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Analytical perception and kinesthetic engagement in evaluation of copper chloride crystallization patterns of wheat, grape juice and rocket samples from conventional, organic and biodynamic cultivation

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Abstract

Background: When a dihydrate cupric chloride solution is crystallized in a petri dish in the presence of extracts of food products, dendritic crystal patterns emerge. The degree of growth, ripening and decomposition of the product is reflected in these patterns as salient unities (gestalts) of phenomenological features. In the present study we evaluated wheat, grape, and rocket (arugula) samples grown under different farming systems, fertilization treatments or horn silica application. The hypothesis of the present study was: samples are more precisely differentiated with a kinesthetic engagement in the perception of the gestalt decomposition than with ranking solely based on analytical criteria**.**

Results: In six out of seven panel tests with three different agricultural products grown with different methods, the following rankings for accelerated decomposability were derived:

i. For wheat: biodynamic < organic < conventional (mineral fertilization and manure) < mineral (mineral fertilization only)
ii. For grapes: biodynamic < organic < conventional (mineral fertilization and compost)
iii. For rocket (arugula): biodynamic < organic < mineral
iv. For rocket (arugula): with horn silica < without horn silica application.

Analytical assessment was compared with kinesthetic priming of the evaluation panel. In six out of seven tests kinesthetic assessments (i) yielded more highly significant differences in ranking between the cultivation methods; (ii) clearly improved matching of the samples in a confusion matrix to the ranking of the cultivation methods; and (iii) generated lower RMSE values.

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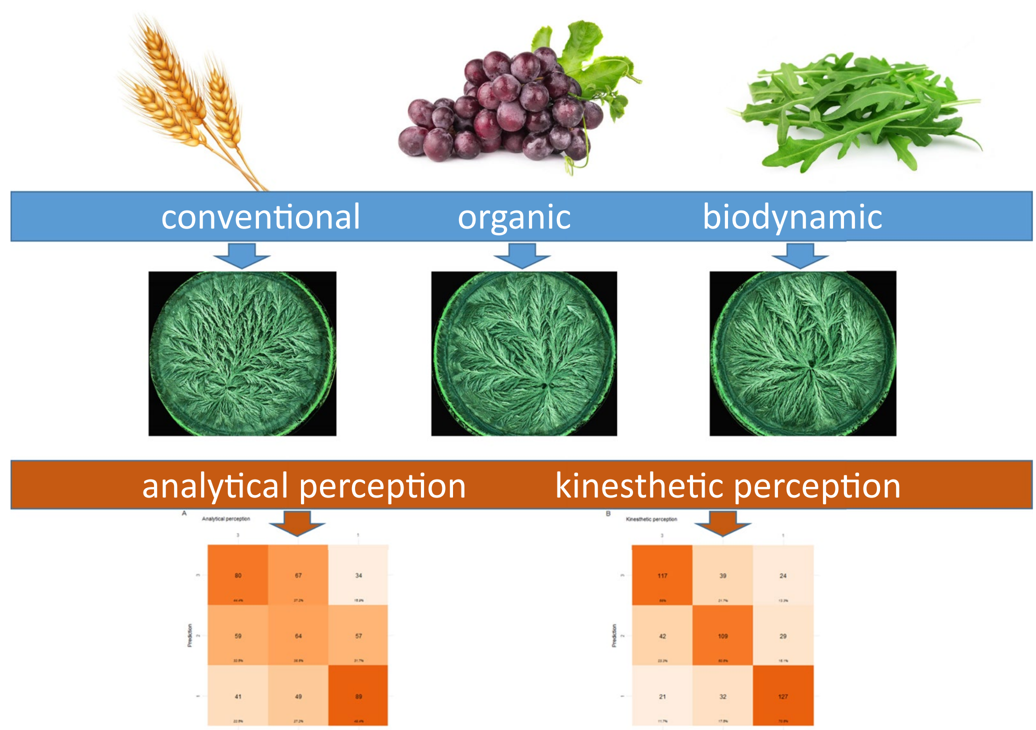
Conclusions: Kinesthetic engagement in gestalt evaluation proved superior to an evaluation based on analytical perception. Highly significant differences between biodynamic and organic variants and also between treatments with and without horn silica application were found in six out of seven tests. In five of the six tests the only difference between organic and biodynamic variants was the application of the biodynamic preparations. The results indicate increased resistance to deterioration of the biodynamic variants, in terms of lower degradation in the crystallization images. This prompts additional research to establish whether the crystallization method can serve as a universal test to monitor the stress resistance of plants.

Keywords: Organic, Biodynamic, Copper chloride crystallization method, Kinesthetic perception, Visual gestalt assessment

Graphical Abstract



Introduction

There is a growing interest in a systems approach to food quality. This interest is triggered by needs for better understanding the interface between nutrition and health [1, 2], and understanding organic food quality [3, 4]. For a long time, health effects of foods have been assigned solely according to their chemical composition, i.e., quantities of health promoting compounds like vitamins or secondary metabolites, or to compounds that may pose a threat to human health like, e.g., nitrate, mycotoxins or acrylamide. However, in the last decade, increasing evidence suggests that not only total amounts, but also bioavailability, bio-absorption and processing of individual compounds in the human body are relevant for human health. These properties have been shown to be linked to the food structural matrix, including its physical, sensorial, and nutritional characteristics [2].

Maintenance of the outer and inner structure of foods is an important aspect of their shelf-life. Aging of whole foods, food extracts, or juices is clearly connected with a loss in quality, on the level of chemical composition (degradation of health promoting compounds), microbiology (increase in the abundance of decomposing microorganisms), and structure (change in physical properties like texture or viscosity). Complementary to direct rating of a food's outer appearance (e.g., color change, signs of microbial mediated decay), resistance to deterioration during aging can also be assessed via evaluating patterns that arise when a food juice or extract is mixed with an aqueous copper chloride solution and allowed to co-crystallize on a Petri dish [5]. Autolytic aging of the food juice or extract is represented by characteristic and reproducible changes in the crystal structures [6, 7]. As opposed to chemical analyses, the resulting crystal structures exhibit properties of the whole food. Basic work on crystallization methods was done by Pfeiffer [8], Selawry & Selawry [9], Engquist [10], Pettersson [11] and Balzer-Graf [12], among others.

Many studies have demonstrated the potential of the crystallization method as an indicator for systemic effects of processing, feeding regime, and production systems across a broad range of agricultural products [3, 6, 13–24]. Kahl et al. [3, 25] discussed validation strategies for systemic approaches to organic food quality determination, including the method of copper chloride crystallization with additives. In the last two decades, these validation strategies stimulated the development of a standardized methodology for crystallization with additives. This addressed sample preparation [14, 25], crystallization conditions [14, 26–28], data evaluation including multivariate statistical analysis of computerized image analysis [19, 29, 30], and visual evaluation using defined morphological criteria [7, 31, 32]. The crystallization method was documented and standardized for several food classes, including apple juice [20], wheat [3, 22], milk [18] and carrots [5].

Nevertheless, there is still a lack of knowledge concerning the physical basis of the pattern formation process. Building upon previous work [33–36], Busscher et al. [37] defined a minimum set of physical parameters to evaluate the basic processes during evaporation and crystallization that influence the overall structure of the copper chloride crystallization patterns, with and without addition of additives [5, 38]. The crystallization patterns depend on the amount and type of additive and the amount of dihydrate cupric chloride [38]. The food sample modulates the conditions affecting dendritic branching, resulting in sample-specific crystallization patterns. The additives influence the structure formation of the cupric chloride crystals without being incorporated into the crystals [37]. When assessing the quality of agricultural products, copper chloride crystallization patterns have been used in conjunction with chemical compound analyses and sensory tasting tests [3, 14, 15, 22, 39]. Using the copper chloride crystallization method, it was possible to visually characterize and rank samples from wheat, carrots, cabbage, tomato and lettuce according to the degree of ripening and tendency to decompose by using coded images [7]. Samples from different cultivation methods could be grouped, characterized and classified according to the criterion associated with decomposition by individual assessors [6, 15, 21, 23, 39, 40] and by an ISO-standardized visual evaluation panel [32, 41]. Conceptually, this relates to estimating the samples' resistance to autolytic deterioration in the sense of 'resilience' (elasticity, capacity to cope) in response to controlled aging of the samples [42].

Although the results from Fritz et al. [32, 40] and Athmann et al. [41] were encouraging, the accuracy varied considerably among panel members, likely due to the different strategies applied by panel members in the perception of the gestalt decomposition. To confirm whether, and if so, which different perceptual strategies were utilized by the different panel members, a qualitative think-aloud methodology was performed [43]. Additionally an "exit interview" was conducted to help interpret the think-aloud utterances.

