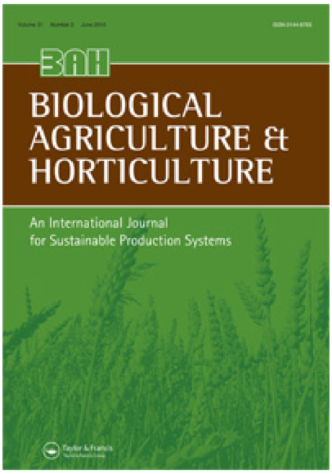

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Standardization and performance of a visual Gestalt evaluation of biocrystallization patterns reflecting ripening and decomposition processes in food samples

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The biocrystallization method is based on the phenomenon that additive-specific, dendritic crystallization patterns emerge when an aqueous dihydrate cupric chloride solution with additives is crystallized on a glass plate. The patterns reflect physiological processes like ripening and decomposition and are applied in differentiating food samples according to feeding regime, production system and degree of processing. The method has been used for decades in organic food quality assessment from an ontological holistic stance. The patterns are evaluated visually and by means of computerized image analysis. The present study describes the development of the visual evaluation from a morphological description of structural features towards the perception of a Gestalt, a salient, coherent 'meaningful-whole', which complies more closely with the pattern formation principle of the method. The methodology was standardized according to ISO-Norms 11035 and 8587 for sensory analysis of food products, adapted for use in the visual evaluation of biocrystallization patterns. Two Gestalts, 'Ripening' and 'Decomposition', reflected in biocrystallization patterns from diverse agricultural products were characterized, trained on and examined. Based on the statistical evaluation, it is concluded that the panel has become reliable and appropriate for ranking biocrystallization patterns according to the intensity of the two Gestalts. The developed level of Gestalt evaluation of biocrystallization patterns provides a basis towards qualitative interpretative judgements on the food quality of a product relating to quality concepts based on plant physiological processes.

Keywords: biocrystallization; food quality; organic food

1. Introduction

The biocrystallization method is based on the phenomenon that additive-specific crystallization patterns emerge when an aqueous dihydrate cupric chloride ($CuCl_2 \cdot 2H_2O$) solution with additives is crystallized on a glass plate (Gallinet & Gauthier-Manuel 1992; Busscher, Kahl, Doesburg et al. 2010a). The patterns emerge through a self-organization process which is influenced by the additive (Kokornaczyk et al. 2011; Busscher et al.

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2014) and appear to reflect physiological processes like ripening and decomposition (Keller 1997; Fritz et al. 2011, 2013), the effect of processing, feeding regime and production system (Weibel et al. 2001; Kahl et al. 2009, 2013; Kahl, Busscher, Hoffmann et al. 2014a; Kahl, Busscher, Mergardt et al. 2014b; Busscher, Kahl, Andersen et al. 2010b; Szulc et al. 2010; Seidel et al. 2013) in a broad range of agricultural products. Hence, the use of the method for decades in organic food quality assessment from an ontological holistic stance (Pettersson 1970; Schudel et al. 1980; Mäder et al. 1993; Balzer-Graf 1996; Balzer-Graf et al. 1997; Granstedt & Kjellenberg 1997; Alföldi et al. 2001; Andersen et al. 2001; Weibel et al. 2001). This premise implies evaluating a sample as a whole, which complements reductionist considerations and meets the requirements of the system orientated approach of organic agriculture (Bloksma et al. 2007; Kahl et al. 2010, 2012; Kusche et al. 2010).

Only recently has the methodology been documented and characterized, including the crystallization chamber and the laboratory procedures (Busscher, Kahl, Doesburg et al. 2010a; Busscher, Kahl, Andersen et al. 2010b; Kahl et al. 2013). Likewise, methodology has been developed for the evaluation of the biocrystallization patterns both from a visual orientation using defined morphological criteria (Huber et al. 2010) and by means of computerized texture and structure analysis (Andersen et al. 1999; Meelursarn 2007; Doesburg & Nierop 2013). The computerized evaluation enabled a standardization of the method, which revealed the main source of variation to be the crystallization process (Busscher, Kahl, Andersen et al. 2010b). Consequently, studies elucidating the physical conditions underlying the crystallization process are ongoing (Busscher, Kahl, Doesburg et al. 2010a).

In the visual evaluation of biocrystallization patterns, four levels of evaluation criteria, reflecting a hierarchical complexity, can be distinguished. These levels are (1) Quantifiable evaluation criteria based on single morphological and local features, e.g. length of side-needles, (2) Quantifiable, descriptive evaluation criteria connected to single morphological features, e.g. regularity of ramifications, (3) Quantifiable, descriptive evaluation criteria of a higher order, that describe gestures or implicit motions in the whole pattern, e.g. coordination, integration of the features, (4) Qualitative descriptive evaluation criteria based on the perception of 'meaningful wholes' or Gestalts in the patterns (adopted from Huber et al. 2010). At present, a standardized and communicable methodological basis has been established for the evaluation of biocrystallization patterns up to level three (Huber et al. 2010). For this standardization process, the ISO-Norm for sensory analysis was applied, ISO-Norm 11035, adapted for use in the visual evaluation of biocrystallization patterns.

