A new quality concept based on life processes

Joke Bloksma, Martin Northolt, Machteld Huber, Geert-Jan van der Burgt and Lucy van de Vijver. Louis Bolk Instituut, Driebergen, the Netherlands, info@louisbolk.nl

1. Introduction

Demand for a new quality concept

Consumers expect organic producers to provide healthy and tasty products. But which qualities enhance health, and what is tasty? And how can all this be realised by crop or stock management?

In the conventional vision, product quality is mainly based on external, nutritive and sensory properties and is strongly directed by traders and trends. Besides tastiness and ripeness, organic consumers expect products to have properties such as 'vitality' and 'coherence', which are not easy to define and thus to explain and transfer. In the past, experimental parameters have been proposed to estimate 'vitality' and 'coherence', but they were neither scientifically validated nor related to a validated quality concept with a relation to human health.

A quality concept which matches the expectations of the organic consumer with the organic view on agricultural production and human health was developed on the basis of two apple studies (Bloksma et al. 2001, 2004) and a carrot study (Northolt et al. 2004). The new quality concept is based on the life processes of growth and differentiation, and their integration. These life processes can be defined in plant physiological terms in order to link the concept to generally accepted science. Growth and differentiation (including ripening) are familiar processes for organic producers. They are aware that effective management of these processes is necessary to obtain a crop with higher resistance (to stress, pests and diseases) and a product with better taste and keeping quality and which may also be better for human health.

Meanwhile, new questions have been raised. Is there indeed a relation between soil health and plant health and human health as expected in organic agriculture? Is the quality of genetically modified and hybrid varieties less 'coherent', and if so, is this a health concern? Do food crops with increased levels of vitamins or phenols enhance health? What do 'coherence' and 'ripeness' mean in terms of taste and consumer health? These questions are very topical, but they are based on vague notions of food quality. A new conceptual framework for these topical questions is needed, as well as better-defined concepts to operationalise these questions.

Long-term aims for research

The new quality concept was developed in cooperation with other research members in the international research association 'Organic Food Quality and Health' (FQH, for projects and partners see www.organicfqhresearch.org). The research association was established to promote research on the health effects of good quality organic food and to develop parameters for quality assessment. The research members distinguish four lines of research:

- the design and validation of a quality concept for organic produce;
- the validation of individual parameters to assess quality differences;
- the establishment of the relationship between quality and agricultural management practices;
- the study of the relationship between good quality food and animal and human health.

2. Description of the Inner Quality Concept

Organic food is not by definition better quality food

Many organically grown products have won the acclaim of the best chefs. Growers know that good taste depends on moderate fertilisation and yield, careful ripening and freshness. Among conventional producers, the need to cut costs has, however, prompted concessions to be made with respect to ripening and freshness. In an effort to cut the cost price, organic agriculture, too, is moving in the direction of higher fertilisation, higher yields, earlier harvests, long trade chains and extended storage. Farmers, growers and traders are exploring the extent to which they can realise these economies without excessively compromising quality. This may explain the large variation in quality in both organic and conventional products. Organic products might score either better or worse on quality. In most cases, it is difficult to attribute these differences to specific cultivation factors. Successful cultivation factors are not always connected with organic regulations.

The further development of organic agriculture thus depends not only on animal friendly and environmentally friendly production methods, but also on the continued acclaim of the best chefs. The new quality concept, named Inner Quality Concept, is described below. In this concept, quality is related to the life processes of growth and differentiation and their integration.

Purpose of the quality concept

The Inner Quality Concept (IQC) provides a framework:

- To link product properties to farm management during production. Organic growers manage the plant's life processes to optimise quality in positive terms of taste, keeping quality and supposed healthfulness. This contrasts with the often negative emphasis of food safety standards (no residues, no microbes, etc.) in industrial agriculture.
- To verify the assumption of organic agricultural communities that healthy food needs to be ripe and coherent (coherence is defined as a high degree of organisation in the plant).

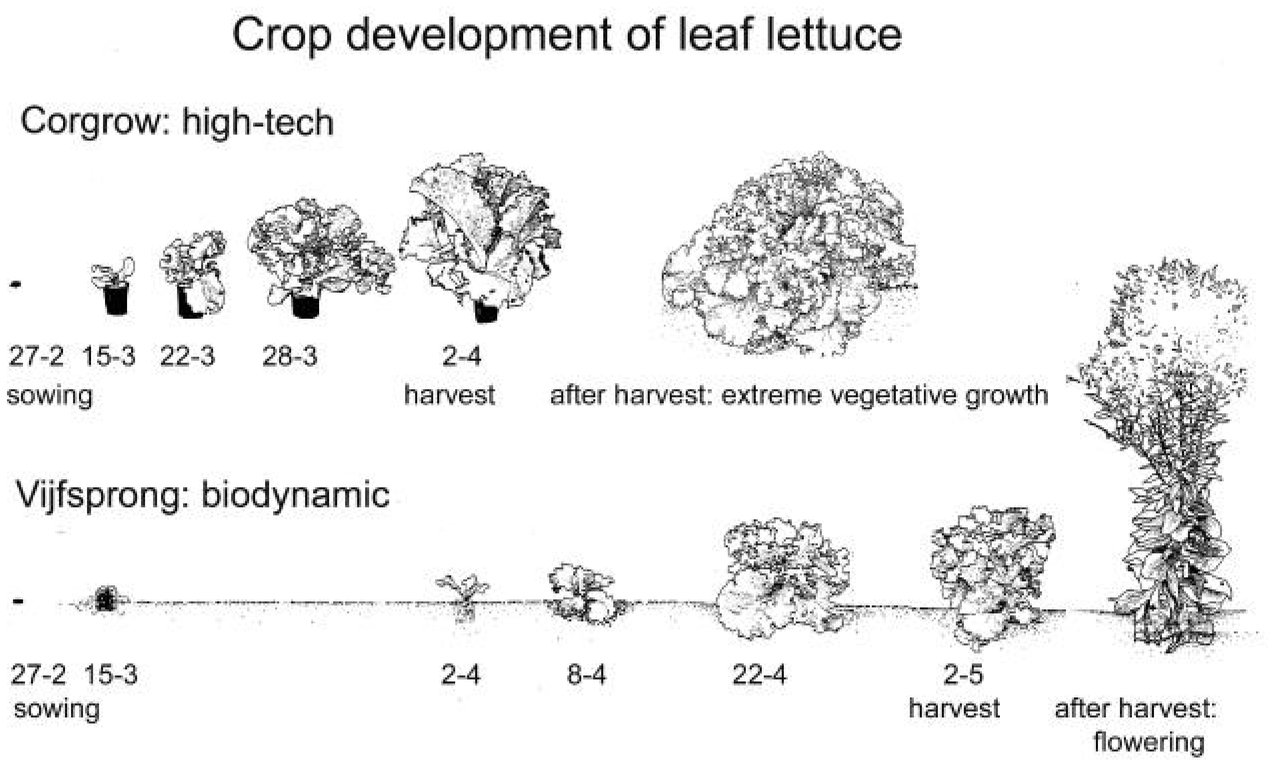
Motive: Comparing leaf lettuce grown in high-tech and organic conditions