It became apparent that two perceptual strategies were deployed: (i) analytical perception using mainly 'atomic features' that characterize the gestalt decomposition (predominantly levels 1 and 2 in Table 1) and (ii) a more global perception applying kinesthetic engagement in the

Table 1 Characteristic features of increased decomposition in wheat copper chloride crystallization images based on four levels of evaluation criteria, reflecting a hierarchical complexity

1. Level **Quantifiable single morphological and local features**	**2. Level** **Quantifiable, descriptive single morphological features**	**3. Level** **Gestures or implicit motions in the whole pattern**	**4. Level** **Kinesthetic criteria**
Decrease of coarse structural features	Increase of 'Flechtwerke'	Decrease of integration	Decrease of fluent interconnected movement
Decrease of side needles	Increase of the angle of side needles	Decrease of 'Durchstrahlung'	Decrease of a sense of presence in the image
		Decrease of center coordination	Decrease of tension in the needle branches from the center to the periphery
		Decrease of 'Beweglichkeit'	Decrease of a consistent dynamic in the filling of the plate

Nomenclature level 1–3 according to Huber et al. [31] and Doesburg et al. [7], level 4 according to Doesburg et al. [47]

perception of the gestalt decomposition, with a subsequent confirmatory analytical evaluation.

Kinesthetic engagement is an observer's kinesthetic sensation, or motoric response, towards observed motions or implicit motions of human, non-human and even inanimate objects [44, 45]. Kinesthetic engagement in crystallization image evaluation involves an embodied simulation of the growth, curvature and tension of the tree-like branches of the crystallization images [46]. Noteworthy, the best scoring panel members predominantly utilized the kinesthetic perceptual strategy. Recently, the authors demonstrated that ranking of crystallization patterns of diverse agricultural products according to their degree of induced decomposition could be improved by kinesthetic engagement [47].

The aim of the present study was to determine whether kinesthetic engagement will improve the evaluation of encoded copper chloride crystallization images from conventional, organic, and biodynamic cultivation methods according to the gestalt decomposition. Based on the experience with aging series [47] our first hypothesis was that kinesthetic priming of the panel will improve the performance of the ranking tests. Based on the outcome of previous studies with cultivation methods [6, 15, 21, 23, 32, 39–41] our second hypothesis was that, according to the criterion of increasing decomposition, we expect the tested treatments to rank in the order biodynamic < organic < conventional with mineral fertilization < mineral fertilization.

Materials and methods

Origin of the wheat samples

Wheat grain samples (cv. 'Titlis') were collected from a long-term field trial comparing different farming systems in Oberwil, Switzerland, (the so-called DOK trial) [48] from harvest year 2005. The eight samples consisted of two replicate samples obtained from four different cultivation methods. Both biodynamic (BioDyn) and bioorganic (BioOrg) field plots were fertilized with manure, but these two systems differed among other things in the use of the biodynamic compost and field preparations. Conventional cultivation methods included mineral fertilizer combined with manure (ConFym) or only mineral fertilization (ConMin), respectively. The grain samples tested were mixed samples obtained from the four replicates of the DOK trial [48]. For more detailed descriptions see Fritz et al. [6].

Origin of the grape juice samples

Grape samples from harvest year 2010 were taken from a long-term field trial established at Geisenheim University, Germany, comparing different cultivation methods [49, 50]. The experimental site is a 0.8 ha Riesling vineyard. The vines were planted in 1991 at a spacing of 1.2 m within rows and 2 m between rows. Starting January 2006, the vineyard was divided into replicate plots of conventional (mineral fertilization and compost; Conv), organic (BioOrg) and biodynamic (BioDyn) viticulture (both EU 834/07) in a randomized block design with 4 field replications. The organic and the biodynamic treatment differed only in the application of the biodynamic preparations. For more detailed descriptions, see Fritz et al. [15].

Origin of the rocket samples

The rocket samples (*Eruca sativa* L.) were derived from a field trial carried out in autumn 2009 at the Wiesengut experimental farm of the University of Bonn. The experimental design was a randomized four factorial split plot design with 4 field replications and the factors i. light intensity (100% photosynthetically active radiation PAR or 55% PAR); ii. N supply (low: 15 kg N/ha or high: 60 kg N/ha; iii. fertilizer type (mineral (ConMin); organic: composted cow manure (BioOrg); biodynamic: composted cow manure with biodynamic compost preparations (BioDyn)); iv. horn silica (with or without). In the present study, only the factors fertilization type and horn silica application (organic samples with or without horn-silica) were considered. The organic and the biodynamic treatment differed only in the application of the biodynamic preparations. For more detailed descriptions, see Athmann [13, 41].

Autolytic decomposition and copper chloride crystallization methods

For the wheat samples, 5 g of wheat whole flour was extracted with 25 ml distilled water and incubated at 28 °C for 3.5 or 14 h. Subsequently, samples extracted for 3.5 h at 28 °C were stored at 8 °C for 3, 8 and 12 days or for 14 h at 28 °C before crystallization. Grape juice was pressed at Geisenheim University, then stored for 1, 2, 3, 5 and 6 days at 5 °C before being crystallized. The rocket leaves were pressed. The pressed rocket juice was stored for 1, 4, 6 and 10 days at 4 °C before being crystallized. For more detailed methodological descriptions see Fritz et al. [6, wheat], Fritz et al. [15, grape juice] and Athmann [13, rocket]. All samples were co-crystallized in the crystallization laboratory at the University of Bonn, Germany. After crystallization, all images were photographed and printed on paper for visual evaluation.

Basics of visual evaluation

In order to evaluate crystallization images, a visual evaluation panel was formed and validated according to ISO-norm 11,035 (establishing sensory profiles by a multidimensional approach) [31, 51]. A set of analytical morphological descriptors were selected and defined. This analytical morphological level of evaluation was subsequently extended towards the perception of crystallization pictures which appear as coherent 'meaningful wholes' or gestalts [7]. Here, ISO 8587 [52] "Sensory Analysis–Methodology–Ranking" was adapted for the development of a ranking for gestalt evaluation. The norm aims at placing a series of test samples in a ranked order based on the intensity of an overall impression. This was utilized for evaluating the crystal gestalts associated with co-crystallizations with fresh to fully decomposed products. The modified ISO 8587 procedure was described by Doesburg et al. [7]. In the present study, the decomposition of gestalt was assessed in order to rank crystallization images of wheat, grape juice and rocket leaves that originating from the field trials testing biodynamic, organic, and conventional management. The use of the gestalt decomposition in this context is tenable within the framework of organic agriculture and food quality research, which argues that the coherence or resilience of organisms is influenced by production measures, including the agricultural management system [53].

The training of the panel to evaluate gestalt decomposition was described in detail by Doesburg et al. [7] and Fritz et al. [32]. Briefly, crystallization pictures from fresh and aged samples (Table 1, Fig. 1) were used to characterize the decomposition of the gestalts for different products. These aging series were used as references. The perception of gestalt decomposition was practiced on these decomposition series. Subsequently, for the tests, evaluation sets containing crystallization images originating from the available treatments were used. For each treatment, three crystallization images were presented to the visual evaluation panel, each comprising three increasing additive amounts (Fig. 2). For the assessment, the gestalt of the images was perceived and assessed on the basis of the practiced series of decomposition. The crystallization images used for training and panel tests were obtained from the same experimental series according to ISO-norm 11,035 [51].

