# The Inner Quality Concept for food, based on life processes

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## Abstract
How can we adequately express the quality of food produced by organic agriculture? To answer this research question, we defined a concept of 'inner quality' (formerly called 'vital quality') based on the life processes growth and differentiation, and their integration. Growers use management methods to influence life processes in their crops, thus optimising the quality of the final product. Traders and consumers can recognise certain product properties as being the result of these life processes. Here, we present a course of validation for the quality concept, together with appropriate quality parameters. The process of validation has been completed in part for two experimental crops, apple and carrot. This quality concept can provide a holistic context for the interpretation of individual food quality parameters as developed by different laboratories.

## Motivation
Many organically grown products have won the acclaim of the best chefs. Growers know that good taste depends on moderate yield and fertilisation, careful ripening and freshness. The need to keep costs down, especially in conventional production but increasingly so in the organic sector as well, has however prompted concessions to be made with respect to inner quality. In an effort to cut the cost price, organic agriculture, too, is moving in the direction of higher yields, higher fertilisation, earlier harvests and trade chains involving lengthy journeys and extended storage. Farmers, growers and wholesalers are exploring the extent to which they can realise these economies without damaging the good level of inner quality.

Meanwhile, new questions have been raised: are genetically modified or hybrid varieties less 'coherent', and if so, is this disadvantageous for health? Do food crops with enriched levels of vitamins or phenols enhance health? What do coherence, structure and ripeness, or typical characteristics mean in terms of taste and consumer health?

In the validation programme of the FAL several experimental parameters appeared to distinguish organically grown products from conventionally grown products and hybrid varieties from field-pollinated varieties. The next research steps are to interpret these differences in terms of their influence on human health, and to find ways to improve crop quality in the growing phase. For this, we need a coherent concept of food quality; a concept in which food quality is more than the sum of exterior characteristics, a few distinct components, and the absence of harmful contaminants; a concept, also, that connects the different phases of plant growth to aspects of the final product and to human or animal health.

We found a quality concept based on the life processes growth, differentiation and their integration in the crop appropriate for this purpose. Growth and differentiation are also recognised as distinct processes in humans and animals, so that it is possible to make the connection between the growing crop, the food product and animal or human health. Growth in humans comprises the production of new cells and recovery, and takes place continually. If there is not enough growth, diseases such as sclerosis crop up. Differentiation shapes the growth of cells and tissues. Cancer is a disease which thrives on insufficient differentiation, and differentiation therapy is being developed to combat it (De Luca et al. 1995).

Consumers' wishes are never uniform: their food preferences depend on individual preferences, on their health and mood. There is a market for produce with different good inner qualities; just as there are people who like tart, crisp long-keeping apples, while others prefer soft, sweet, aromatic apples. In other words, optimum inner quality differs from person to person. These different accents can be realised in the growing season.

### Long-term aims

The international research association 'Organic Food Quality and Health' (FQH) was established to promote research into the health effects of good quality organic food, and to work on this challenging research question in particular. The research members have distinguished four lines of research:
- the validation of a quality concept for organic produce (an example introduced in this article).
- the validation of individual parameters to assess quality differences (see elsewhere in these proceedings).

- the establishment of the relationship with management practices in agriculture (here, only for apple).
- the study of the relationship between good quality food and health (not in this article).

The research discussed here concerns the development of a coherent quality concept. We designed a provisional concept based primarily on the life processes of growth and differentiation and the integration of both. The concept includes relevant empirical parameters and a research methodology for measuring health effects on humans and animals. The validation of a concept like this is complex and requires several steps which are mentioned in figure 3.

**Short-term aim**

The short-term purpose of this study is to examine several different methods of analysis for apple trees and fruits, grown in controlled series with large variations in growth, differentiation and integration.

## Method

We chose to develop the quality concept using apple as our experimental crop, because we had already gained a considerable amount of knowledge about the inner quality aspects of apples in previous research. In addition, concepts such as growth and differentiation are commonly used by fruit growers. They are familiar with the terms vigour and bearing and can take appropriate measures to regulate these. The same type of experiment is now being conducted for carrots (Northolt et al. 2003), see figure 1.