In 1990, a large-scale lettuce grower applied for organic certification. This company grew lettuce in a closed hydro culture system (no nutrient leaching), with full climate control (no disruptions in growth), sterile conditions and insect netting. Pesticides were not necessary. In the eyes of the company's directors, this was a first-class 'organic' approach. In the eyes of long-standing organic growers, however, such cultivation practices could never result in top-quality lettuce.

Louis Bolk Instituut conducted an experiment to compare this modern cultivation system with biodynamic cultivation. The purpose of the experiment was to further develop organic standards and quality standards (Lammerts van Bueren et al. 1991). Leaf lettuce of the same variety was sown on the same date in the two different growing situations.

Table 1 presents the differences in cultivation, crop properties and quality of the harvested product. Figure 1, depicting the development series of both crops, shows that the high-tech lettuce completed its growth twice as quickly as the biodynamic lettuce. The high growth rate resulted in a young, fresh, vulnerable lettuce with a watery taste, high nitrate content and low levels of vitamin C. The slow-growing lettuce was firm, with a full taste, better keeping quality, low nitrate content and high levels of vitamin C. After harvesting, a selection of plants from each type of crop was planted in an organic greenhouse so that their further development could also be studied. The fast-grown lettuce grew enormously, producing leaves, until it started to rot. The slow-growing lettuce flowered and formed seed following the natural pattern of development.

Figure 1: Comparison of crop development of leaf lettuce (Lammerts van Bueren and Hospers 1991). Dates are presented as numbers ('27-2' means February 27th)



The fast grown lettuce had lost its capacity to flower and form seed after harvest, or in other words, it may have lost an aspect of differentiation. The fast-grown lettuce was also high in nitrate, and low in sugar, vitamin C and dry weight. The question that was not answered in this study was what the consequences of this might be for the crop's nutritive quality.

The lettuce example demonstrated the importance of balanced growth in the growing stages of the crop for the acquisition of mature quality properties. We had to work out the balance and tried to do this using the optimal proportion between two major life processes of 'mass growth' and 'differentiation in form and substances'.

The life processes of growth and differentiation in plants

Growth can be defined as the production of organic matter by increase in size or volume. This process involves the uptake of water, carbon dioxide and minerals. In plants, growth is made possible by the process of photosynthesis, which produces the sugars (as primary components) from which compounds such as starch, cellulose, amino acids and proteins are derived.

Differentiation can be defined as the process of specialisation in terms of shape and function. An example is cell differentiation in plants, animals and humans: a young cell, which is initially multifunctional, gradually acquires one specific function and shape. Specialisation is a refinement that is expressed in terms of shape, scent and colour. For example, fruits ripen, leaves change colour in the autumn, the growth of a shoot ends in a terminal bud and seeds become dormant. The primary components are converted into secondary components such as phenols, vitamins, aromas, wax, etc. Thus 'differentiation' in this context has a broader meaning than only the 'formation of a new plant organ'.

Since these two processes, growth and differentiation, occur simultaneously in living organisms, they cannot be separated. But as agricultural practice shows, it is nevertheless useful to *distinguish* between them and to see them in their relative proportions. For example, Figure 2 shows that growth processes dominate the first formed leaves, and that differentiation processes gradually become more pronounced in later formed leaves.