This article reports the initiative of a European consortium comprising five biocrystallization laboratories and nine connected scientists to extend the analytical morphological level of biocrystallization pattern evaluation towards the level of Gestalt evaluation based on references from defined samples (judgement level four). A Gestalt is defined as 'a perceptual pattern or structure possessing qualities as a whole that cannot be described merely as a sum of its parts' (Collins English Dictionary 2014), which complies more closely with the pattern formation principle of the method. The concept of Gestalt implies reciprocal part-whole interactions as the whole depends on the parts to come forth, and simultaneously the parts depend on the coming forth of the whole to be assigned significant instead of superficial (Bortoft 1996; Parnas 2012; van der Bie 2012; Galotti 2014). Gestalt recognition and application form key principles in diagnosing and solving unique, complex and context-specific problems in disciplines where a parts-alone view does not suffice, as for instance in clinical intuition (Elstein & Schwartz 2002; Lyneham et al. 2008; Stolper et al. 2010), visual perception (Moore & Egeth 1997; Han et al. 1999; Jusczyk et al. 1999; Happé & Frith 2006), language and music processing (Herrmann et al. 2003; Croft & Cruse 2004; Koelsch & Siebel 2005) and in the characterization and diagnosis of mental disorders (Parnas 2012; Westen 2012; Nordgaard et al. 2013). In the realm of Gestalt evaluation of biocrystallization patterns, the parts refer to the characterizing morphological and gestural criteria. Weight and significance of the perceived criteria is thus assigned in the context of the recognized Gestalt.

The Gestalt principle of perceptual organization of visual items into meaningful wholes is described by the Gestalt Law of Prägnanz (Lund 2001; Fulcher 2003; Galotti 2014). The process of pattern (Gestalt) recognition and application is commonly explained by three stimuli driven, bottom-up perceptual models: (1) template matching, (2) feature analysis and (3) prototype matching, which all agree that pattern recognition is a process of matching between, e.g. visual, stimuli and information from memory (Lund 2001; Fulcher 2003; Baars & Baars 2007). The influence of context, expectation and experience are, however, described best by task-driven, top-down attentional processes (Drew et al. 2013; Pinto et al. 2013; Galotti 2014).

2. Materials and methods

The development of a method for Gestalt evaluation of biocrystallization patterns followed a previously described three-phase approach (Niemeijer & Baars 2004), adapted for using biocrystallization patterns. These phases entail the selection and prioritization of the Gestalts to be developed, the characterization of the prioritized Gestalts and finally the creation of a measurement instrument (Figure 1).

2.1 Selection and characterization of the Gestalts

The process started with an inventory of Gestalts that could be developed. For this, biocrystallization patterns obtained from different agricultural products representing different Gestalt categories were presented to the project group. These categories included plant organ types [e.g. root, leaf, flower, fruit and seed (Geier 2005)] and plant physiological processes [e.g. growth, ripening and decomposition (Bloksma et al. 2007; Fritz et al. 2011)]. Prioritization of the Gestalts to be developed was based on group-consensus and the availability of reference material which is a prerequisite for the development of a method. Reference material consisted of glass plates with biocrystallization patterns from a defined origin (see below), which were stored under standardized conditions (26°C, 53% humidity). For the characterization of the prioritized Gestalts, biocrystallization patterns connected to these Gestalts were collected. Patterns originating from diverse agricultural products were selected, exhibiting extensive morphological variations as a Gestalt represents a characteristic which can manifest morphologically in diverse ways (Bortoft 1996; Parnas 2012; van der Bie 2012; Nordgaard et al. 2013).

In accordance with the followed methodology (Niemeijer & Baars 2004), concept mapping was applied for the actual Gestalt characterization. Concept mapping can be used to organize the perception of a group of people towards a complex issue (here Gestalt) in a structured manner (Swanborn 1999). First the prevailing perceptions of the participants were made clear and the characterizing features were inventoried. Features were restricted to the three levels of evaluation criteria in concordance with Huber et al. (2010). This was followed by a prioritization of relevant features.