This study was conducted on a bio-dynamic apple orchard in the Netherlands. The apple trees were 12 years old, of the variety Elstar and growing on weak rootstocks (M9, 2460 trees/ha). The soil was light clay and fixed nitrogen easily. In order to test our hypothesis, we used seven ranged reference series which produced small variations in growth and differentiation. The series were: duration of ripening (5 harvest dates), yield or bearing (5 levels), sunlight exposure ( 3 levels), post-harvest ageing (5 dates), fertilisation level (5 levels), type of nutrients (granulated commercial fertilisers versus partly composted cow manure), bio-dynamic field preparations (yes versus no). The series were designed to assess the whole range of possible variation from too low, or too little, to too high, or too much, with the optimum being somewhere in the middle. Data for the first 4 series were collected in 2000, the last 3 series were implemented over three years (2001-2003), and an extensive evaluation of crop and apple quality was made in 2002. The experimental conditions were controlled for homogeneity of the constant factors.

*Figure 1: Overview of the FQH experiments by Louis Bolk Institute and the presumed effect of more of each factor on the life processes*

| crop | harvest | Series in | Growth | Differentiation | Integration |
|---|---|---|---|---|---|
| apple | 2000 | Bearing (=yield, 5x) | ↓↓ | | |
| | | Sunlight (3x) | ↑ | ↑↑ | ↑ |
| | | Ripening (5 harvest dates) | ↑ | ↑↑ | |
| | | Post-harvest ageing (5x) | ↓↓ | | ↓ |
| apple | 2002 (2001-2003) | Nutrients (5x) | ↑↑ | ↓ | |
| | | compost/ comm.fert. (2x) | | | ↑? |
| | | Bd-preparations / not (2x) | | | ↑? |
| carrot | (pilot 2002) 2003 | nutrients (3x) | ↑↑ | ↓ | |
| | | sunlight (3x) | ↑ | ↑↑ | ↑ |
| | | ripening (5 harvest dates) | ↑ | ↑↑ | |

## Results and discussion about the Inner Quality concept

Life processes play a crucial role in this quality concept: they provide the conceptual coherence. Life processes are related to management measures: it is the grower, above all, who nurtures the life processes in crops or livestock. But life processes can also be related to product properties and health effects. Life processes can be divided into growth processes and differentiation processes, and these processes can occur in varying proportions and degrees of mutual interaction (integration). In figure 2 we present the ‘Inner Quality concept’ for apple (Bloksma et al. 2003), which is an improved version of the ‘Vital Quality concept’ (Bloksma et al. 2001). This concept for apple can easily be transformed to other products, as is done in the brochure *Life processes in crops* (Bloksma and Huber 2002).

*Figure 2: The ' Inner Quality concept' for apple (Bloksma, Northolt, Huber et al. 2004)*

| **crop management (grower)** | **Life processes** | **Properties (consumer)** |
|---|---|---|
| | **1. Growth (G)** | |
| • no limits in nutrients and water<br>• defruiting when heavy bearing<br>• growth stimulating pruning etc.<br>• more space, wider plant distance. | • expansion, production of mass.<br>• Photosynthesis -> primary metabolites.<br>• filling reserve organs.<br>• germination. | • big green mass, high yield.<br>• big, tart, crispy, juicy fruit.<br>• starch, amino acid, protein, etc.<br>• strong buds and fruit. |
| | **2. Differentiation (D)** | |
| • light and warm growing place.<br>• reducing heavy growth.<br>• binding down young twigs.<br>• Artificially ethylene. | • refining, ordering.<br>• ripening, replenish reserves.<br>• induction of generative organs. | • differentiated refined forms .<br>• order,<br>• firm cell walls.<br>• ripened (ethylene).<br>• many flower buds and seeds. |
| | **1+2 Integration of G and D** | |
| • growing species and stage-typical care for G and D.<br>• balanced nutrients, regular and slow release of nutrients (compost).<br>• appropriate varieties.<br>• diversity?<br>• Bd preparations?<br>• Human attention? | • species and stage-typical proportions and interaction of G and D; so real 'maturing'.<br>• prim. -> secondary metabolites.<br>• self-regulation. | • species and stage-typical proportion of G and D properties.<br>• crispy, coloured and aromatic apple.<br>• phenols, vitamin C, wax, etc.<br>• high ratio protein/total N<br>• many fertile generative organs.<br>• resistance to stress, pests and diseases. |