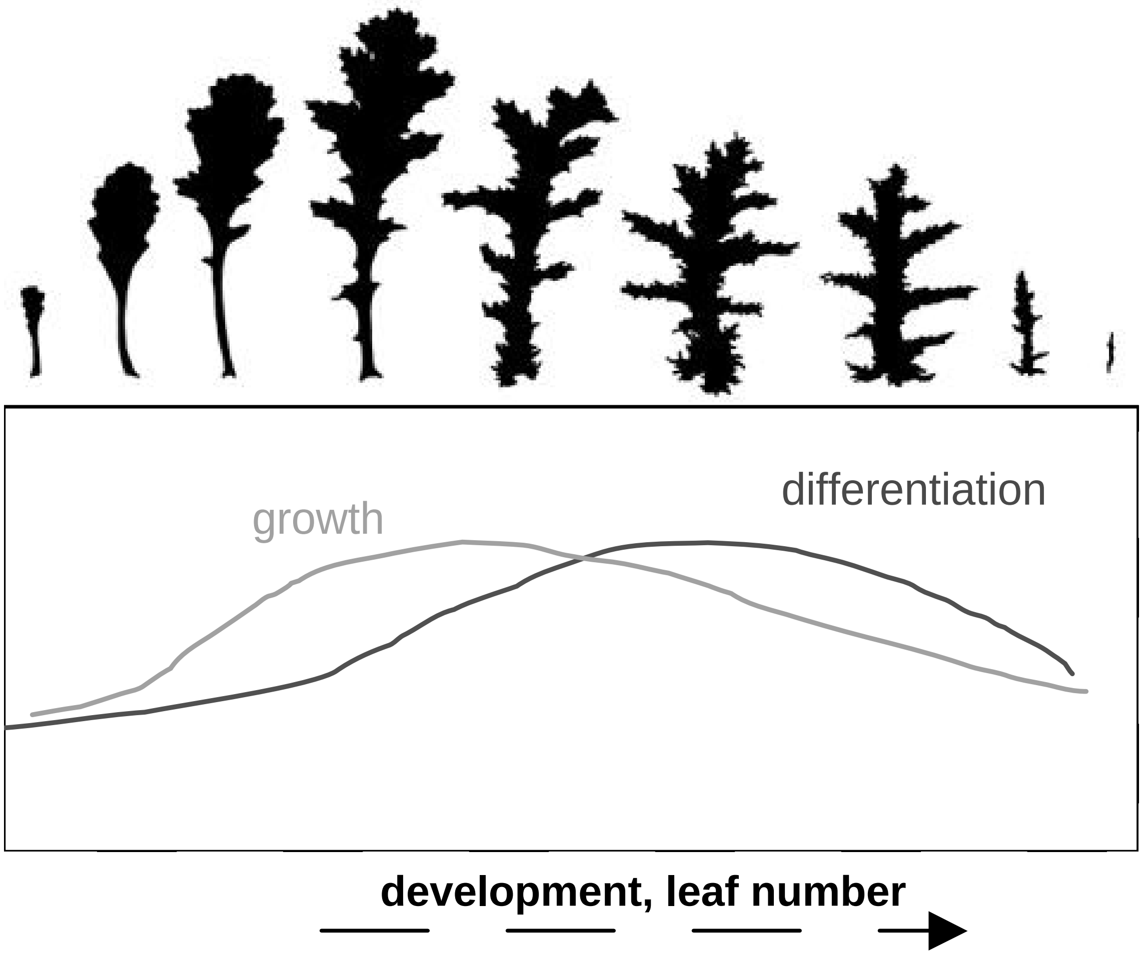
Growth does not take place at equal rates in the different organs of a plant. In carrot, leaves grow vigorously in July while the root grows thicker in August and September. In the case of apple shoots, leaves, roots, flowers, flower buds and fruits each realise their own maximum growth rate at different periods in the year (Bloksma et al. 2004). This implies that growth and differentiation should be considered per organ and in relation to time.

Table 1: Comparison of the cultivation and quality of leaf lettuce grown under high-tech (intensive) and bio-dynamic conditions (Lammerts van Bueren and Hospers, 1991).

	Corgrow technologic	**de Vijfsprong biodynamic**
cultivation		
cultivation	automatic, continuous	rotation
substrate	plastic pot with peat in water	peat block in greenhouse soil
manure	water with minerals	60.000 kg composted manure/ha
light	illumination 20 hours/day	natural
temperature	heated continuously	only during raising
pesticides	none	none
prevention of diseases	disinfected, insect netting	rotation, resistance
weed control	sterile substrate	1x hoeing, 1 x hand weeding
various treatments	none	4x biodynamic preparations
crop		
start of growth	rapidly	gradually
cultivation period	5 weeks	10 weeks
lettuce head	luxurious open	compact
leaf colour	bright green	light green
leaf form	long narrow	round
leaf	vulnerable	firm
weight in gram	110 (2 plants/pot)	136 (1 plant)
quality		
taste	fresh watery	soft sweet, like lettuce
storability	wilts easily	stays crisp longer
nitrate mg/l	2837 (very high)	687 (moderate)
sugar in % total soluble solids	2.1 (low)	2.5 (good)
dry matter in %	4.2 (low)	5.3 (good)
vitamin C	low	moderate
ripeness	little	good
rot in self-disintegration test	much	little
characteristics	young and vulnerable	full ripe and strong
quality	watery	firm
cultivation dependent on	technique, energy, nutrients	weather, labour, manure

Figure 2: Growth and differentiation expressed in the leaf form during development of Groundsel

The leaves of groundsel (Senecio vulgaris) are presented in a consecutive line-up from the first leaf grown on the stalk, far left, to the last leaf, far right. The first leaf is small and undifferentiated. This is followed by a stage of vigorous growth of both petiole and leaf blade. The leaves at the centre have attained their maximum size and the differentiation of their shape is becoming apparent. Differentiation gradually takes over, and the leaves become smaller and more toothed. The influence of growth has given way to the influence of differentiation and the last leaf 'ripens' into a narrow, pointed shape. It is time for flowering to start.



Balance of growth and differentiation to obtain maximum quality

The need for some balance between growth and differentiation can be recognised by looking at situations of imbalance, as in the next examples:

- Plants grown in shade are tall and weak and lack the fine structured forms developed by light (may indicate too little differentiation).
- A lettuce crop that grows rapidly due to excessive fertiliser often lacks taste and may be susceptible to disease (may indicate too much growth).
- Emergency flowering in drought reduces vigour (may indicate too little growth).
- Aphids suck growing substances and this results in dry, mummified fruits (may indicate too little growth).