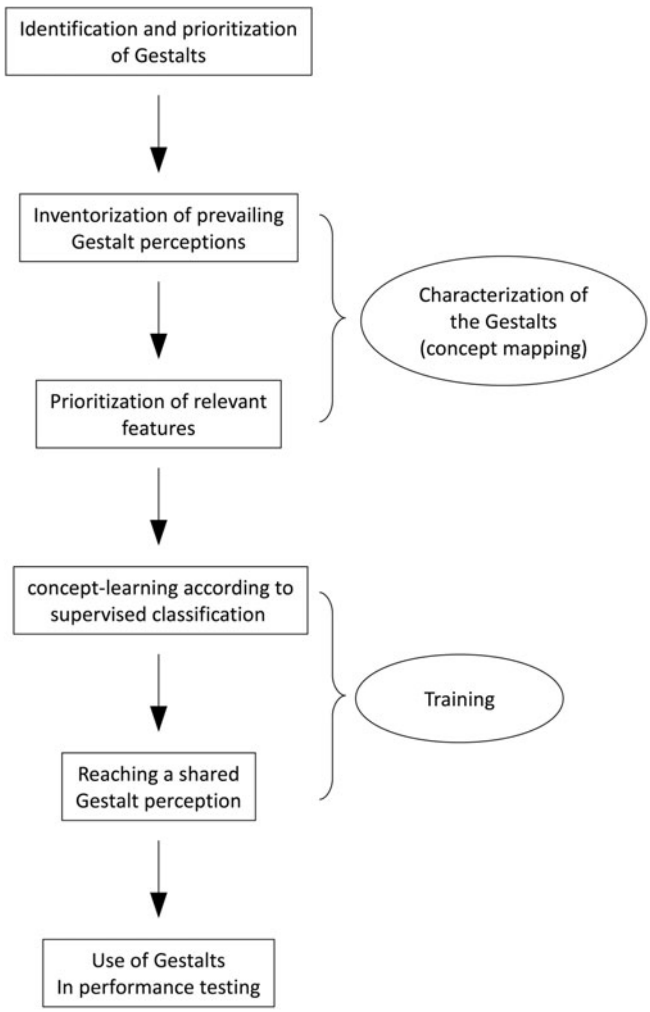

Figure 1. Schematic representation of the process towards a shared Gestalt perception.

These characterizing features were utilized during the successive panel training process in which a common perception of the Gestalts ‘Ripening’ and ‘Decomposition’ was obtained via concept-learning according to supervised classification, i.e. utilizing a feedback-based approach (Ashby & Maddox 2005; Galotti 2014), thereby embracing the Gestalt principles of perceptual organization to recognize the meaningful wholes.

2.2 Developing the measurement instrument

The development of a scientifically acknowledged and communicable method for Gestalt evaluation of biocrystallization patterns builds upon the standardized methodology established for the analytical morphological evaluation [level three (Huber et al. 2010)]. For this standardization process, the main norm for sensory analysis was applied, ISO-Norm 11035 – Sensory Analysis – identification and selection of descriptors for establishing a sensory profile by a multidimensional approach (ISO 1994) and connected ISO norms for specific items [ISO 5492:1992, ISO 6658:1985, ISO 6564:1985, and ISO 8598:1988 (Huber et al. 2007)]. ISO 11035 describes the necessary steps to be taken towards a standardized panel for sensory profiles. This norm was adapted for use in the visual evaluation by modifications from food samples to biocrystallization patterns (Huber et al. 2010). For the development of a measurement instrument for Gestalt evaluation ISO-Norm 8587 – Sensory Analysis – Methodology – Ranking (ISO 2006) was found more appropriate. This norm allows for assessing differences among several samples based on the intensity of an overall impression, which complies more closely with the concept of Gestalt compared with the mono-dimensional descriptor evaluation according to ISO 11035. The norm aims towards placing a series of test samples in a ranking order, which implements the inner order apparent in the prioritized Gestalt 'Ripening', from unripe to ripe to overripe and the Gestalt 'Decomposition', from fresh to decomposed.

According to ISO 8587 the following steps were taken: formation of the panel, collecting biocrystallization reference patterns of the selected Gestalts as reflected in the different agricultural products (see below). Patterns were selected representing a polarity of extremes and, if available, the middle point between the two extremes from the selected agricultural products (see Figures 2 and 3). The panel was trained (see below), panel tests were performed and the tests were statistically evaluated. The norm refers to several normative references which were already taken into account during the development of the methodology for the analytical morphological evaluation of biocrystallization patterns, according to ISO 11035.

2.3 Training and panel tests

A process of concept-learning according to supervised classification (Ashby & Maddox 2005; Galotti 2014) started via email and telephone conferences. Training sets were available as portable document format (PDF) files. These contained, similarly to the developed references for the Gestalts, a polarity of extremes and, if available, the middle point between the two extremes from the diverse plant products. Training sets were presented coded and in random order to the panel. For each Gestalt-plant product combination, a minimum of six training sets were available. For the Gestalt 'Ripening', patterns were selected from carrots, tomato and lettuce. For the Gestalt 'Decomposition', patterns were selected from carrots, cabbage and wheat. For wheat, three mixing ratios of $CuCl_2{\cdot}2H_2O$ and additive per sample were shown; all other products were assessed based on one mixing ratio. An answer form was established where assessors could rank according to the development in time, for the Gestalt 'Ripening' from unripe to ripe to overripe and for the Gestalt 'Decomposition' from fresh to decomposed. During the training the reference pictures could be used, as well as the list of described features.

