifetime of the product determine the product state. The change in the product is a series of such product states at successive time points. Each product state has an assigned quality associated with it, which is determined by the user through the perception, evaluation and appreciation of the product, as described above, under 'Quality assignment by the user'. Hence, the quality change of the product can easily be determined, given the time series of product states.

Behaviour of a product

During the normal lifetime of a product, the variable intrinsic product properties change as a result of processes occurring in the product. Examples of such processes include the (further) ripening of fruit, and

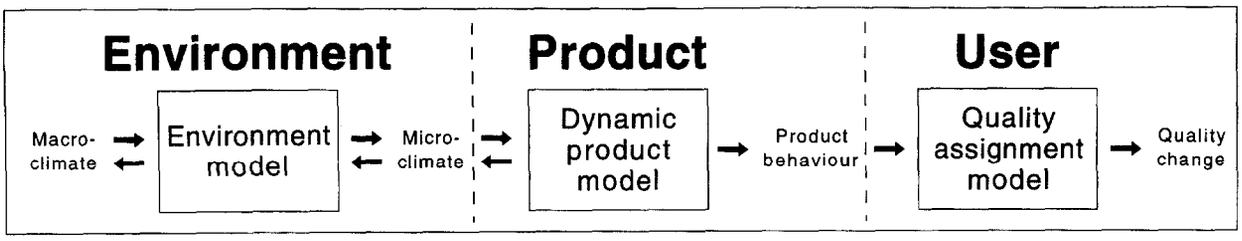


Fig. 2

A quality change model is a composition of three separate submodels for the entities affecting the changes in assigned quality: the quality assignment by the user, the physiological behaviour of the product in a particular environment and the changes in this environment.

the opening of broccoli buds. Many processes are complex systems of chemical reactions (respiration, colour development), whereas other processes have a physical nature (osmosis, diffusion). Yet other processes have both chemical and physical aspects, such as the complex combination of processes affecting the firmness of a product. Firmness may be described as a combination of turgor pressure, which is a physical quantity, and of the concentrations of various chemical compounds such as pectins, which are affected by chemical reactions.

Each process causes changes in one or more variable product properties. The action of a process may be affected by external factors, such as ambient temperature, as well as by other product properties, both fixed and variable. Thus, a variable product property that is affected by one process may influence the action of another process in the product that acts on another variable product property. These patterns of interactions between processes result in the observed complex physiological behaviour of agricultural products.

During the lifetime of a product, processes may be activated or inactivated. For example, during the distribution of vegetables in modified-atmosphere packaging (MAP), the respiration, and consequently the rate of deterioration, gradually decreases because of the low oxygen concentration, but increases again quite suddenly when the packaging is opened.

Apart from such discrete events as opening MAP, a process may also become activated or inactivated as a result of a continuous change in the product. For example, many fruit in the pre-mature stage will ripen slowly until they reach the climacteric stage. On reaching the climacteric stage (a hyperactive state in many fruit just before ripening), the rates of ripening processes will increase, so that the effects of these processes become important. Denaturation of enzymes during blanching is another example of a process becoming inactivated, and because enzyme denaturation is irreversible the enzymic process cannot be activated any more.

The environment of a product

As stated above, many processes occurring in agricultural products during postharvest storage are affected by conditions in the environment immediately surrounding the product. The product environment can be represented by external factors, of which the most important are temperature, relative humidity, and the concentrations of oxygen, carbon dioxide and ethylene.

The environment of a product can also be affected by processes occurring in the product: respiration affects the oxygen and carbon dioxide concentrations, evaporation increases the relative humidity, and heat production changes the temperature in the environment. The effect of a product on the environment will become relevant when it is contained in a relatively small closed space, for example inside a layer of packaging. Under such conditions, the environment may become unfavourable for minimizing the loss of product quality; for example, evaporation of a product wrapped in a foil may cause the relative humidity inside the foil to rise, causing fungal infections[9]. On the other hand, in the case of MAP, the packaging material is designed to exploit the processes occurring in the product to bring about an environment that is favourable for minimizing quality change[10].

Definition of a quality change model

To model the changes in the quality assigned to a product that is subjected to particular environmental conditions, three separate submodels are needed for the three quality-determining entities: quality assignment, product behaviour and product environment. These three models and their interactions are depicted in Fig. 2. The models will be described from right to left.

The quality assignment model

A quality assignment model (QAM) describes how a homogeneous group of users assigns quality to a given product. The QAM specifies the product properties that are relevant for that particular group of users. For each relevant product property, the QAM specifies the relationship between the product property and its appreciation by the group of users. Furthermore, the QAM contains a quality function (comparable to the preference function in the model of Lancaster[3]) that combines the appreciations of the individual product properties into a single uni-dimensional measure of quality.

Wilkinson and Polderdijk developed a QAM for the assignment of quality to tulip bulbs by various user groups in the Dutch tulip bulb chain[11,12]. In this model, the quality function was in the form of a summation of individual quality attributes, of the squares of quality attributes, and of the products of pairs of quality attributes, each sum weighted by a weight factor. In this case, the weight

factors are based on the results of questionnaires sent to members of the links in the distribution chain. The first summation (of the individual quality attributes) represents the quality attributes with linearly increasing or decreasing appreciations, such as bulb damage and bulb disease (less damage and less disease always give a higher quality). The second summation (of the squares of individual quality attributes) represents the quality attributes with an optimum appreciation. The last summation (of the products of individual pairs of quality attributes) represents appreciations of specific combinations of quality attributes. For bulb quality, such an interaction exists between bulb damage and bulb disease: if bulbs are damaged, less weight is given to the presence or absence of disease. This reflects the knowledge of the users that a damaged bulb is more susceptible to disease whether or not any signs of disease are visible.