We define 'balance in life processes' as: the development of crops with a moderate resistance to stress and diseases and with aromatic and firm food products. Some authors describe this as 'maturing' (Rosenfeld 1998, Strube and Stolz 2004) or 'maximum natural development for vegetable growth, flowering and fruiting'. Biodynamic growers express this as 'coherence' and 'plant-specificity' (Koepf et al. 1976).

Defining optimum food quality as a balance in life processes is not a new concept. This mode of thought has long held sway among biodynamic researchers (e.g. Schuphan, 1961; Klett, 1968; Pettersson, 1970; Koepf et al.1976; Kunz, 1999; Bauer, 1999) and in plant physiology (e.g. Herms and Mattson, 1992; Lerdau et al., 1994; Galston, 1994). The way we use this idea, however, is new: the life processes are used to form a framework for a coherent quality concept including various quality properties. In addition the quality properties of the final product can be linked to crop properties and to management tools.

Another new aspect of this concept is that it does not include a single optimum quality. For example, some consumers like green, firm, juicy apples, and others prefer blushed, sweet, aromatic apples. So, there is some freedom to choose a more growth-related or a more differentiation-related optimal balance when managing the crop.

The Inner Quality Concept

In Table 2 we present the 'Inner Quality Concept' for a general crop, which is a generalisation of the Inner Quality Concept developed for apple (Bloksma et al. 2004) and for carrot (Northolt et al 2004). It is described more popularly in the brochure *Life processes in crops* (Bloksma and Huber 2002).

The IQC has three components, in horizontal rows, which describe the life processes of growth and differentiation, and their integration. The vertical columns give the four different descriptions for crop management, the physiological life processes, the properties of the crop and the properties of the food product.

Two meanings of 'vitality'

The term 'vital products' is attractive for a concept dealing with life processes. In any event, it has considerable commercial appeal. Nevertheless we omitted 'vitality' from the first quality concept because of its ambiguity. Some, mainly in conventional agriculture, use 'vital' for products with an emphasis on growth processes: the fresh, green, growing, young and lively product (vitality meaning 1 in Table 2). Others use 'vital' for products which were grown with a balance between growth and differentiation, and with optimum self-regulatory properties, coherence and self-realisation (vitality meaning 2 in Table 2).

Initially, we gave the concept the name 'Vital Quality Concept', but because of these different confusing meanings of 'vital', the concept was renamed 'Inner Quality Concept' (IQC).

Experimental parameters mainly focus on coherence

Several experimental parameters are proposed to assess the coherence aspects of products:

- biocrystallisations or copper chloride crystallisation (Engquist 1970, Busscher et al. 2004),
- luminescence or biophotones (Popp et al. 1981, Popp and Li 1993, Strube 2003),
- physiological amino acid status (Wistinghausen 1975, Stolz 2003),
- electrochemical measurements (Kollath 1978, Staller 2003),
- capillary rising pictures (Tingstad 2002, Skjerbaek et al. 2005).

The mentioned parameters, however, have not been clearly interpreted in terms of quality, i.e. what aspect of quality is measured? The IQC provides a framework for further investigations to demonstrate the meaning of these parameters. In the apple- and carrot experiments of the Louis Bolk Instituut, we demonstrated some experimental parameters in food products grown with different balances between growth and differentiation. Biocrystallisation pictures in particular, are able to show both the life processes of growth and differentiation, and their integration. In future we expect to find in the balance (the integration) between the life processes the key to work out the relevance of 'coherence' for health.

Table 2: The 'Inner Quality concept' for a general crop.

	Crop management *in communication with grower*	**Life processes** *grower, plant physiologist*	**Properties of crop** *grower*	**Properties of product** *grower, consumer, retailer*	
Growth	• no limits in nutrients, light and water (fertilisation, breaking and watering). • extra CO_2 (in greenhouses). • warmth (crop ridges, greenhouses). • more space (wider plant distance, defruiting, weeding).	• production of mass: forming cells, tissues, organs. • expansion. • absorption of water and nutrients. • photosynthesis -> primary metabolites. • maintenance of basic metabolism.	• big mass, high yield. • large, dark-green leaves. • grows until harvest. • many fungal diseases and sucking insects. • strong seeds and flower buds.	• firm, tart, crisp, crunchy, juicy. • high glucose, starch, nitrate, amino acid, protein, etc. • low dry matter, vulnerable, short storable. • high initial value in luminescence (biophotons). • perradation, fullness, expansion in biocrystallisation pictures.	**Vitality (meaning 1)**
Differentiation	• light (no shade, pruning, clean windows). • a little growth stress (limited water, limited fertilisation, root pruning). • binding down young apple twigs. • ethylene hormone.	• refining, ordering. • ripening of all organs. • replenish reserves. • secondary metabolites. • induction of generative organs.	• differentiated refined forms (fine leaf serrations, cork, colour). • order, symmetry. • growth is completed (final bud). • many flower buds and seeds. • biting insects.	• form and colour is completed (stumpy carrot, yellow ground colour in apple) • high dry matter. • high secondary metabolites (phenols, vitamins, tannine, resin, wax, aromas) • bitterness. • hyperbolic decay in luminescence (biophotons). • structure in biocrystallisation.	
Integration of Growth and Differentiation	• optimal proportion in stimulating growth and differentiation (species and stage typical). • appropriate varieties. • disease preventive soil. • diversity of agro-ecosystem. • biodynamic preparations?	• maturing • enough primary -> enough secondary metabolites. • self-regulation.	• species and stage-specific full-grown and ripe. • resistance against pest, diseases and stress. • crop: wound healing after damage. • many fertile generative organs.	• attractive (coloured, glossy) • optimum taste (juicy, crispy and aromatic). • optimal nutrient composition. • high ratio protein/total N. • species typical in spectral range luminescence. • coherence in biocrystallisation.	**Coherence, vitality (meaning 2)**

Perspective to enlarge the concept to animal and humans

We see some similarities between the major life processes in plants (growth and differentiation) and the major life processes in animals and humans (proliferation and differentiation). We expect in future to relate this concept to animal production and to human health, to be able to cross the bridge from soil to plant to animal and finally human health. For example, the development in medicine of 'differentiation therapy' in which vitamin A-derivates are used to treat human cancer cells *in vitro* (De la Luca et al. 1995). Cancer is defined by too much uncontrolled growth of cells without enough differentiation. Using treatment with vitamin A-derivatives, a product of differentiation processes in the plant, undifferentiated cancer cells change into differentiated more healthy ones.