Two panel tests were performed, in March and June 2011. Training continued as above in between the two panel tests. Each panel test was performed over two days in the sensory laboratory at University of Kassel, Germany, designed according to ISO 8595 1988 about requirements for sensory cabins. The second panel test was performed without the use of the reference pictures and the list of described features. The panel, consisting of nine trained assessors, received simultaneously a minimum of two printed biocrystallization patterns which were presented coded and in random order. The panel was asked to identify the Gestalt concerned and to rank the biocrystallization patterns according to a specified criterion of global intensity, i.e. 'Ripening' or 'Decomposition'. Biocrystallization patterns for references, training and panel tests were obtained from the same experimental

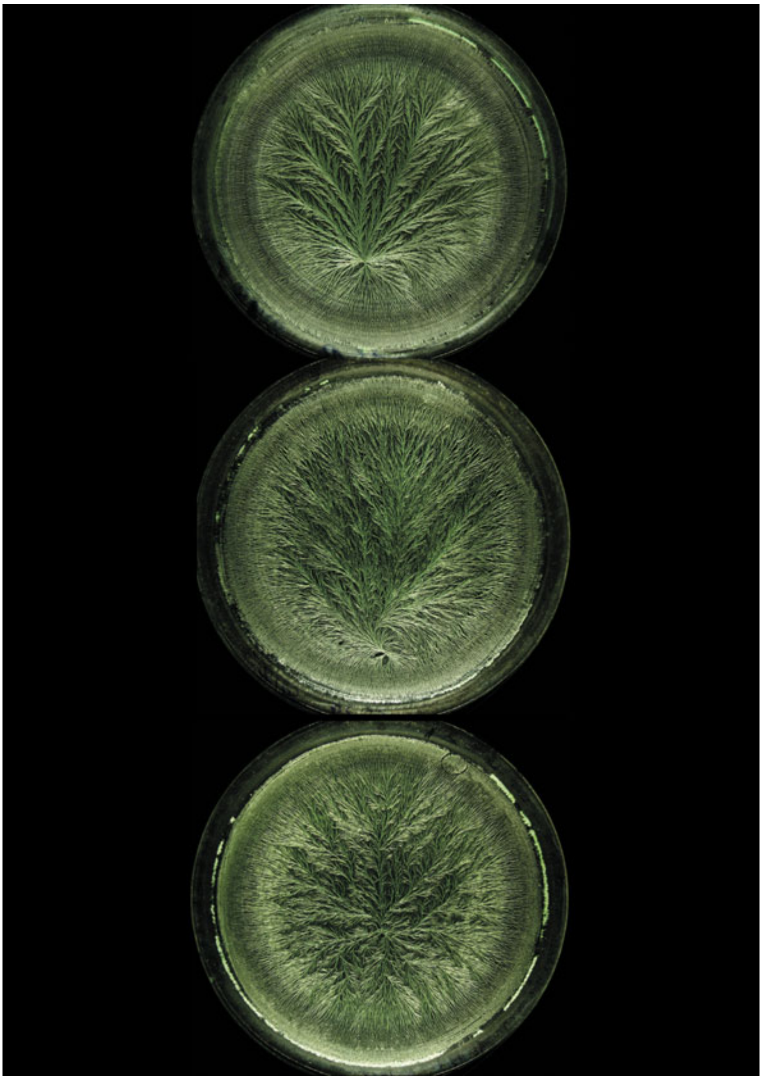

Figure 2. Carrot biocrystallization pattern references for the Gestalt 'Decomposition'. Top, biocrystallization pattern of fresh carrot juice. Middle, biocrystallization pattern of juice after 3 days storage at 4°C; bottom, biocrystallization pattern of juice after 7 days storage at 4°C.

series. To circumvent insufficient numbers of available biocrystallization patterns for the Gestalt 'Ripening' for tomatoes and carrots, a discrete number of patterns was mirrored horizontally and coded differently.

2.4 Statistics

SPSS statistical software (version 19.0, SPSS Inc., Chicago, IL, USA) was used to perform statistical analyses. In the perspective of the standardization of the panel, the agreement between the assessors is of importance, which is in accordance with ISO 8587. Because there are multiple assessors evaluating multiple decomposition and ripening stages, i.e.

Figure 3. Lettuce biocrystallization pattern references for the Gestalt ‘Ripening’. Top, biocrystallization pattern of unripe lettuce, harvest 20 June; middle, biocrystallization pattern of moderately ripe lettuce, harvest 2 July; bottom, biocrystallization pattern of fully ripe lettuce, harvest 21 July.

from fresh to increasingly decomposed and from unripe to increasingly ripe, respectively, an overall measure for agreement between assessors is Kendall’s coefficient of concordance (*W*). The deviation from the ISO-norm’s recommended Friedman test was motivated by the fact that the Friedman test requires a minimum of three decomposition and ripening stages, which exceeded the available number of decomposition stages available for the cabbage biocrystallization patterns. Kendall’s *W* is a non-parametric statistic suitable for quantifying the overall agreement among three or more assessors (Siegel & Castellan 1988; Martin & Bateson 2007). Output ranges between 0 (no agreement) and 1 (complete agreement). The coefficient measures overall agreement but not whether the assessors make correct classifications. Significance of Kendall's *W* can be tested using a transformation to χ^2. The reliability of the panel in discriminating Gestalts was evaluated by determining the percentage of correct identification of the Gestalt concerned and the percentage of correct ranking.