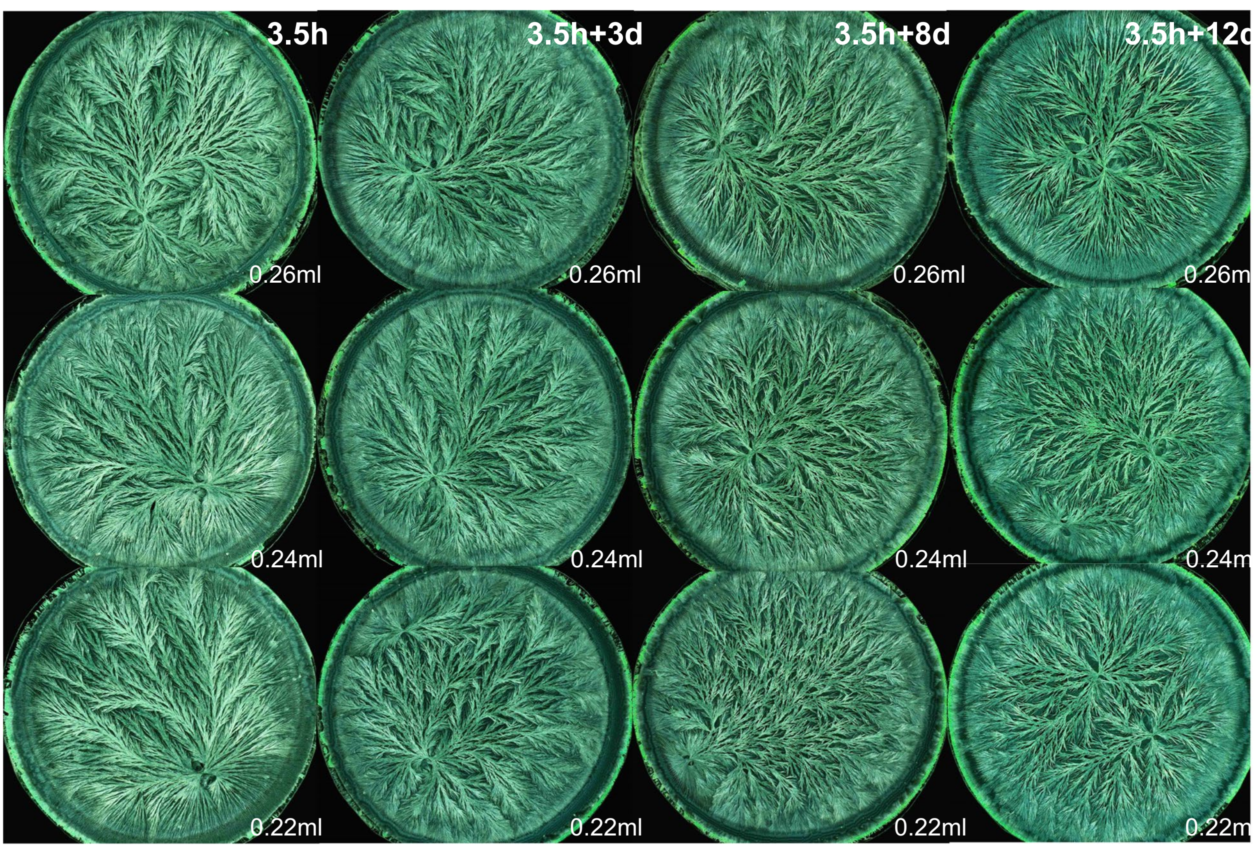


Fig. 1 Example crystallization images of wheat with increasing intensity of controlled decomposition (3.5 h and additional 3 d, 8 d and 12 days storage of the wheat extract). Per plate, the amount of $CuCl_2$ $2H_2O$ was 160 mg and the amount of wheat extract was 0.22 ml, 0.24 ml and 0.26 ml, respectively. The images were made from one sample from the conventional production method

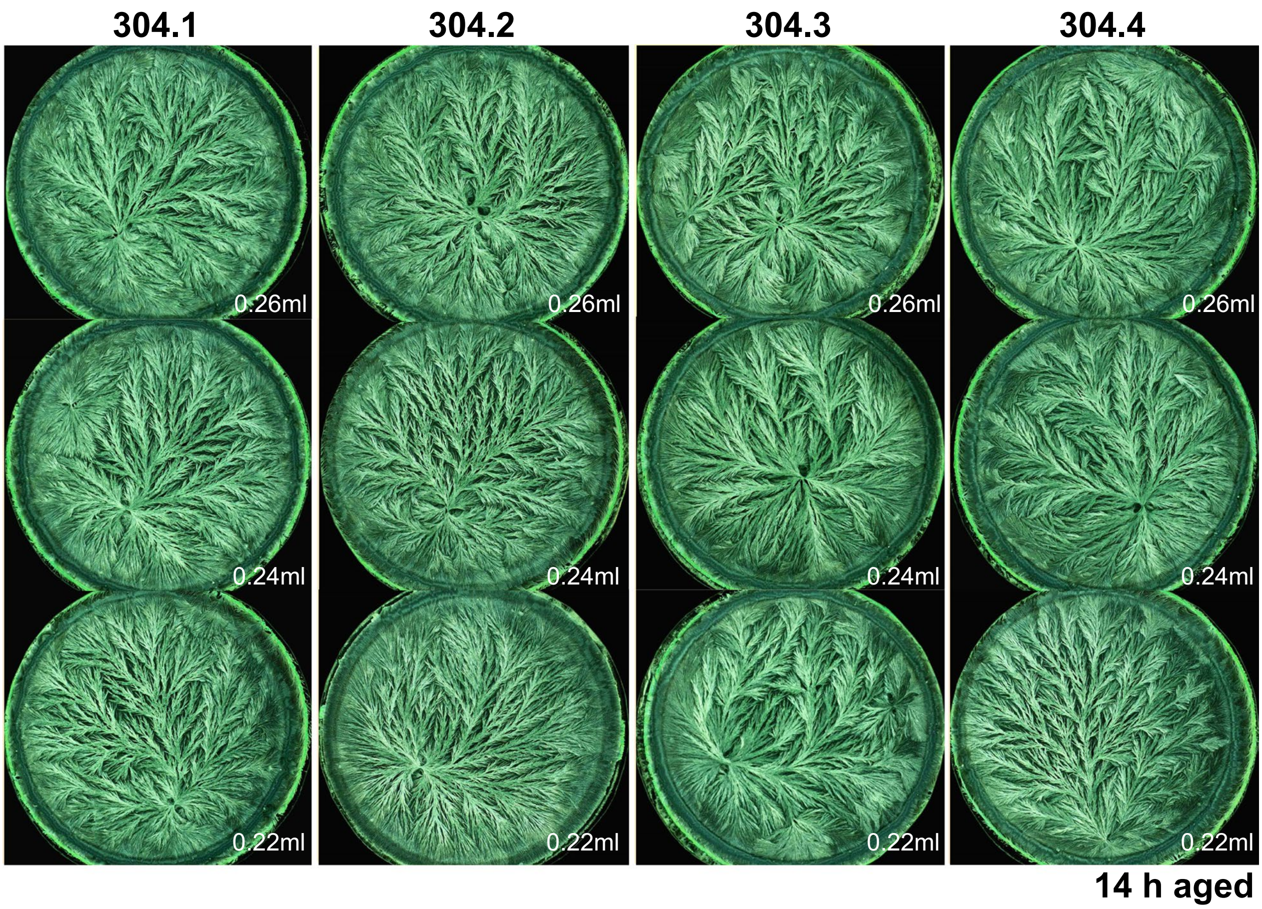


Fig. 2 Example of an evaluation set for the ranking of encoded wheat crystallization images (14 h aged) originating from four different cultivation methods. Image coding is as follows: 304.1 = ConFym, 304.2 = ConMin, 304.3 = BioDyn, 304.4 = BioOrg. The amount of extract per image was 0.22 ml, 0.24 ml, 0.26 ml. All images contained 160 mg $CuCl_2$ $2H_2O$ per plate

Visual evaluation—training and exam

Consensus training was initiated via email and telephone conferences. The encoded training sets were given to the panel in random order as PDF (Portable Document Format) files. Images included three different ratios of $CuCl_2 \cdot 2H_2O$ and additive per sample (e.g., Fig. 2). The images were ranked by each panel member independently according to the perceived intensity of the gestalt decomposition. During the training in six sessions over 6 weeks, the pictures were subsequently decoded in order to discuss discrepancies in interpretation and to reach a full consensus in the ranking.

Panel tests (exams) were performed for wheat on April 4–6 2016 and repeated on October 4–5 2016; for grape juice on April 3–5 2017; for rocket on March 13–14 2018 and repeated on September 27–28 2018 for the ranking of the respective treatments (according to the criterion of increasing decomposition). Before the second test for each food product, which typically occurred 6 months after the first exam, the panel received additional training that occurred over six sessions over 6 weeks. Each panel test was performed in isolated compartments in the Sensory Testing Laboratory at the University of Kassel, Germany, in accordance with ISO 8589 [54]. The wheat panel tests consisted of 14 sets, the grape juice panel tests consisted of 30 sets (15 sets printed in the original layout and 15 sets where the pictures were mirrored on the vertical axis), the rocket panel tests consisted of 16 sets for the ranking of the fertilizer treatments and 32 sets for the ranking of the horn silica treatments.