3. Method for validation of the Inner Quality Concept

Validating a new concept

There is a risk of using circular reasoning when introducing a new overall quality concept (such as the IQC) that contains new aspects AND new parameters. It is difficult to introduce an unknown aspect such as integration, to associate it with crop management measures and to measure it with experimental parameters such as luminescence and biocrystallisations.

A methodological foothold can be achieved by simultaneously working on the theory of the new concept, and executing experiments to evaluate the concept (Streiner and Norman 2001). In Table 3 we present the course of validation followed for the Inner Quality Concept.

Table 3: Validation route for the 'Inner Quality Concept'

	completed (+) or partly (+/-)
1. Development of quality concept for organic products.	
a. based on life processes (growth, differentiation and integration of both). b. relating processes and properties (see table 2). c. making processes measurable by parameters d. relating with holistic health concept by physicians and dieticians	+ + + + / -
2. Testing face validity	
a. Life processes recognised by workers in the field (e.g. farmers). b. Life processes recognised by specialists (e.g. physiologists).	+ + / -
3. Testing content validity of concept.	
a. Is concept consistent in itself? b. Is concept consistent with current theories?	+ + / -
4. Testing predictive validity of concept.	
Is concept consistent with existing empirical data?	+ / -
5. Testing reliability of established parameters	
a. Good correlation between parameters for the same item? b. Same results by different observers and laboratories?	+ / - + / -
6. Responsivity to change	
Do parameters discriminate sufficiently?	+ / -
7. Development of a new parameter.	
a. Parameter compared with established parameter in controlled field study.	+ / -
b. If no established parameter, the parameter is based on logical reasoning (here on physiological theories).	+ / -

The first step was to validate the new quality concept as described at the beginning of this chapter (step 1). Over the years, we discussed and improved the quality concept presented in Table 2 with many colleagues in science and the field (step 2).

Growth and differentiation are recognised by plant physiologists, e.g. in the 'growth-differentiation-balance-hypothesis' or GDBH (Herms et al. 1992; Lerdau et al., 1994). According to the GDBH, growth is necessary for primary metabolism and differentiation for secondary metabolism. Unfortunately, plant physiological theory on integration processes such as self-regulation is still underdeveloped. In other words, this most interesting aspect of the *content validity* (step 3) is not yet completed.

Controlled series with extremes in growth and differentiation

In order to find the range of and the optimum balance between growth and differentiation during cultivation, it is necessary to grow crops under extreme conditions of growth and differentiation, and to demonstrate the consequences of one or the other for the harvested product. It is also necessary to know how the balance between the life processes can be managed during cultivation.

To this end, we designed experiments in which conditions were varied to induce the extremes of growth or differentiation in the crop. In Table 4 we present an overview of the experiments with the presumed effects of varying the cultivation factors on the life processes. By comparing the results with our expectations, we largely completed step 4 of the validation course for apple and carrot.

Table 4: Overview of the FQH experiments by the Louis Bolk Instituut and the presumed effect of management factors on the life processes.

crop	harvest	series in	Growth	Differentiation	Integration
Lettuce [1)]	1991	high-tech versus organic	↑↑	↓?	↓?
Apple [2)]	2000	bearing (= yield, 5x)	↓↓		
		sunlight (3x)	↑	↑↑	↑
		ripening (5 harvest dates)	↑	↑↑	
		post-harvest ageing (5x)	↓↓		↓
Apple [3)]	2002 (2001-2003)	nutrients (5x)	↑↑	↓	
		compost / commercial fertiliser (2x)			↑?
		biodynamic preparations / none (2x)			↑?
Carrot [4)]	2003	nutrients (3x)	↑↑	↓	
		sunlight (3x, shade nets)	↑	↑↑	↑
		ripening (3 harvest dates)	↑	↑↑	

1. Lammerts van Bueren and Hospers 1991. 2. Bloksma et al 2001. 3. Bloksma et al 2004. 4. Northolt at al. 2004.

Experimental parameters for quality

In order to understand the significance of experimental parameters such as luminescence and biocrystallisation, we assessed them for products grown in controlled conditions. We also correlated the results with as many established parameters as possible (step 7).

Experimental parameters may correlate with established parameters (*convergent validity*), such as resistance to diseases and evaluation of taste (step 7a). In that case, the experimental parameters offer no added value and the parameter which is least expensive to implement will be chosen in the future. On the other hand, there may be no correlation which might suggest that a new aspect of quality may have been found. A new aspect such as integration might be derived from plant physiology theories by logical reasoning (for example, self-regulation may be derived from growth and differentiation). This method of argumentation is known as *construct validity* (step 7b).

Individual parameters must be validated by the laboratories that produce them. The biocrystallisation method and the luminescence method have been validated for selected crops almost up to steps 5 and 6 (Busscher et al. 2004, Kahl et al. 2003). More correlations with products grown in controlled conditions and evaluations as regards human health are necessary in order to understand the significance of these methods.