2.5 Origin and processing of samples

2.5.1 Ripening carrots

Carrots cv. Rodelika originated from a field trial at the Domäne, Frankenhausen estate, Germany, comparing two carrot varieties and two levels of *N*-input (0 and 150 kg N ha^{-1}). The design of the trial was described by Fleck et al. (2005). Carrots were sown on 23 April 2004 and harvested at three intervals: 22 June, 15 July and 31 August to achieve the ripening stages 'unripe' to 'ripe'. A bulk sample from the 0 kg N ha^{-1} samples was used for analysis. Mixing ratio additive – $CuCl_2{\cdot}2H_2O$ was 70 µl–90 mg, respectively, henceforth denoted as 70–90, in a total volume of 6.0 ml (Busscher, Kahl, Andersen et al. 2010b).

2.5.2 Ripening tomatoes

Tomatoes cv. Vienna from organic origin, produced in a heated greenhouse, were obtained from Gebr. Verbeek BV. (Velden, the Netherlands). Quantification of the developmental stage was performed visually by means of a colour-fan ranging between intensity 1 (green, unripe) to intensity 8 (red, ripe). Bulk samples of fully grown tomatoes were harvested on 19 October 2004 at colour intensities 1, 5 and 8 from the bottom three clusters and left at room temperature for three days. The resulting stages were indicated as 'unripe', 'ripe' and 'overripe'. Tomato pulp, obtained with a Green Star GS-3000 juice extractor (Keimling Naturkost, Germany) was extracted at 50% w/v in 25°C de-mineralized water at 180 rpm for 30 s. The extract was filtered over a 110 µm nylon filter and crystallized at mixing ratios 620–140 and 755–170.

2.5.3 Ripening lettuce

Lettuce cv. Batavia red Mohican originating from a 2008 field trial comparing conventional, organic and biodynamic farming systems (Heimler et al. 2011) was planted on 29 May 2008 and harvested at three intervals: 20 June, 2 July, 21 July to achieve the ripening stages 'unripe' to 'ripe'. Lettuce was juiced (juicer Porkert Model 532, J. Porkert a.s., Prague, Czech Republic), filtered with paper filters grade 604 (Schleicher & Schuell, Dassel, Germany) and crystallized at mixing ratios 400–150, 500–150 and 600–150 on each harvest date.

2.5.4 Decomposition carrots

Organically cultivated carrots were bought on 19 August 2002 in a local organic food store (Tegut, Witzenhausen, Germany) one day before the study. Carrot juice was prepared in three different ways; with the Green Star GS-3000 juice extractor (Keimling Naturkost, Buxtehude, Germany) fitted with either the light- or heavy-resistance spring and with the Champion juicer (Keimling Naturkost, Buxtehude, Germany). The juice was sieved over a 110-µm nylon filter and left to stand for 20 min. at room temperature. Freshly prepared carrot juice was crystallized at a mixing ratio of 50–50, after which the remainder was stored in sterilized centrifugal tubes at 4–6°C in the dark and crystallized again on days 3 and 7 (Busscher, Kahl, Andersen et al. 2010b). The training and examination sets utilized biocrystallization patterns originating from the juice from all three juice extractors. The minor differences observed due to the different juice extractors were believed to aid the gaining of conceptual flexibility.

2.5.5 Decomposition cabbage

Cabbage cvs. Premstaettner Schnitt, Zehetbauer and Unterpfleichfelder originating from Dottenfelderhof (Bad Vilbel, Germany) were harvested on 6 November 2003. The cabbage samples were juiced (Porkert Model 532, J.Porkert a.s., Prague, Czech Republic), filtered with paper filters grade 604 (Schleicher & Schuell, Dassel, Germany) and crystallized at mixing ratios 150–150, 200–150, 250–150 and 300–150 on 11 November 2003, after which the remainder filtrate was stored in sterilized centrifugal tubes at 4–6°C in the dark and crystallized again on day 3.

2.5.6 Decomposition wheat

Wheat cv. Titlis originating from the DOK (biodynamic [D], organic [O] and conventional [K for German: 'konventionell']) trial in Switzerland (Mäder et al. 2002), was sown on 4 November 2004 and harvested at full maturity on 23 July 2005. The samples from the five different cultivation methods, Bio-dynamic, Bio-organic, Integrated, Integrated no manure and Unfertilized consisted of bulk samples of the four field replicates. Freshly prepared meal from the five samples was extracted at 16.7% w/v in 28°C distilled water for 3.5 h, filtered with paper filters grade 604 (Schleicher & Schuell, Dassel, Germany) and crystallized at mixing ratios 330–50, 360–150 and 390–150 (Fritz et al. 2011). The remainder was stored in sterilized centrifugal tubes at 4–6°C in the dark, and crystallized again on days 3 and 12 to determine the rate of decomposition relative to the cultivation method.

Patterns were removed from the selected series exhibiting technical failures, e.g. multi-centredness, recrystallization and/or an extreme nucleation time. With respect to the latter, visual evaluation and structural image analysis of biocrystallization patterns showed there is a marked, reproducible variation of morphological criteria in relation to the nucleation time (Busscher, Kahl, Andersen et al. 2010b; Doesburg & Nierop 2013). All biocrystallization patterns were photographed for use in the panel tests (Huber et al. 2010).