Examination of the imbalances clearly points to the existence of an optimum balance between the processes. For example, strong growth with insufficient differentiation results in large fruits without aroma and colour, poor storability and crops which are susceptible to many fungal diseases and sucking insects. Strong differentiation with poor growth on the other hand leads to emergency ripening with dry, bitter, small fruits. These crops are susceptible to powdery mildew and biting insects.

Several experimental parameters have been found in previous research to assess of organic products, such as copper-chloride crystallisations, capillary rising pictures, white light luminescence (biophotons), spectral range luminescence, electrochemical measurements and resistance tests to pests, diseases and other stress. Clear and reproducible differences have been established, but have not been clearly interpreted in terms of quality, i.e. what aspect of quality is measured and how can this be regulated in the growing phase. We expect that the parameters mentioned above primarily express aspects of integration, and that is one of the reasons why we designed a quality concept based on growth, differentiation and their integration. To understand the meaning of these experimental methods, we need to execute them on products grown in controlled conditions, in series characterised by variations in growth, differentiation and their integration. We also have to correlate the results with as many established parameters as possible.

We followed a course of validation for the quality concept in figure 3 and finished the steps indicated with √.

*Figure 3: Scientific validation route to measure inner quality of food products with in italics the methodological steps and √ means this step is already done (Streiner and Norman, 2001).*

| | | **done ?** |
|---|---|---|
| **1. Develop hypothesis of food quality suitable for organic products and their consumers**<br>*defining what is suitable for organic agriculture and their consumers* | | |
| | 1. based on life processes (growth, differentiation and integration of both).<br>2. relating processes (growers) and product properties (consumers).<br>3. related to holistic human health concept by physicians and dieticians. | **Ō**<br>**Ō**<br>**(Ō )** |
| **2. Develop a quality concept**<br>*distinguishing domains, items, to find relevant properties and parameters* | | |
| | See figure 2 on the Inner Quality concept and fig. 1 for the parameters (Bloksma et al. | **Ō** |

| | | |
|---|---|---|
| | 2003) | |
| **3. Consistency of the hypothesis on 'Inner Quality Concept'** *(testing the validity of the theoretical construct)* | | |
| | **3.1. Consistent in itself ?** | **Ō** |
| | **3.2. Consistent with current theories ?** yes for growth and differentiation; no for integration. | **Ō / -** |
| | **3.3. Consistent with existing empirical data ?** only a few controlled studies available. | **Ō / -** |
| **4. Predictive validity of the concept** | | |
| | **4.1. Meaning recognised by workers in the field** *(face validity)* and also for other crops than apple. | **Ō** |
| | **4.2. Are quality aspects recognised by specialists**? *(content validity, all domains and items are included ?)* yes for growth and differentiation; partly for integration (f.e, the 'growth-differentiation-balance-hypothesis', Herms et al. 1992). | **Ō / -** |
| **5. Predictive validity of individual parameters (depends on parameter)** | | |
| | **5.1. Absence of systematic error**; does it measure what is should? *(validity)*. | **Ō / -** |
| | **5.2. Same results by different observers, laboratories, days, etc**. *(reproducibility)*. | **Ō / -** |
| | **5.3. Enough discrimination?** (*sensitivity of response to changes in quality*). | **Ō / -** |
| | **5.4. Parameter consistency:** Good correlation between parameters for the same item? *(internal consistency)*. | **Ō / -** |
| **6. Development of a new parameter** depends on parameter | | |
| | **6.2. Parameter compared with established parameter in an experiment with controlled products** (*convergent validity*) for growth parameters many √. | **Ō / -** |
| | **6.3. Parameter based on logical reasoning** (e.g. of physiologic concepts) if no established parameter is available and **Experimental results to confirm validity of hypothesis** *(construct validity)*. | **Ō / -** |