Analytical perception and kinesthetic engagement in gestalt evaluation

The effect of contextual sensitivity in the visual evaluation of crystallization images originating from different farming methods was tested by comparing subjects' performance while primed according to the two perceptional strategies (analytical vs. kinesthetic engagement), as described previously for decomposition series by Doesburg et al. [47]. Subjects were assigned randomly to either group A or B. Subjects of group A were instructed to evaluate the crystallization images according to an analytical perceptual strategy (single object recognition) by adhering to the use of 'atomistic features' (i.e., utilizing solely the criteria of the levels 1 and 2 in Table 1). Subjects of group B were instructed to evaluate the images according to a kinesthetic engagement in gestalt perception and a subsequent secondary, confirmatory 'atomistic' evaluation (i.e., mainly levels 3 and 4 in Table 1). On day two, the perceptual strategy was switched between the groups.

Decomposition of the samples was perceivable on all four levels of visual evaluation criteria (Table 1; Figs. 2, 3). On the two levels of single morphological features, decomposition resulted in a decrease of the number and length of the side needles. Additionally, the side needles and branches exhibited a larger ramification angle. In the example given for evaluation of wheat cultivation methods in Fig. 3, the crystallization image of the ConMin sample (Fig. 3) failed to form any clear branches. On the gesture level (Table 1; Level 3), a decrease was observed in the coordination ability from the crystallization center, in combination with a decrease in the perradiation and the organic curvature. The needle branches became less apparent, and were less able to extend to the periphery of the dish. On the level of kinesthetic criteria, a loss of tension in the needle branches running from the center to the periphery and a decrease of a consistent dynamic in the filling of the plate was notable.

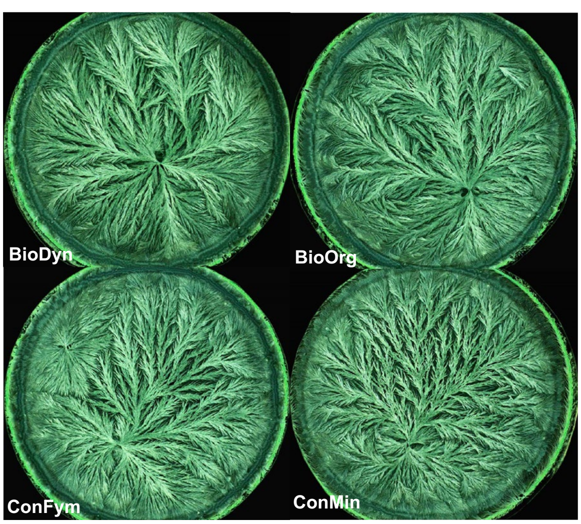


Fig. 3 Decoding of exemplary crystallization pictures of wheat of Fig. 2 to illustrate the criteria of Table 1. The amount of extract per image was 0.24 ml and 14 h aging. All images contained 160 mg $CuCl_2$ $2H_2O$ per plate

Statistical analysis

SPSS statistical software (version 19.0, SPSS Inc., Chicago, IL, USA) was used to perform statistical analyses. The average rank order of the samples was calculated. As recommended in ISO 8587 [52], the Friedman test was applied for ranking. "In a very general manner, this test gives the maximum opportunities for demonstrating recognition of differences among the samples by the assessors" [52, p. 6]. In addition to testing the ranking order for significance, the Friedman test was also used for pairwise comparisons between adjacent ranks.

To determine the classification error in the ranking order, the root mean square error (RMSE) was used, calculated on the basis of the subjects' confusion matrices. A confusion matrix is an N x N matrix used for evaluating the performance of the subjects' ranking, where N is the number of target classes. The matrix compares the actual target values with those predicted by the subject. The missclassified outcomes are represented on the off-diagonals of the confusion matrix. Based on the outcome of previous studies [6, 15, 16, 21, 23, 32, 39, 40], target values were defined according to the hypothesized order of increased decomposition: BioDyn < BioOrg < ConFym < ConMin. Additionally, RMSE values were calculated for all other possible orders. The RMSE gives extra weight to larger classification errors compared to the more commonly used mean absolute error. A lower RMSE score indicates a lower classification error.

RMSE scores were evaluated with Rstudio Version 1.3.1093 [55]. "The mean RMSEs for the two perceptual strategies were compared by means of a paired sample t-test from the "rstatix" Rcran package version 0.7.0 (https://www.rdocumentation.org/packages/rstatix). Graphs were plotted with the RStudio packages "ggplot2" version 3.2.1 [56] "ggpubr" version 0.4.0 (https://www.rdocumentation.org/packages/ggpubr), and "cvms" version 1.2.1 (https://www.rdocumentation.org/packages/cvms/versions/0.2.0)" [47].

Results

Ranking wheat production methods according to the perceived degree of decomposition

In the first wheat exam in April 2016, the perceived degree of decomposition by both priming groups yielded the ranking order (from fresh to decomposed): BioDyn < BioOrg < ConMin < ConFym, which conflicted with the hypothesized ranking. The differentiation between the BioOrg and ConMin samples was highly significant (post hoc pairwise comparison $p < 0.001$; Appendix Table 6). Post hoc pairwise comparisons between BioDyn and BioOrg or ConFym and ConMin was not significant for either type of perceptual priming. The summed classifications of the evaluation panel were plotted in confusion matrices to assess the effect of perceptual priming (Appendix Fig. 8). The overall degree of consensus between the classification increased tendentiously in response to a kinesthetic priming of the panel (p = 0.44; Appendix Fig. 9). This is reflected in a slightly lower RMSE value for the kinesthetic priming results (0.838) than analytical priming (RMSE = 0.926; Appendix Fig. 9), which can also be deduced from the decreased coloring of the off-diagonals of the confusion matrix (Appendix Fig. 8).

Motivated by the results of the best performing evaluators during the wheat exam, in October 2016, panel training in analytical perception and kinesthetic engagement in gestalt evaluation of wheat crystallization pictures was augmented with 6 additional online sessions over 6 weeks. In the second exam, 6 months later, the ranking of the cultivation methods according to increasing decomposition changed for both types of perception, such that the ranking corresponded to the hypothetical ranking: BioDyn < BioOrg < ConFym < ConMin (Table 2). The confusion matrix depicts a clearly improved matching of the samples to the cultivation methods with kinesthetic priming (Fig. 6a). The mean RMSE values of the two perceptual strategies were significantly different (p = 0.047; Fig. 7). The lower RMSE value for kinesthetic engagement (0.681) indicated a significantly lower classification error than analytical priming (RMSE = 0.919; Fig. 7a). This can also be seen in the lighter color of the off-diagonals of the confusion matrix in kinesthetic perception compared to analytic perception (Fig. 6a). With analytical perception, only the cultivation methods BioOrg versus ConFym could be significantly separated in ranking decomposition (Table 2). With kinesthetic engagement in gestalt evaluation, all cultivation methods could significantly be distinguished in the hypothesized ranking order. The error rate of classification using kinesthetic gestalt perception decreased for the second exam to 7% on average (Table 2). The results of the wheat exam in October 2016 supported the working hypothesis of the current investigation.

Ranking grape juice production methods according to the perceived degree of decomposition

In a grape juice examination performed in April 2017, the ranking of decomposition in cultivation methods was the same for both types of perception: BioDyn < BioOrg < Conv (Table 3, Fig. 4a). With analytical perception, significant differences were observed only for the variants BioDyn and BioOrg (Table 3). Kinesthetic priming of the panel resulted in highly significant differences for all variants according to the hypothesized correct ranking order. Compared to analytical perception, the error of the assignment BioDyn and BioOrg versus Conv decreased from 55 to 37% with kinesthetic engagement in gestalt evaluation.