3. Results

3.1 Selection and prioritization of the Gestalts

Upon presenting biocrystallization patterns representing different Gestalt categories, the project group decided to focus on the Gestalt category that reflects plant physiological processes, e.g. growth, ripening and decomposition (Bloksma et al. 2007; Fritz et al. 2011). This was motivated by the fact that these processes are largely defined and allow correlations between biocrystallization patterns and compound analyses. A prerequisite for the development of a method is the availability of reference material, which was taken into account too. Within this category, the following Gestalts were proposed: (1) the influence of nitrogen fertilization levels, (2) light-shadow influences, (3) ripening stages and (4) effects of decomposition. There was a clear preference to continue with the

Gestalts 'Ripening' and 'Decomposition' and to focus on the plant-organ that is connected to food instead of the development of the whole plant. Therefore, Gestalts (1) and (2) were not considered for further analysis.

3.2 Characterization of the prioritized Gestalts

The decision which biocrystallization patterns and experimental series to include in the characterization phase was based on group consensus and two prerequisites. That is, whether the patterns represent clear features and whether there is consistency in the treatment of the product within the theme 'Decomposition'. Within the context of this project, decomposition was performed by cool (4–6°C) storage succeeding semi-sterile juicing or extraction (Busscher, Kahl, Andersen et al. 2010b; Fritz et al. 2011). Within the theme 'Ripening', patterns were selected from carrots, tomato and lettuce. Within the theme 'Decomposition', patterns were selected from carrots, cabbage and wheat.

For the characterization of the Gestalts by concept mapping the project group members provided a description of features that connected to the Gestalts 'Ripening' and 'Decomposition' applicable to biocrystallization patterns of the available products. The Gestalt characterizations were inventoried and relevant features were prioritized (Tables 1–6). This resulted, in concordance with Huber et al. (2010), in three levels of evaluation criteria reflecting a hierarchical complexity: (1) Quantifiable single morphological and local features, (2) Quantifiable, descriptive single morphological features, (3) Gestures or implicit motions in the whole pattern.

3.3 Standardization and reliability of the panel and its development

The agreement between the assessors as a measure for the standardization of the panel was generally very high for both Gestalts over all products tested and showed a consistent improvement in the second panel test (Tables 7 and 8). The agreement ranged from $W = 0.716$ for wheat 'Decomposition' to $W = 1.000$ for carrot 'Decomposition' as well as carrot and lettuce 'Ripening' for the second panel test, the latter W-value indicating complete agreement among the assessors. The reliability of the panel in discriminating Gestalts was evaluated by determining the percentage of correct identification of the Gestalt concerned, i.e. 'Ripening' or 'Decomposition', and the percentage of correct ranking. The percentage of correct identification of the Gestalt concerned was in both

Table 1. Features characterizing increased 'Ripening' as reflected in carrot biocrystallization patterns.

Quantifiable single morphological and local features	Quantifiable, descriptive single morphological features	Gestures or implicit motions in the whole pattern
Increase of fullness of side-needles	Decrease of Flechtwerke	Increase of integration
Decrease of Quernadeln	Increase of substance spirals	Increase of Beweglichkeit
Decrease of the $CuCl_2$ rim in the periphery		Increase of zonality

Note: Nomenclature according to Huber et al. (2010).

Table 2. Features characterizing increased 'Ripening' as reflected in tomato biocrystallization patterns.

Quantifiable single morphological and local features	Quantifiable, descriptive single morphological features	Gestures or implicit motions in the whole pattern
Increase of Quernadeln	Increase of ramifications	Increase of Durchstrahlung, Beweglichkeit and integration from unripe to ripe
Decrease of coarse structural features	Increase of the angle of side needles	Decrease of Durchstrahlung, Beweglichkeit and integration from ripe to overripe
	Connection to periphery increases from unripe to ripe	Decrease of radiality
		Increase of zonal dissolution

Note: Nomenclature according to Huber et al. (2010).

Table 3. Features characterizing increased 'Ripening' as reflected in lettuce biocrystallization patterns.

Quantifiable single morphological and local features	Quantifiable, descriptive single morphological features	Gestures or implicit motions in the whole pattern
Decrease of coarse structural features	Increase of ramifications	Increase of Beweglichkeit
Decrease of Quernadeln		Increase of integration Increase of centre coordination Decrease of radiality Increase of Durchstrahlung

Note: Nomenclature according to Huber et al. (2010).

Table 4. Features characterizing increased 'Decomposition' as reflected in carrot biocrystallization patterns.

Quantifiable single morphological and local features	Quantifiable, descriptive single morphological features	Gestures or implicit motions in the whole pattern
Increase of curly needles 'Crosswise centres' appear Decrease of fullness of side needles	Increase of Flechtwerke	Decrease of integration Decrease of centre coordination Decrease of Durchstrahlung Decrease of zonality

Note: Nomenclature according to Huber et al. (2010).

Table 5. Features characterizing increased 'Decomposition' as reflected in cabbage biocrystallization patterns.