4. Experiments to validate the Inner Quality Concept

4.1. Apple, between growth and differentiation

We chose to develop the quality concept using apple because we had already gained a considerable amount of knowledge about the inner quality aspects of apples in previous research. In addition, the aspects of growth and differentiation are commonly used by apple growers. They are familiar with 'vigour and bearing' and take measures to regulate these.

Method

In Figure 3, we present results from two apple studies in which an orchard was divided into several different plots, so that one cultivation factor could be varied in gradual degrees from too little to too much. The cultivation factors were: bearing level (35, 75, 100, 125, 140 fruits per tree by hand thinning), sunlight exposure (3 positions in the tree), ripening (5 harvest dates with 7 day intervals), post-harvest ageing (1, 4, 8, 12 days on the shelf after 3 months of cold storage), nutrient level (0, 40, 80, 120, 160 kg N/ha supplied by commercial organic fertilisers, farm yard compost or commercial fertilisers) and, finally, biodynamic preparations (present/absent).

In both studies the apples were grown in the biodynamic orchard 'Boomgaard ter Linde' in the south-western part of the Netherlands. We used full grown apple trees of the Dutch variety Elstar on dwarf rootstock M9, 2460 trees/ha, grown on limy humus sea loam with trickle irrigation. The experiment was replicated four times.

We measured many properties of the soil, the growing trees and the apples after harvest and after storage. The results were studied in relation to the management factors and mutual correlations were computed. This procedure enabled us to contribute to the validation of the Inner Quality Concept (step 3, Table 3), the validation of new parameters (steps 5.and 6) and the evaluation of orchard management. Details about the methods and results of the apple series are described elsewhere (Bloksma et al. 2001 and 2004). Here, we mention only some of the results that are relevant to the IQC.

Parameters for growth

The parameters for tree growth are fruit-bearing (with equal shoot growth and bearing in previous year), shoot growth (with equal bearing), leaf size or colour (with equal shoot growth), nitrogen content in bud, nitrogen and magnesium contents in leaf, and scab infestation. The parameters for fruit growth are: fruit size or weight (with same bearing), firmness (with equal bearing and shoot growth), acidity, nitrogen content, amino acid content, protein content, tart and crisp taste, growth score on crystallisation pictures, initial luminescence, and susceptibility to fruit rot.

Parameters for differentiation

Parameters for tree differentiation are: autumn colours and bud formation (with equal bearing). Parameters for fruit differentiation are: degree and hue of blush, yellow ground colour, shape of fruit, sheen, starch conversion, differentiation score on crystallisation pictures, and luminescence.

Parameters for growth or differentiation depending on limiting factor

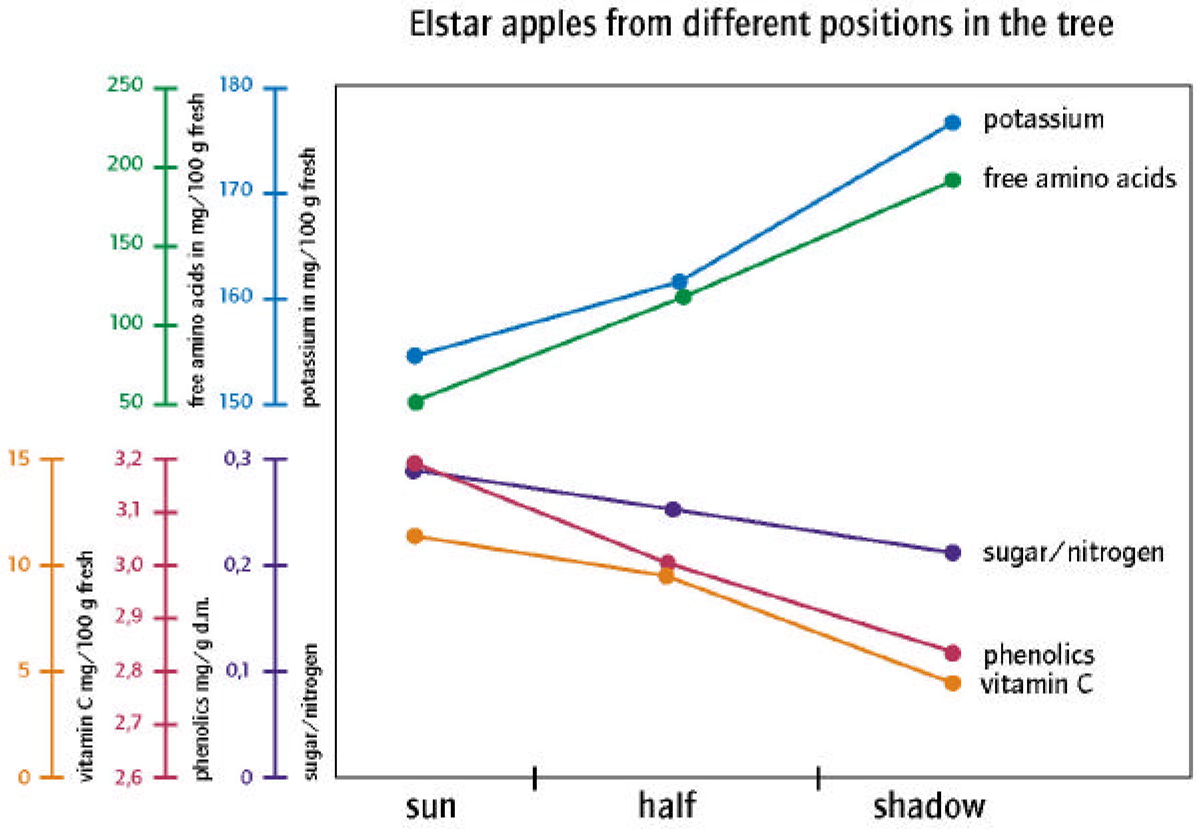
Both growth and differentiation are important for most plant processes. We recognised that many parameters can be expressions of either growth or differentiation, depending on which is the limiting factor for the crop. For example, when fertilisation is taken as the limiting factor for bud formation,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

Parameters for integration

The results found in the literature and from these experiments enabled us to select parameters which may 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 pictures, and species-typical colour ratio in spectral-range luminescence.