There is a risk of using circular reasoning when introducing a new definition of quality containing experimental parameters. After all, it is difficult to introduce an unknown concept (in this case, integration) with unknown crop management measures (such as biodynamic preparations) and to measure it with experimental parameters. Experimental parameters may correlate with established parameters (*convergent validity*), such as resistance to disease and evaluation of taste. In that case, the experimental parameters offer no added value and the parameter which is least expensive to implement may be chosen. On the other hand, there may be no correlation and this might suggest that a new aspect of quality may have been found. A methodological foothold might then be achieved by simultaneously working on the theoretical foundations of the new concept, and executing experimental series to evaluate the concept. By logical reasoning, a new concept such as integration, might be derived from known plant physiology concepts (in this case, growth and differentiation and, for example, self-regulation). This way of arguing is known as *construct validity*. The new concept may then be evaluated by comparing the actual results of experimental crop management measures, with the expected results. Unfortunately the plant physiologic bases of integration processes, such as self-regulation, are still underdeveloped. In other words, this most interesting aspect of the validation process is not yet completed.

## Results and discussion about the apple experiments

Details about the results of the apple series are described in the two apple studies (Bloksma et al. 2001 and 2004). We mention only some of the most interesting results here.

With increasing ripeness, the CC-crystallisation images of apple juice showed increasing openness towards the periphery. Looking at ripening in this way, we also recognised increasing openness in the conventional content analyses: hard sour fruits with starch and phenols change into tasty, juicy fruits with aromatic substances. An image-creation method likes this helps to get a picture of a process that increases overall insight. In the future, this expensive method might be replaced by cheaper conventional analyses.

With increasing sunlight exposure, the spectral range luminescence typical for apple increased. In addition, the free amino acid content decreased, the ratio protein:amino acid increased and the ratio sugar:nitrogen also increased. All these parameters are indications of the same general conclusion, that the product is 'more finished' in the sun. Also, higher contents of phenols and vitamin C indicate that a sun-ripened product has more resistance to decay and stronger self-regulation, and is thus more integrated and 'itself'. In the shade, more building blocks (amino acids and nitrate) accumulate, waiting for sugar to assimilate in the tissue. It is known that high amounts of amino acids and nitrate in food are not healthy. In the measurements, we found that shadow and over-fertilisation had a similar effect. Both can be explained by the C/N plant physiology. The crop can be improved by providing both more light and less fertiliser.

As expected, higher fertilisation stimulated growth characteristics and caused a decline in differentiation characteristics: there was a longer period of shoot growth and there were more shoots, but there were also more fungal infections, darker and larger leaves, higher nitrogen levels in the bud, leaf and fruit, and more and stronger blossom formation for the following year. Higher levels of fertilisation yielded larger apples which were less firm and slightly less tart, with less blush, a lower phenol content and a greater susceptibility to fruit rot. After two to three years it had become clear that the 0 kg N/ha and 40 kg N/ha regimes were inadequate (the trees had a non-bearing year) and that fertilising with 160 kg N/ha was too much (more fruit rot, less tasty). For this site, a fertilisation regime of about 100 kg N/ha best achieved the two-fold objective of regular yield and good inner quality. This is what we call the optimal apple-typical proportion between growth an differentiation.

We found clear correlations between management measures, tree characteristics and fruit characteristics. This means that growers can regulate apple quality during the growing season. On the basis of these apple experiments, we can distinguish respective sets of growth and differentiation parameters and evaluate them in the light of conventional fruit cultivation science.