Quantifiable single morphological and local features	Quantifiable, descriptive single morphological features	Gestures or implicit motions in the whole pattern
Increase of Quernadeln 'Crosswise centers' appear	Increase of multi-centredness	Decrease of Beweglichkeit Decrease of integration Decrease of Durchstrahlung Increase of thinning out

Note: Nomenclature according to Huber et al. (2010).

Table 6. Features characterizing increased 'Decomposition' as reflected in wheat biocrystallization patterns.

Quantifiable single morphological and local features	Quantifiable, descriptive single morphological features	Gestures or implicit motions in the whole pattern
Decrease of coarse structural features Decrease of side needles	Increase of Flechtwerke Increase of the angle of side needles	Decrease of integration Decrease of Durchstrahlung Decrease of centre coordination Decrease of Beweglichkeit

Note: Nomenclature according to Huber et al. (2010).

panel tests 100% for all products evaluated. The percentage of correct ranking improved in the second panel test to 85% for wheat 'Decomposition' and 100% for carrot 'Decomposition' and carrot and lettuce 'Ripening'.

4. Discussion

Reviews of comparative studies of the effects of different farming systems on crop and product quality revealed that the biocrystallization method in several studies correctly discriminated the farming systems, but also pointed towards the lack of objective means of evaluation (Woese et al. 1997; Heaton 2001; Siderer et al. 2005). To meet this criticism, computerized image analysis was introduced (Andersen et al. 1999). At present, computerized image analysis is increasingly used in biocrystallization research (Kahl et al. 2009, 2013; Kahl, Busscher, Hoffmann et al. 2014a; Kahl, Busscher, Mergardt et al. 2014b; Busscher, Kahl, Andersen et al. 2010b; Szulc et al. 2010; Baumgartner et al. 2012; Doesburg & Nierop 2013) as it allows the evaluation of large datasets which is necessary for, among others, methodological studies. Nevertheless, visual evaluation remains superior in qualitative interpretative judgements on the food quality of a product (Balzer-Graf 1996; Balzer-Graf et al. 1997; Keller 1997; Fritz et al. 2011, 2013). Visual evaluation is commonly performed by individual experts in a process of comparing biocrystallization patterns obtained from differently treated samples. Interpretation requires relating the differences in pattern features to reference patterns from defined samples. Until recently, however, methodological consensus between the different experts was lacking. A first

Table 7. Agreement between the assessors and percentage correct ranking as a measure for respectively the standardization and the validity of the panel towards the Gestalt 'Ripening'.

Ripening	March panel test	June panel test
Tomato	Three ripening stages; five exam sets $W = 0.678$; $n = 45$; $p < 0.001$; PCR = 90%	Three ripening stages; six exam sets $W = 0.877$; $n = 54$; $p < 0.001$; PCR = 93%
Carrot	Three ripening stages; five exam sets $W = 1.000$; $n = 45$; $p < 0.001$; PCR = 100%	Three ripening stages; six exam sets $W = 1.000$; $n = 54$; $p < 0.001$; PCR = 100%
Lettuce	Three ripening stages; four exam sets $W = 0.973$; $n = 36$; $p < 0.001$; PCR = 98%	Three ripening stages; six exam sets $W = 1.000$; $n = 54$; $p < 0.001$; PCR = 100%

Notes: Exam sets consisted of coded biocrystallization pattern prints reflecting three successive ripening stages presented in random order. A panel consisting of nine trained assessors was asked to identify the Gestalt concerned (i.e. 'Ripening' or 'Decomposition') and to rank the biocrystallization patterns according to the development in time, for the Gestalt 'Ripening' from unripe to ripe to overripe. W: Kendall's coefficient of concordance as an overall measure for agreement between assessors, n: number of evaluations performed, *p*: significance, PCR: percentage correct ranking.

fundamental step towards an objective means of visual evaluation was the standardization and validation of a visual evaluation panel based on defined morphological criteria, according to adapted ISO-Norms for sensory analysis (Huber et al. 2010). The present study was undertaken with the aim to extend this analytical morphological level of biocrystallization pattern evaluation towards the perception of salient 'meaningful wholes' or Gestalts in the patterns relating to plant physiological processes.

Two Gestalts, 'Ripening' and 'Decomposition', reflected in biocrystallization patterns from diverse agricultural products were characterized, trained on and examined. Based on the statistical evaluation, it is concluded that the panel has become reliable and appropriate for ranking biocrystallization patterns derived from diverse agricultural products according to the intensity of the perceived Gestalts 'Ripening' and 'Decomposition'. The agreement between the assessors, evaluated as Kendall's coefficient of concordance, showed a consistent improvement over all products tested in the second panel test, which most likely points to the iterative effect of a prolonged period of concept-learning.