The secondary metabolites in the plant, such as phenols, vitamins, aromas and colouring agents, are integration parameters. The formation of the raw material (assimilates, primary metabolites) is a growth process; the subsequent conversion to secondary metabolites is a differentiation process. The integration of both processes is necessary for high contents of secondary metabolites. A correlation with either growth or differentiation is found depending on the time of year that measurements are taken and the limiting factors in the production system. We found that the experimental series for apple were not suitable for evaluating the degree of integration with the required degree of certainty. Too many assumptions remained unproven regarding the effects of biodynamic preparations in promoting integration.

Figure 3: Elstar apples at different positions in the tree.



Evaluating crop management for apple quality

The biocrystallisation pictures of apple juice from progressively riper fruits showed increasing openness towards the periphery. Looking at ripening as 'an opening of gestures' also allowed us to recognise the successive transition of solids into gaseous substances in conventional content analyses: firm, sour fruits with high starch and phenols changed into tasty, juicy fruits with vaporous, aromatic substances. A picture-creating method is useful in getting a physical image of a process and increases overall insight. In the future, this expensive method might be replaced by the cheaper conventional analyses, but for now its expense is more than offset by its usefulness in revealing the process.

With increasing sunlight exposure, the spectral range luminescence typical for apple increased. In addition, the free amino acid content decreased, the ratio of pure/raw protein increased and the ratio of sugar/nitrogen also increased, (Figure 3). All these parameters are indications of the same general conclusion: that the product is 'more completed' in the sun. Also, higher contents of phenols and vitamin C indicate that a sun-ripened product is more resistant to decay, and is thus more integrated. In the shade, more building substances (amino acids and nitrate) accumulate, as the plant waits for sugar to assimilate in the tissue. High quantities of free amino acids and nitrate in fruit and vegetables are known to be undesirable for human health and keeping quality. We found that shade and over-fertilisation had a similar effect on the balance between life processes: the accent shifted from differentiation to growth. Both can be explained by C/N plant physiology. The crop can be improved both by providing more light, and using 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 resulted in 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 too low and 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 orchard, a fertilisation regime of about 100 kg N/ha best achieved the two-fold objective of regular yield and optimal inner quality. This is what we call the optimal apple-specific balance between growth and differentiation.

4.2. Carrot, between growth and differentiation

Carrot has a more straightforward physiology than a perennial crop such as apple. It might therefore be easier to study the integration aspects of growth and differentiation in this crop. In addition, some organic carrots are famous for their carroty taste which is often lacking in conventional carrots.

Method

In Table 4, we present the carrot study, in which a carrot crop was divided into several series which gradually varied: 3 nutrient levels, 3 sunlight exposure levels, ripening (3 harvest dates). The carrots were grown on the Dutch biodynamic mixed farm 'Warmonderhof', on reclaimed, well-drained sea clay. The field was moderately fertile and the crop followed onions in the rotation. We used the open-pollinated cultivar Rodelika (Bingenheimer Saatgut AG). We divided a large carrot field into 4 replicate blocks. The carrots grew on ridges. The nutrient levels were 0, 100, 200 kgN/ha, applied in the form of blood and feather meal pellets. Unfortunately, it was a warm and wet season, so that the nutrient level was not a true limiting factor. The light levels 100, 85, and 52% light were realised by using shade nets once the young plants were established. Plants were evaluated on 6 different dates.

We measured many properties of the soil, the growing crop, and the carrots, after harvest and after storage. The results were studied in relation to the management factors, and mutual correlations were computed. This procedure enabled us to contribute to the validation of the Inner Quality Concept, the validation of the new parameters and the evaluation of carrot management. Details about the methods and results of the carrot experiments are described elsewhere (Northolt et al. 2004). As with apple, we only mention some of the results here that are relevant to the Inner Quality Concept.

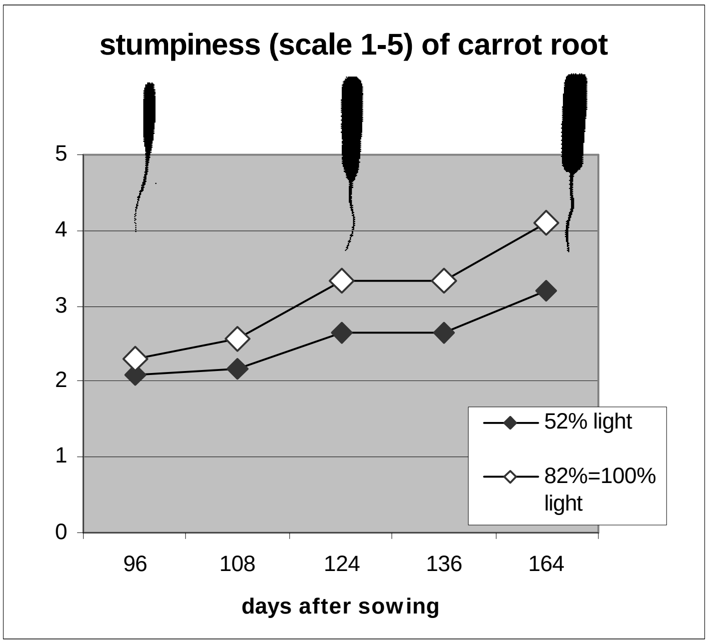
Parameters for growth

Parameters for crop growth are: weight of leaves and leaf colour. Parameters for carrot growth are: root weight, monosaccharide content, nitrate content, emission of spectral range luminescence and rot in storage test (trend).