Table 2 Results of the wheat exam in October 2016

Perceptual strategy	BioDyn	BioOrg	ConFym	ConMin	Error classification BioDyn+BioOrg vs. ConFym+ConMin
Analytical	**perception**				
Person 1-6	**1.58**	**1.92**	**3.20**	**3.33**	**15 %**
Pairw. comp.	└> *p*=0.076 <┘	└> *p*<0.001 <┘	└> *p*=0.528 <┘		
(Analytical)	**+ kinesthetic engagement in gestalt evaluation**				
Person 1-6	**1.36**	**1.93**	**3.12**	**3.60**	**7 %**
Pairw. comp.	└> *p*=0.004 <┘	└> *p*<0.001 <┘	└> *p*=0.017 <┘		

Ranking of crystallization images by analytical and kinesthetic perception according to the perception of increasing decomposition

Post hoc Friedman test pairwise comparisons were performed between adjacent ranks when applicable

BioDyn biodynamic, *BioOrg* bioorganic, *ConFym* conventional mineral fertilizer + manure, *ConMin* conventional mineral fertilizer

Table 3 Ranking of grape juice crystallization images according to increasing decomposition during the analytical perception and kinesthetic engagement exams in April 2017

Perceptual strategy	BioDyn	BioOrg	Conv	Error classification BioDyn+BioOrg vs. Conv
Analytical	**perception**			
Person 1-6	**1.69**	**2.10**	**2.22**	**55 %**
Pairw. comp.	└> $p<0.001$ <┘	└> $p=0.257$ <┘		
(Analytical)	**+ empathic gestalt perception**			
Person 1-6	**1.43**	**2.04**	**2.53**	**37 %**
Pairw. comp.	└> $p<0.001$ <┘	└> $p<0.001$ <┘		

Friedman test pairwise comparisons were performed between adjacent ranks

BioDyn biodynamic, *BioOrg* bioorganic, *Conv* conventional—mineral fertilizer and compost

The significantly lower RMSE value for kinesthetic engagement (RMSE = 0.742) indicated a lower classification error than analytical priming (RMSE = 0.989; $p = 0.039$; Fig. 7b). This can also be seen in the reduced coloring of the outer diagonals of the confusion matrix in kinesthetic perception compared to analytic perception (Fig. 6b). The confusion matrix indicates a considerably better classification of the samples when the panel is primed according to a kinesthetic perception. The results of the grape juice exam in April 2017 supported the working hypothesis.

Ranking rocket fertilization treatments according to the perceived degree of decomposition

Coded pictures of three fertilization methods of rocket (Fig. 4b) were ranked according to the criterion of increasing decomposition during two exams occurring 6 months apart. After the first exam, there were six additional online training sessions provided over 6 weeks. The Friedman test revealed no significant differences in the analytical perception of rocket crystallization images for either exam. The error of the classification of the two organic variants compared to the conventional variant was with 65% and 70%, close to the randomly expected classification of 67% (Table 4, Appendix Table 7). Application of kinesthetic perception in gestalt evaluation, led to a ranking of the fertilization methods in the order: BioDyn < BioOrg < ConMin in both exams. The difference between BioDyn and BioOrg was highly significant in both panel tests, whereas the difference between BioOrg and ConMin was not significant. The error in the classification of the two organic variants compared to the conventional variant was 52% in both exams. The additional training before the second exam did not improve the results (Table 4, Appendix Table 7) [41].

The difference in mean RMSE values of the two perceptual strategies in both panel tests were close to the significance threshold ($p = 0.064$; $p = 0.048$). The lower RMSE value of the kinesthetic engagement indicates a lower classification error (Fig. 7c, Appendix Fig. 9b; first panel test RMSE 1.103 versus 0.923 and second panel test RMSE 1.139 versus 0.901 for, respectively, an analytical versus a kinesthetic priming). This can also be seen in the reduced coloring of the off-diagonals of the kinesthetic perception versus analytic perception confusion matrices (Fig. 6c, Appendix Fig. 8b). When comparing the error rate of different samples, it was noticeable that the error rate was much higher for rocket than for wheat, implying that the panel experienced significantly more difficulties with the ranking of rocket crystallization images, compared to wheat crystallization images.

Ranking according to decomposition levels—rocket horn silica application

All panel examinations of horn silica treatments (Fig. 5) were consistent with the hypothesized decomposition ranking: with horn silica < no horn silica (Table 5,

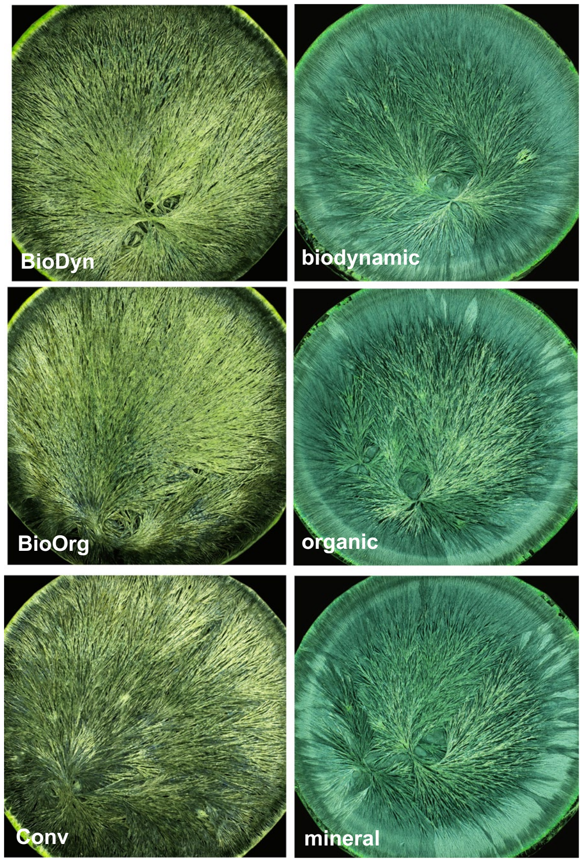


Fig. 4 Crystallization pictures of grape juice (left) and rocket juice (right) to illustrate the criteria of Table 1. The amount of extract per image was **a** grape juice 0.24 ml, after 3 days of juice aging, and **b** rocket juice 0.30 ml, after 4 days of juice aging. All grape images contained 160 mg$CuCl_2$ $2H_2O$ per plate and all rocket images contained 150 mg $CuCl_2$ $2H_2O$ per plate

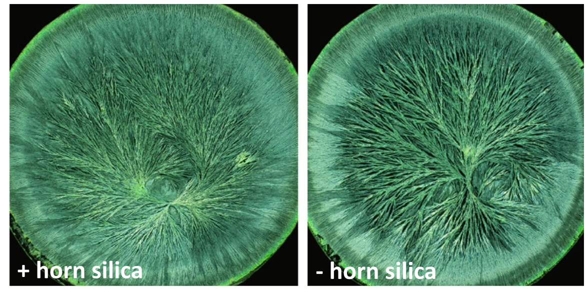


Fig. 5 Crystallization pictures of rocket to illustrate the criteria of Table 1. The amount of extract per image was 0, 30 ml, the juice had been aged for 4 days. All images contained 150 mg $CuCl_2$ $2H_2O$ per plate

Appendix Table 8). Using analytical perception only, differentiation between the crystallization images of the two variants was significant in both exams (Table 5, Appendix Table 8). The error in classification was 43% in both panel tests. With additional kinesthetic engagement in gestalt evaluation, the difference was highly significant in both panel tests, with an error in classification of 30% and 29%, respectively. The two exams, performed 6 months apart yielded very similar results, suggesting that the additional training had no impact on image evaluation of these treatments [see also 41].

In both exams, the assignment of samples to horn silica variants was improved with kinesthetic engagement compared to analytical perception, as can be observed in the confusion matrices (Fig. 6d, Appendix Fig. 10). The two perceptual strategies were significantly different in the first exam ($p=0.022$) and just above the significance level in the second exam ($p=0.053$; Fig. 7d, Appendix Fig. 11). For both test dates, the lower mean RMSE values achieved with kinesthetic engagement (0.540 and 0.522) compared to analytical perception (0.656 and 0.638) indicate improved classification of the crystallization images to their respective treatment (Fig. 7d, Appendix Fig. 11).

Discussion

Perception in evaluation and accuracy of the results

The current study investigated the potential underlying sources of variability in accurately recognizing patterns of gestalt decomposition in crystallization images of extracts of wheat, grape, and rocket (arugula) by trained and experienced panel members [32]. We questioned whether different perceptual strategies were used among the panel members, and if so, whether the panel could be trained and improved by adopting to the perceptional strategy deployed by the best performing panel members. By means of a qualitative think-aloud methodology [43], it became apparent that two perceptual strategies were deployed: (i) analytical perception using mainly 'atomic features' that characterize the gestalt decomposition (predominantly levels 1 and 2 in Table 1) and (ii) a more global perception applying kinesthetic engagement in the perception of the gestalt decomposition, with a subsequent confirmatory analytical evaluation. Noteworthy is that the best scoring panel members predominantly utilized the global (ii) perceptual strategy. The kinesthetic engagement was previously characterized and added as level 4 to Table 1 [47]. The panel was subsequently trained on the perception of the gestalt decomposition, imbued with kinesthetic criteria.