As a QAM describes only how a specific group of users assigns quality to a certain product, several such models have to be used to describe quality assignment by different groups of users. As the product behaviour does not depend on the quality assignment, these different QAMs can be connected to a single dynamic product model. In the case of tulip bulbs, two QAMs are defined, depending on the intended usage of the bulbs. One model is for bulbs destined for 'dry sales' directly to the consumer, whereas the other is for bulbs destined for the production of cut flowers ('forcing'). In both models, quality assignment is described primarily as a linear function of bulb damage and bulb disease. The QAM for forcing gives more weight to disease, whereas the model for dry sales gives more weight to damage and other aspects of external appearance. Data about how consumers evaluate bulb quality were obtained with a technique derived from conjoint measurement.

This technique has also been used to analyse the assignment of quality to ham[13].

The dynamic product model

The changes in the product properties represent the behaviour of the product in its environment. A dynamic product model (DPM) describes how environmental conditions affect product behaviour. A DPM consists of several submodels, each describing a single process occurring in the product or an aspect of a process. An example of how complex physiological behaviour can be decomposed into the constituting subprocesses, which are then described in separate submodels, can be found in the chilling-injury model of Tijskens *et al.*[14] The detrimental effect of radicals (process 1), generated both within and outside the product (process 2), is prevented by a radical-scavenging system (process 3), which deteriorates at lower temperatures (process 4). The reaction rates of these four subprocesses all depend on temperature according to Arrhenius' law (process 5). Each subprocess describes a small but well-defined part of the behaviour of intrinsic product properties. The initial conditions and boundaries together with the generic model formulation explain and describe the various forms that chilling injury, as a process and as a property behaviour, can show.

The environment model

An environment model describes the changes in the environment of the product. If the product is packaged, the environment model describes the changes in the conditions inside the package (the micro-climate), as they are affected by physical processes such as the diffusion of gases through the foil or the package, and by processes in the packaged product such as respiration, evaporation and heat production.

In the case of non-packaged products, an environment model will generally reduce to a series of environmental conditions at successive points in time.

Conclusions

The quality of a perishable product depends on the characteristics of the product itself, on criteria imposed by the user of the product on these characteristics and on alternative products. These three factors lead to the complex behaviour of quality observed during the post-harvest distribution of perishable products. The concepts of assigned quality and of acceptability of a product have been introduced, in which the effects of these three quality-determining factors are explicitly separated.

Assigned quality is an evaluation of the state of a product at a particular point in time. The product state is determined entirely by intrinsic product properties, which are in turn influenced by the environment. The product state is evaluated against quality criteria that reflect the needs and goals of the user of that product. The assigned quality therefore depends on three factors: the user of the product, the intrinsic properties of the product itself, and the interaction between the product and its environment. The assigned quality is important for product research, as it refers only to the changes in the product and to the criteria of a particular group of users. Product research is concerned with increasing the sales of a product by improving the product itself.

The acceptability of a product is an evaluation of the assigned quality in the context of extrinsic properties of the product such as its price, and in relation to other available products. Product acceptability includes a trade-off between price, availability and quality, whereas for the assigned quality itself, the price and the availability of other products are irrelevant. Market research and consumer research focus on acceptability, and study how product sales can be increased using only economic instruments (e.g. price changes, advertising), hence without changing the product.

The changes in the quality assigned to a product can be formalized in a quality change model. Such models consist of three submodels: one describing the quality assignment by the user, one describing the physiological behaviour of the product, and one describing the change in the environment of the product.

The use of separate submodels has several advantages. First, the separation of product behaviour and quality assignment allows a description of the phenomena occurring in a product, independent of the user's attitude, and enables the same product model to be reused for

different user groups. The separation also allows a clear description of the quality notions of users.

Separating the changes in the environment from the product behaviour has a similar advantage. However, in much of the literature on this topic, the processes occurring in the package and the behaviour of the packed products are combined into one model. Thus, such models directly link the product behaviour to the conditions outside the package. Separate modelling of the environment and of the product leads to a clearer conceptual description, and enables reuse of both the environment model and the dynamic product model.

Second, different analysis and modelling techniques can be used for the three entities. The environment model describes physical processes, whereas the product model describes complex biochemical processes. Quality assignment has a psychological nature, for which empirical models may be more appropriate.

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Conference Report

Nordic Milk Protein Conference*

P. Jelen

As indicated in the conference announcement, the two aims of this small but delightful conference were to offer scientists and doctoral students the opportunity to interact in a workshop-type setting, and to provide a stimulus for future research activity in the field of milk protein. Although the conference was targeted primarily at participants from Scandinavian universities, the 50 or so attendees, from no less than 14 countries, represented all of the major dairy research establishments – universities, state and industrial research institutes, government laboratories and private industry – with an excellent mix of senior academics, established researchers and young aspiring dairy scientists.

The conference was divided into three distinct subtopics of the main theme: milk protein structure; bioactive peptides produced from milk protein; and milk protein functionality. There were four half-day sessions, each introduced by a main invited lecture. The contributed presentations that followed were shorter, often focusing on a specific research problem under investigation. Many of the speakers were postgraduate students reporting on their work in progress, and enjoying the opportunity to discuss their results in the presence of their peers, professors and present or future colleagues.

Protein structure

The first invited speaker, Carl Holt (Hannah Research Institute, Ayr, UK), opened the conference with a contribution that focused on the proposed role of the casein micelle as a mechanism of biological protection of the mammary gland against calcification as a result of

* Held in Wadahl, Norway, 6–8 March 1996

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