Parameters for differentiation

Parameters for crop differentiation are: fine forms in leaves (trend), colouration of the leaves (hypothesis, but here too much growth for autumn colouration). Parameters for carrot differentiation are: root form (pointed to stump, Figure 4), dry matter, and emission ratio in spectral range luminescence.

Figure 4: Form of the carrot root in relation to ripeness and light exposure (Northolt et al. 2004).



Parameters for integration of growth and differentiation

Parameters for crop integration are: incidence of pests and diseases (hypothesis, because no spontaneous pests and diseases occurred). Parameters for carrot integration are: carotene content, orange colour of root (trend), saccharose content, total sensory appreciation and carrot taste.

Evaluating crop management for carrot quality

The design of this carrot experiment, with only three levels of fertilisation, light and ripeness, did not reveal the desired optimum levels. Series with at least five levels will give a better chance of finding significant results. The experiment did clearly show, however, that the best quality resulted from a combination of the lowest level of fertiliser, the highest degree of light and the latest harvest date. Carrots grown in these conditions had the best taste, lowest nitrate content and best keeping quality. All three factors shift the balance in favour of differentiation. The type of soil on which this experiment took place is highly conducive to growth: all management measures taken here should aim to reinforce the differentiation process.

5. Progress made in the validation of the concept

The Inner Quality Concept based on life processes offers good prospects as a tool for improving the production of high quality crops and measuring the health effects of these products in the future. Growth and differentiation are well distinguished. The integration aspect is still the weakest part of the concept and needs to be developed further, see section 3, Table 2.

Parameters are especially useful for the Inner Quality Concept when they express the three aspects of the concept: growth, differentiation and integration. Such parameters might involve crop observations (e.g. a test of resistance to stress, diseases and pests), content analyses dealing with sugar/nitrogen ratios, physiological amino acid status and secondary metabolites (phenols), biocrystallisation pictures, and spectral-range luminescence. The new holistic parameters have a secondary purpose: they also provide scientists with a new perspective from which to study life processes. In the future, these parameters might be replaced by the cheaper content analyses.

Another holistic parameter, the electrochemical measurements (pH, redox potential, resistance) yielded little to no effect in these apple and carrot studies.

Recommendations for future research

Further research is necessary to complete the validation of the quality concept. Our suggestions are listed below:

- The integration aspect and associated management measures need to be translated in plant physiological terms by experiments with some physiologically well-documented crops.
- Experiments should be carried out with other crops than apple and carrot. Such experiments should fulfil the following requirements:
  - a simple crop with few organs;
  - serial implementation of management measures, with at least 5 levels of one variable from too low to too high in growers' opinion, while other factors remain constant;
  - diseases and pests should not be prevented (and may even be intentionally introduced) after the young stage, as degree of resistance is an important integration parameter.
- The relationship between the quality concept and human or animal health needs to be established from a holistic health perspective. Louis Bolk Instituut has already started animal feeding experiments. Such research can only be done if foodstuffs are available which have been produced with well-balanced processes, in the sense described above, and which have thus achieved an optimum level of quality (defined hereunder).

6. Perspective for farmers, traders and consumers

In other chapters of this book, several experiments are described which compare organically grown products with conventionally grown products. The next steps will be to interpret these differences in terms of their effects on human health, and to find ways of improving crop quality in the production phase. This will require a coherent concept of food quality; a concept in which food quality is more than the sum of exterior characteristics, some specific health components, and the absence of harmful contaminants. Moreover, we need a concept that connects the different phases of plant growth, to properties of the harvested product, and to human or animal health. The Inner Quality Concept can meet these requirements.

Trade and consumers should recognise quality

Consumers of organic products do not attach value only to organic cultivation methods, but also to the freshness, taste, ripeness and keeping quality of the product. Together, these attributes justify the higher price of organic products. In table 1 (right column) traders and consumers find characteristics of the products with an emphasis on growing processes (e.g. big, firm, juicy, storable) or an emphasis on differentiation processes (e.g. ripeness, sweetness, colour). Optimum quality is a balance of characteristics that falls somewhere in between. Consumers have some leeway in choosing for emphasis on one or the other. Traders can use Table 1 to find the corresponding crop properties and can ask growers to keep this in mind in stimulating the corresponding life processes.

Quality-driven cultivation

In Table 1 (left column), growers will find the management tools to influence life processes. Fertilisation is the most common method of stimulating plant growth (especially with nitrogen), but may also be achieved by breaking the soil, to promote mineralization, and watering. In greenhouses, extra carbon dioxide can be added. Growth is also enhanced by a warm growing site, more space between plants, defruiting and weeding.

Management tools for stimulating differentiation are also available. The most important of these is to maximise light: shade must be minimised by pruning trees, thinning and cleaning greenhouse windows. Differentiation can also be stimulated by taking measures to limit growth. Mild forms of growth limitation include restricted water supply, limited fertilisation and root pruning. In apple production, binding down young twigs is a trick to initiate flower bud formation (differentiation). In tomato growing, artificial ethylene hormone is applied.

The grower thus has different tools by which to achieve an optimum balance and integration between growth and differentiation (specific for the plant species and development stage). Moreover, we expect more integration from using appropriate varieties, soil that helps prevent soil diseases, encouraging diversity of the agro-ecosystem and, probably, applying biodynamic preparations.

Relation with human health

Since growth, differentiation and their integration are universal processes in all living systems, it is not unthinkable that human health might be favourably influenced by the use of food products with balance and integration between growth and differentiation. Does a ripe, balanced food product enhance the self-regulatory capacities of the consumer? These are exciting questions for future research.

7. References

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