**Parameters for growth**

The parameters of tree growth are: fruit-bearing (on condition of equal shoot growth and bearing in previous year), shoot growth (on condition of equal bearing), leaf size or colour (on condition of equal shoot growth), nitrogen content in bud, nitrogen and magnesium contents in leaf, and scab infestation.

The parameters of fruit growth are: fruit size or weight (on condition of same bearing), firmness (on condition of equal bearing and shoot growth), acidity, nitrogen content, amino acid content, protein content, tart and crisp taste, growth score on crystallisation images, high initial luminescence, susceptibility to fruit rot.

**Parameters for differentiation**

Parameters of tree differentiation are: autumn colours and bud formation (on condition of equal bearing).

Parameters of fruit differentiation are: degree and hue of blush, yellow ground colour, shape of fruit, sheen, starch conversion, aroma and sweetness in flavour (on condition of sufficient assimilates), phenol content (on condition of sufficient assimilates), differentiation score on crystallisation images, hyperbolic decline of luminescence.

**Parameters for growth and differentiation**

For most plant processes, both growth and differentiation are important. Many parameters can express either growth or differentiation, depending on which is the limiting factor for the crop. For example, when fertilisation is taken as the limiting factor for bud formation, then bud formation is a parameter of growth. If the limiting factor is sunlight exposure, bud formation acts as a differentiation parameter in a light exposure series.

Another example of parameters which express both growth and differentiation, is the content of secondary substances in the plant, such as phenols, vitamins, aromas and colouring agents. The formation of the raw material (assimilates) is a growth process; the subsequent conversion to secondary metabolites is a differentiation process. A correlation with either growth or differentiation is found depending on when the measurements were taken and what the limiting factors are.

**Parameters for integration**

There are parameters which can potentially give an indication of the degree of integration. These are: resistance to diseases and pests, overall taste, phenols, ratio of proteins to free amino acids (=physiological amino acid status), integration score on crystallisation images, species-typical colour ratio in spectral-range luminescence.

Copper-chloride crystallisations and spectral-range luminescence (=florescence excitation spectroscopy elsewhere in these proceedings) dovetail well with the quality concept since both techniques can be evaluated on all three aspects: growth, differentiation and integration. In this studies we did not find consistent results from the electrochemical measurements.

## Recommendations for future research

Further research is necessary to validate the quality concept. Our suggestions are listed below:

- The integration concept and its management measures need to be substantiated in plant physiological terms, so that integration experiments may be designed for apple and other crops.
- Experimental series need to be carried out for other crops than apple and carrot. Such experiments should fulfil the following requirements:
  - a simple crop with a limited number of organs;
  - serial implementation of management measures, with gradual changes in one variable, from too low to too high, while other factors remain constant;
  - diseases and pests should not be prevented and eradicated after the young stage, as degree of resistance is an important integration parameter.
- The inner quality concept needs to be reviewed more extensively in the context of other quality concepts.
- The relationship between the quality concept and human or animal health needs to be established from a holistic perspective on health. This should be followed by health care research.

## Conclusions

The 'Inner Quality concept' based on life processes seems to offer good perspectives as a tool for improving the production of high quality crops and measuring the health effects of these products in future. The distinction between growth and differentiation is well recognised. The integration aspect, or the coherence of a product, is still the weakest part of the concept and needs to be developed further. For this purpose, a validation route was designed which has so far been executed in part.

For the Inner Quality concept, parameters are especially useful when they are expressed at all three levels of the concept: growth, differentiation and integration. Such parameters are crop observations (incl. a test of resistance to stress, diseases and pests), content analyses dealing with sugar:nitrogen ratio (physiological amino acid status) and secondary metabolites (phenols), copper-chloride crystallisations and spectral-range luminescence (=fluorescence excitation spectroscopy). The role of holistic parameters is to open scientists' eyes to new aspects resulting from life processes, and might be replaced by cheaper content analyses in the future.

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