The potential of the biocrystallization method lies within its susceptibility to characteristic qualitative traits of the additive in question, influencing the overall morphology of the crystallization patterns. These traits comprise for instance the degree of ripening, the effect of processing, feeding regime and production system (Weibel et al. 2001; Kahl et al. 2009, 2013; Busscher, Kahl, Andersen et al. 2010b; Szulc et al. 2010; Fritz et al. 2011, 2013; Seidel et al. 2013). This susceptibility is also evident for laboratory procedure parameters such as the nucleation time and the mixing ratio $CuCl_2{\cdot}2H_2O$ – additive (Andersen et al. 2003; Busscher, Kahl, Doesburg et al. 2010a; Doesburg & Nierop 2013). Consequently, conceptual flexibility is a prerequisite for the applicability of Gestalt perception of biocrystallization patterns. The additives examined in this study imbued the biocrystallization patterns with extensive morphological variation due to variations in plant variety, production system, laboratory processing technique, nucleation time and mixing ratio. Nevertheless, the panel's ability to rank the biocrystallization patterns correctly according to the Gestalt concerned, and according to the ranking of the development in time, proved to be generally very high over all products tested. This indicates that the panel did indeed reach a considerable level of conceptual flexibility in the applied Gestalts.

Table 8. Agreement between the assessors and percentage correct ranking as a measure for respectively the standardization and the validity of the panel towards the Gestalt 'Decomposition'.

Decomposition	March panel test	June panel test
Cabbage	Five samples; two categories; two decomposition stages; five exam sets; $W = 0.751$; $n = 45$; $p = 0.000$; PCR = 93%	Six samples; two categories; two decomposition stages; six exam sets; $W = 0.857$; $n = 54$; $p = 0.000$; PCR = 96%
Carrot	Five samples; 3 categories; 3 decomposition stages; five exam sets; $W = 0.958$; $n = 45$; $p = 0.000$; PCR = 97%	Six samples; 3 categories; 3 decomposition stages; six exam sets; $W = 1.0$; $n = 54$; $p = 0.000$; PCR = 100%
Wheat	Four samples; three categories; three decomposition stages; 4 exam sets; $W = 0.447$; $n = 36$; $p = 0.000$; PCR = 72%	Six samples; three categories; three decomposition stages; six exam sets; $W = 0.716$; $n = 54$; $p = 0.000$; PCR = 85%

Notes: Exam sets consisted of coded biocrystallization pattern prints reflecting two to three successive decomposition stages presented in random order. A panel consisting of nine trained assessors was asked to identify the Gestalt concerned (i.e. 'Ripening' or 'Decomposition') and to rank the biocrystallization patterns according to the development in time, for the Gestalt 'Decomposition' from fresh to decomposed. W: Kendall's coefficient of concordance as an overall measure for agreement between assessors, n: number of evaluations performed, *p*: significance, PCR: percentage correct ranking.

The comparatively low percentage of correct ranking in wheat 'Decomposition' for the first and second panel test, 72% and 85%, respectively, is reflected in a slightly impaired panel agreement (Kendalls *W* respectively 0.447 and 0.716), which, however, cannot be ascribed to a single outlying evaluator. This indicates a general reduced perception of the development in time of the decomposition process, as reflected in wheat biocrystallization patterns. Whether the decomposition steps were not stringent enough or Gestalt expression in wheat biocrystallization patterns is generally unstable could not be deduced from the present experimental set-up.

Is Gestalt perception in biocrystallization patterns restricted to experienced assessors? In the authors' experience, peer tutoring can facilitate the process towards acquiring a Gestalt perception in biocrystallization patterns even by relatively inexperienced assessors. Nevertheless, an extensive period of concept-learning is imperative in order to achieve an acceptable level of conceptual flexibility required for a more general application of Gestalt evaluation.

The two characterized Gestalts are both relatively conserved among the biocrystallization patterns analysed in this study. For instance the Gestalt 'Ripening' is characterized by an increase of e.g. the frequency of branching (ramification), the organic curvature and the integration of the form elements in biocrystallization patterns obtained from ripening carrots, tomatoes and lettuce. Conservation of the Gestalt across such diverse plant products suggests that similar physical processes are involved in Gestalt-specific pattern formation. This premise suggests that the Gestalts should relatively easily be transferable to biocrystallization patterns obtained from other agricultural products, as was confirmed already for the Gestalt 'Decomposition' in grape juice biocrystallization patterns (Fritz et al. in preparation). In this respect, it is noteworthy that a theoretical underpinning has been proposed for the frequency of branching in biocrystallization patterns in relation to the viscosity and mean molecular weight of the additive (Busscher et al. 2014).

The standardized morphological evaluation criteria have served the elaboration of a computerized structure analysis (Doesburg & Nierop 2013). The developed algorithm allows a quantification of physically defined morphological (width and length) properties of the biocrystallization patterns with which novel and thus far overlooked morphological features may be identified. This points to a potential reciprocal relationship; visual evaluation driving the development of the structure analysis and vice versa. The development of a computerized Gestalt evaluation mimicking the visual evaluation seems, however, unlikely as the latter depends on the principles of perceptual organization to recognize the 'meaningful wholes', which implies that the resulting 'wholes' may have properties their component parts lack.

The developed level of Gestalt evaluation of biocrystallization patterns provides a standardized and communicable methodological basis towards qualitative interpretative judgements on the food quality of a product, relating to quality concepts based on (plant-) physiological processes (Bloksma et al. 2007; Kahl et al. 2012). Potential fields of application are the authenticity of organic products, the effect of processing treatments and estimating differences in the degree of resilience (ability to regain the balance after a disturbance).

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