Recently, the authors demonstrated that an ISO-standardized visual evaluation panel could correctly rank crystallization patterns of diverse agricultural products according to their degree of induced decomposition. Moreover, the panels performance improved by adopting a kinesthetic engagement [47]. In the present study,

Table 4 Ranking of crystallization images according to analytical or kinesthetic perception of increasing decomposition of rocket salad in March 2018

Perceptual strategy	BioDyn	BioOrg	ConMin	Error classification BioDyn+BioOrg vs. ConMin
Analytical	**perception**			
Person 1-8	**1.95**	**1.98**	**2.07**	**64.8 %**
Pairw. comp.	*Test not significant*			
(Analytical)	**+ kinesthetic engagement in gestalt evaluation**			
Person 1-8	**1.59**	**2.14**	**2.29**	**51.6 %**
Pairw. comp.	└> $p<0.001$ <┘	└> $p<0.169$ <┘		

Friedman test pairwise comparisons were performed between adjacent ranks (table taken from Athmann et al. [41])

BioDyn biodynamic, *BioOrg* bioorganic, *ConMin* conventional mineral fertilizer

we examined whether this also holds true for the ranking of products from different cultivation methods. To this end, we compared subjects' performance, based on the perception of the gestalt "Decomposition", while primed according to two perceptional strategies (levels: analytical vs. kinesthetic engagement), according to a within-subject design.

Over a period of three years, a total of seven exams with three different agricultural products and different farming methods were conducted. In April 2016, the first exam of different cultivation methods of wheat yielded no significant differences between the use of analytical perception or kinesthetic engagement in gestalt evaluation approaches. After additional training, the second panel test observed significant differences between the evaluation methods and produced results that were consistent with the hypothesized ranking of wheat decomposition.

Quantifiable atomic features could be significantly distinguished in the ranking of wheat cultivation methods (BioOrg and ConFym; $p<0.001$) in the second panel test, and in the ranking of BioDyn and BioOrg treatments of grape juice in the third panel test ($p<0.001$). In contrast, none of the rocket fertilization methods could be significantly differentiated by the fourth and fifth panels test. The application of kinesthetic gestalt perception improved panel evaluations, such that the second panel test could distinguish all four wheat cultivation methods ($p=0.004$; $p<0.001$; $p=0.017$), the third panel test could differentiate all three grape juice cultivation methods ($p<0.001$; $p<0.001$), and the fourth and fifth panel exams of rocket crystallization images identified significant differences between the biodynamic and the organic fertilization treatment ($p<0.001$). Since the second panel test, RMSE values have indicated that ranking/classification error was consistently lower for kinesthetic evaluations than for analytical evaluations.

In general, the classification of cultivation methods according to the criterion of increasing decomposition was more difficult in all exams than the classification of aging series in Doesburg et al. [47]. It is possible that in the first exam, the panel was not yet sufficiently trained for the selective application of the two types of perception for cultivation methods. Intensive training took place before the second exam with wheat, during which the assessment criteria were further developed. These results suggest that the reliability of visual evaluation of copper chloride crystallization images can be strongly influenced and improved by intensive training. In the last exams with rocket, a repetition of the training did not lead to any further improvement of the results, suggesting that the panel was already well trained and the crystallization images were more difficult to differentiate. From the seven conducted exams, six exams supported the first hypothesis that kinesthetic priming of the panel improved the performance in the ranking tests.

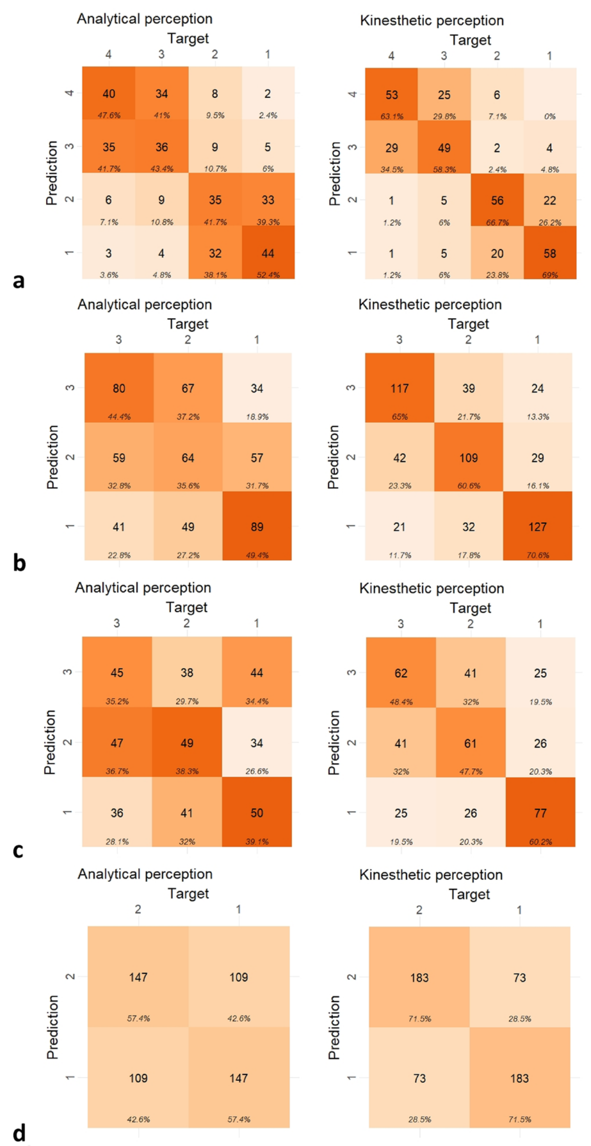


Fig. 6 Confusion matrices for ranking test **a** wheat in October 2016 with classes 1: BioDyn, 2: BioOrg, 3: ConFym, 4: ConMin, **b** grape juice in April2017 with classes 1: BioDyn, 2: BioOrg, 3: Conv, **c** rocket in March 2018 with classes 1: biodynamic fertilization, 2: organic fertilization, 3: mineral fertilization, **d** rocket in September 2018 with classes 1: with horn silica and 2: without horn silica, representing the performance of the panels' summed classifications according to analytical (left) or kinesthetic priming (right). Both the prediction and the target values are given. Each tile contains the number of observations and the column percentage. The diagonal indicates the correct classification counts. Color intensity is based on the number of counts

Ranking of cultivation methods according to gestalt decomposition

The ranking of cultivation methods/fertilization treatments according to increasing decomposition was biodynamic < organic < conventional < mineral in four out of five exams. The ranking ConMin < ConFym was observed only in the first exam, in both types of perception to evaluate crystallization images from wheat. However, the differences were small and not significant. After more training, the ranking of cultivation methods according to increasing decomposition in the second exam with wheat was ConFym < ConMin. With kinesthetic perception, the difference between ConFym and ConMin was significant. This result indicates that intensive training is important for high accuracy of visual evaluation of copper chloride crystallization images.

The combined results generally confirmed our second hypothesis that, according to the criterion of increasing decomposition, the samples were ranked biodynamic < organic < conventional with farmyard manure < mineral. This ranking is in accordance with the results of previous studies with cultivation methods [6, 15, 21, 23, 32, 39–41]. Fewer decomposition criteria in the crystallization images were indicators of higher resistance of the sample to decomposition. High decomposition resistance indicates a high ability to maintain the structure under stress in the sense of "resilience" (elasticity, ability to withstand stress). The experimental results support the concept of food quality, which is expressed in organic farming in a higher stress tolerance and a higher resilience, respectively [42].

Highly significant differences between biodynamic and organic variants were found with kinesthetic perception in the 2nd panel test with wheat, the 3rd panel test with grape juice, and in the 4th + 5th panel test with rocket salad. Also, highly significant differences were found in the 6th and 7th panel test with rocket lettuce and horn silica. In the 3rd to 7th panel tests, the only difference between the biodynamic and organic variants was the application of biodynamic preparations. The results indicate increased resilience of the biodynamic variants in terms of the absence of degradation tendencies in the crystallization images.

Inter-subjective kinesthetic perception

Subjective, kinesthetic perception has previously been shown to result in greater accuracy than analytical perception in the evaluation of copper chloride crystallization images [47]. The visual perception of complex objects is described by two approaches [57, 58]. On the one hand, object recognition occurs via a selective pathway, which corresponds to analytical perception. On the other hand, object recognition occurs via a global perception of the whole image [59]. Kinesthetic gestalt perception is a form of global perception [47]. Kinesthetic engagement means that while observing a movement, the movement is experienced [45]. Kinesthetic engagement can also be

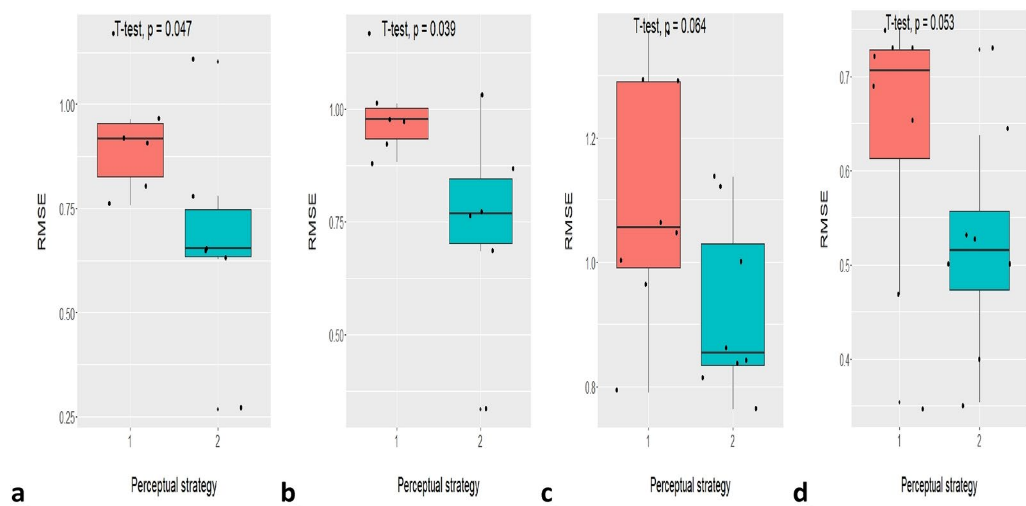


Fig. 7 Mean RMSE values for analytical perception (1) and kinesthetic engagement (2) for **a** wheat cultivation methods in October 2016, **b** grape juice cultivation methods in April 2017, **c** rocket fertilization treatments in March 2018 and **d** rocket horn silica treatments in September 2018

Table 5 Ranking of crystallization images of rocket with or without horn silica treatment according to increasing decomposition via analytical or kinesthetic perception, in September 2018

Perceptual strategy	with Horn silica	no Horn silica	Error classification
Analytical	**perception**		
Person 1-8	**1.43**	**1.57**	**42.6 %**
Pairw. comp.	└> p=0.018 <┘		
(Analytical)	**+ kinesthetic engagement in gestalt evaluation**		
Person 1-8	**1.29**	**1.71**	**28.5 %**
Pairw. comp.	└> p<0.001 <┘		

Friedman test pairwise comparisons were performed between adjacent ranks (table taken from Athmann et al. [41])

experienced while viewing static images exhibiting an apparent movement [44, 45]. In this case, the embodied simulation that underlies kinesthetic perception occurs on the psychological level for which the mirror neuron system provides the underlying neurological basis [44, 60].

In sensory analysis, subjective perception becomes inter-subjective through the training and standardization of a panel [51]. For panel training in visual evaluation of copper chloride crystallization images, ISO standards for sensory analysis were applied to make individual subjective perceptions inter-subjective [7, 47]. The results of the present study suggest that inter-subjective evaluation of kinesthetic perceptions is also possible with crystallization images.

Conclusions

In the present study, kinesthetic engagement in gestalt evaluation improved the classification of cultivation methods of copper chloride crystallization images compared to analytical perception. Encoded copper chloride crystallization images of different cultivation, fertilization or horn silica application treatments were accurately ranked according to the hypothesized order of decomposition (biodynamic < organic < (conventional with farmyard manure) < mineral) in six out of seven tests. These results are consistent with the findings of Doesburg et al. [47], who used kinesthetic perception to evaluate a decomposition series. Kinesthetic engagement in gestalt evaluation can be a useful tool to improve the visual assessment of copper chloride crystallization images.

Less evidence of decomposition in the images indicated greater resistance to decomposition. High aging resistance indicated greater ability to maintain structure under stress. It is therefore an indicator of higher stress tolerance of agricultural products, an important concept of organic food quality [42]. Future experiments should investigate whether the higher decomposition resistance in the crystallization images reflects a higher resistance to decomposition during storage. Possibly, the copper chloride crystallization method can indicate the decomposition or stress resistance ability of plants .

Appendix

See Tables 6, 7 and 8.

Table 6 Ranking of wheat crystallization images according to increasing decomposition in April 2016, based on analytical perception or kinesthetic engagement in Gestalt evaluation

Perceptual strategy	BioDyn	BioOrg	ConMin	ConFym	Error classification BioDyn+BioOrg vs. ConFym+ConMin
Analytical	**perception**				
Person 1-6	**1.57**	**1.79**	**3.19**	**3.45**	**13 %**
Pairw. comp.	└> *p*=0.282 <┘	└> *p*<0.001 <┘	└> *p*=0.189 <┘		
(Analytical)	**+ kinesthetic engagement in gestalt evaluation**				
Person 1-6	**1.49**	**1.82**	**3.33**	**3.36**	**10 %**
Pairw. comp.	└> *p*=0.105 <┘	└> *p*<0.001 <┘	└> *p*=0.857 <┘		

Friedman test pairwise comparisons were performed between adjacent ranks

BioDyn biodynamic, *BioOrg* bioorganic, *ConFym* conventional mineral fertilizer + manure, *ConMin* conventional mineral fertilizer

Table 7 Ranking of crystallization images according to analytical or kinesthetic perception of increasing decomposition of rocket in September 2018

Perceptual strategy	BioDyn	BioOrg	ConMin	Error classification BioDyn+BioOrg vs. ConMin
Analytical	**perception**			
Person 1-8	**1.99**	**2.01**	**2.00**	**70.3 %**
Pairw. comp.	Test not significant			
(Analytical)	**+ kinesthetic engagement in gestalt evaluation**			
Person 1-8	**1.58**	**2.14**	**2.28**	**52.3 %**
Pairw. comp.	└> $p<0.001$ <┘	└> $p<0.261$ <┘		

Friedman test pairwise comparisons were performed between adjacent ranks (table taken from Athmann et al. [41])

BioDyn biodynamic, *BioOrg* bioorganic, *ConMin* conventional mineral fertilizer

Table 8 Ranking of crystallization images of rocket salad with or without horn silica treatment according to increasing decomposition via analytical or kinesthetic perception in March 2018

Perceptual strategy	with Horn silica	no Horn silica	Error classification
Analytical	**perception**		
Person 1-8	**1.43**	**1.57**	**43.4 %**
Pairw. comp.	└> $p=0.034$ <┘		
(Analytical)	**+ kinesthetic engagement in gestalt evaluation**		
Person 1-8	**1.30**	**1.70**	**30.1 %**
Pairw. comp.	└> $p<0.001$ <┘		

Friedman test pairwise comparisons were performed between adjacent ranks (table taken from Athmann et al. [41])

See (Figs. 8, 9, 10 and 11)

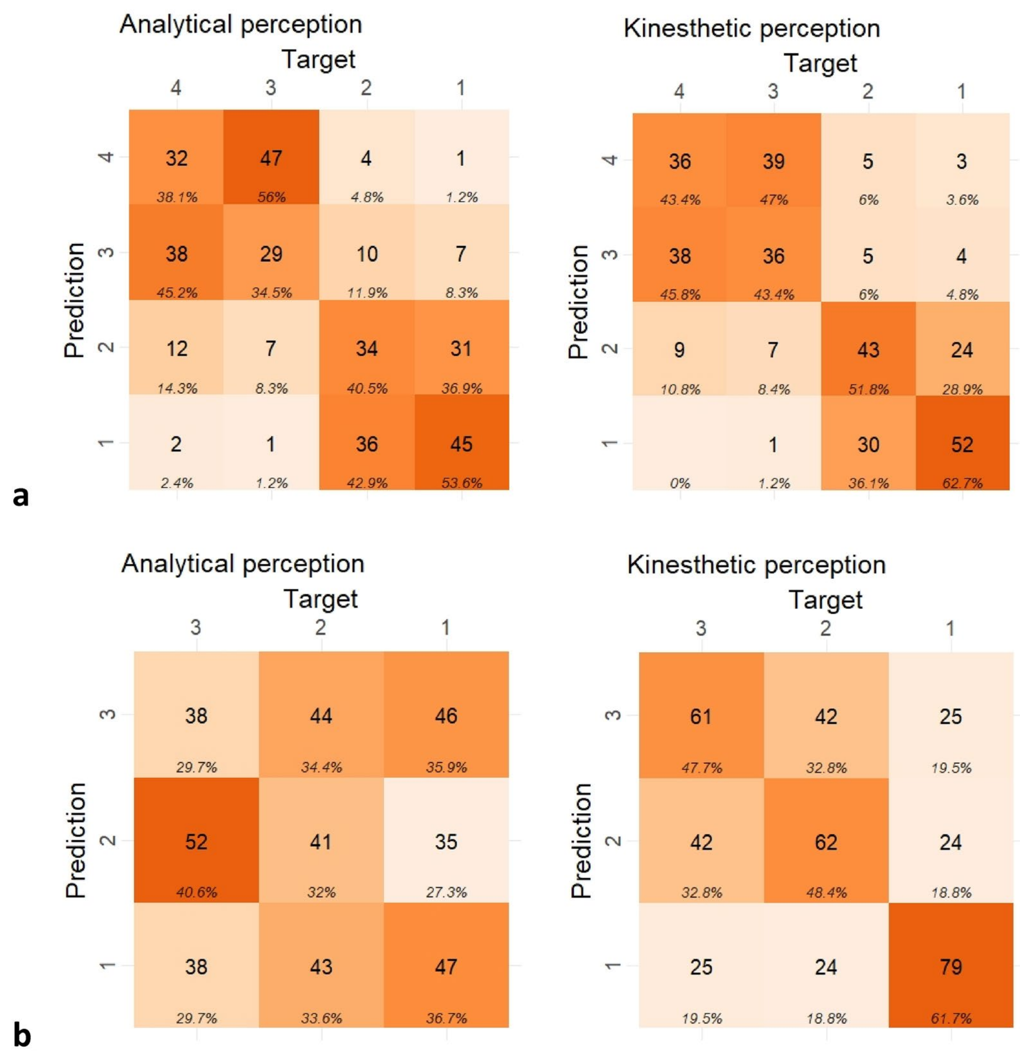


Fig. 8 Confusion matrices for the ranking test. **a** Wheat in April 2016, **b** rocket September 2018, representing the performance of the panels' summed classifications after analytical (left) or kinesthetic priming (right). The classes 1–4 indicate the different farming methods (1: Biodynamic; 2: Bioorganic; 3: Conventional mineral fertilizer + manure; 4: Conventional mineral fertilizer) for both the prediction and the target (hypothesized class: 1–2-3–4) values. Each tile contains the number of observations and the column percentage. The diagonal indicates the correct classification counts. Color intensity is based on the number of counts

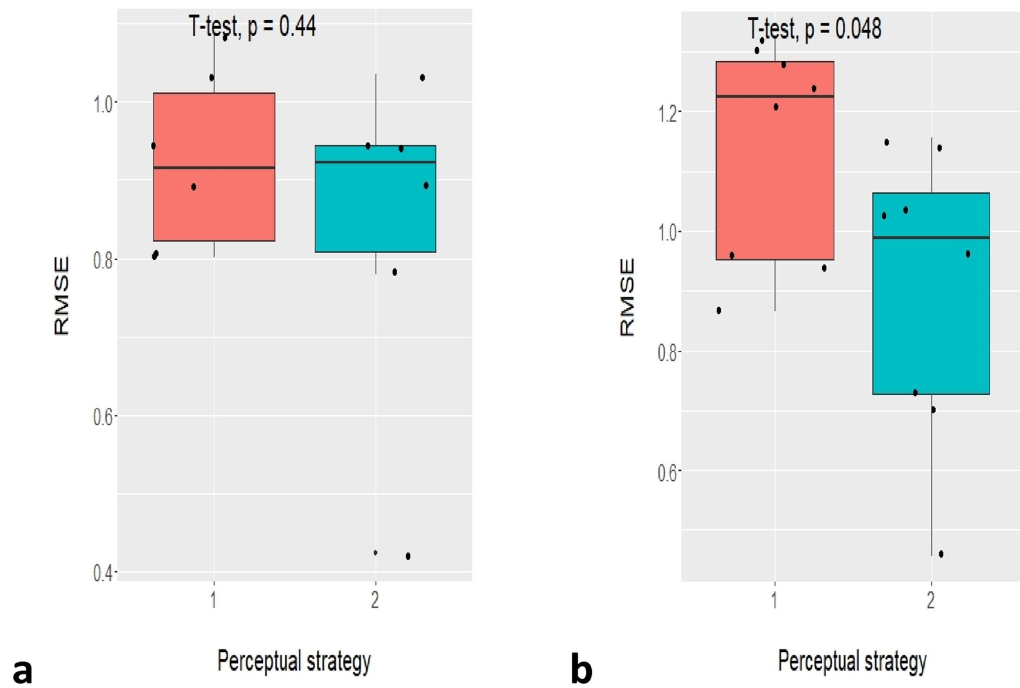


Fig. 9 Mean RMSE values for analytical perception (1) and kinesthetic engagement (2) strategies during the ranking test **a** wheat in April 2016, **b** rocket salad in September 2018

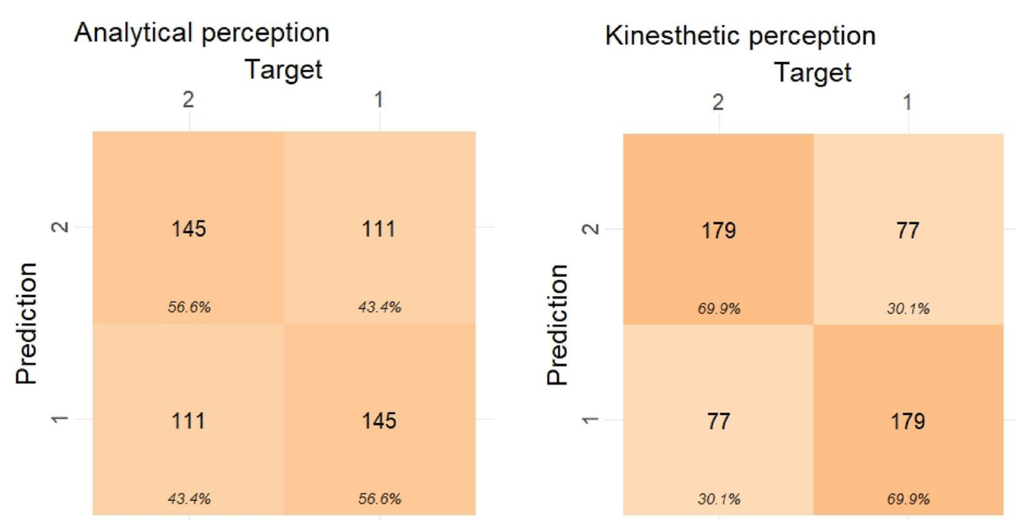


Fig. 10 Confusion matrices for the rocket ranking test in March 2018, with horn silica application, representing the performance of the panels' summed classifications according to analytical (left) or kinesthetic priming (right). The classes 1–2 indicate the different horn silica applications (1: without horn silica; 2: with horn silica application) for both the prediction and the target (hypothesized class: 1–2) values. Each tile contains the number of observations and the column percentage. The diagonal indicates the correct classification counts. Color intensity is based on the number of counts

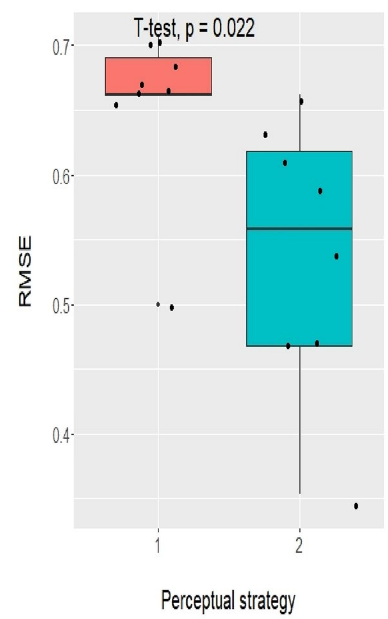


Fig. 11 Mean RMSE values of analytical perception (1) and kinesthetic engagement (2). Ranking tests of rocket salad with and without horn silica in March 2018

Abbreviations
BioDyn: Biodynamic; BioOrg: Bioorganic; ConFym: Conventional—mineral fertilizer + manure; ConMin: Conventional—mineral fertilizer; Conv: Conventional—mineral fertilizer and compost.

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Author contributions
JF, PD and MA designed the work, interpreted the results and wrote the manuscript. JF and PD made the statistics. JF did the funding acquisition. All authors did the Investigation. All authors read and approved the final manuscript.

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Availability of data and materials
All pictures and datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent of participate
Not applicable.

Consent for publication
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Competing interests
The authors declare that they have no competing interests.

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