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Wine quality under integrated, organic and biodynamic management using image-forming methods and sensory analysis

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Abstract

Background and aims: The image-forming methods copper chloride crystallization, capillary dynamolysis and circular chromatography are presented as an instrument for assessing wine quality. Wine quality of samples from a long-term field trial comparing integrated, organic and biodynamic management were investigated by using image-forming methods and sensory analysis.

Methods and results: Concerning the image-forming methods copper chloride crystallization, capillary dynamolysis and circular chromatography, the images of encoded samples were (i) grouped into pairs with similar image features; (ii) characterized based on reference images (e. g. high–low resistance to degradation); (iii) ranked (according to the characterization), and (iv) assigned to the different production methods (classified). Wine samples from organic and biodynamic management needed less wine per sample for a similar expression of structural characteristics than wine samples from integrated cultivation. Organic and biodynamic samples also show structures that indicate less degeneration than integrated samples. Due to these properties, nine coded wine samples from 2010 could be (i) grouped, (ii) characterized, (iii) ranked and (iv) classified without errors, i.e., assigned to the cultivation methods of integrated, organic and biodynamic agriculture. In sensory analysis, the wine derived from biodynamic management had the highest aroma intensity. In the other parameters the differences were not significant.

Conclusion: Analysis with the image-forming methods copper chloride crystallization, capillary dynamolysis and circular chromatography complements sensory analysis for a more complete description of the characteristic properties of wines originating from different management systems.

Significance of the study: If further studies confirm these results, the image-forming methods copper chloride crystallization, capillary dynamolysis and circular chromatography may be developed as a complementary tool to sensory and chemical analysis in assessing wine quality.

Keywords: Sensory analysis, Image-forming methods, Copper chloride crystallization, Circular chromatography, Wine quality, Integrated, Organic, Biodynamic viticulture

Background

Demand and production of permanent crops originating from organic or biodynamic farming are growing around the world [1]. The share of organic and biodynamic production for permanent crops is high in proportion to arable crops or grassland. Especially in Europe, organic and biodynamic viticulture spread rapidly in the last 20 years and have now reached a surface of almost 400,000 ha [1].

In order to compare integrated, organic and biodynamic viticultural systems, a long-term field trial was set up in Geisenheim, Germany, in 2006 (INBIODYN

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systems comparison trial, [2]). The three production systems showed marked differences on vine growth and yield [2–5], while chemical analyses carried out to describe the quality of the wines originating from the different management systems showed only slight differences in the period of conversion [5]. This is well in accordance with meta-analyses, revealing heterogeneous effects of organic and biodynamic management on winegrape and wine quality [3, 6]. In the current study, we describe results from wine quality investigations with sensory analyses and the image-forming methods copper chloride crystallization, capillary dynamolysis and circular chromatography, carried out complementary to chemical analyses for samples from the INBIODYN trial in the fifth year after conversion.

Out of the three image-forming methods applied, the methodology of image production and evaluation has been most profoundly described for copper chloride crystallization. The basis of the copper chloride crystallization method is that when an aqueous copper(II) chloride solution ($CuCl_2–2H_2O$) with additives is crystallized on a glass plate, additive-specific crystallization patterns are formed [7, 8]. The patterns are formed by a self-organization process influenced by the additive [9, 10]. Developmental series of physiological processes such as maturation and degeneration become visible in the crystal images through a typical systematic structural change [11, 12].

The crystallization process and the laboratory method have been described and documented by Busscher et al. [7, 13] and Kahl et al. [14]. For the visual evaluation of the copper chloride crystallization patterns, defined morphological criteria according to the ISO-Norm 11035 [15] for sensory analysis were developed [16] A computer-aided texture and structure analysis was also developed for the crystal structures [17–20]. Studies are currently being carried out to describe the physical conditions for the crystallization process [7, 21]. Computer image analysis of the crystal structures of copper chloride crystallization images could distinguish conventional and organic wheat samples [19, 22]. With visual evaluation of copper chloride crystallization, capillary dynamolysis and circular chromatography-encoded samples from organic and conventional production systems could repeatedly be classified according to the cultivation method [12, 23–28].

Various studies were conducted to reveal the influence of different viticultural management systems on wine sensory characteristics, but outcomes are ambiguous [3]. While several studies did not observe differences in sensory characteristics of conventional and organic wines either derived from field trials [5, 29, 30] or commercial wineries [31, 32], some other studies detected differences in sensory attributes when quantitative descriptive

analysis was applied, but results are not consistent. Wines from conventional viticulture were described as complex, vegetal, floral, and fruity [5, 31], whereas biodynamic wines were perceived as more balanced and full-bodied with a stronger minerality [5]. Organically grown *Vitis vinifera* L. cv. Cabernet Sauvignon wines from Australia were described as being more rich, vibrant and complex compared to conventional wines from the same randomized field trial [33]. While organically grown *Vitis labrusca* cv. Seyval wines from the US and *Vitis vinifera* L. cv. Sangiovese wines from Italy were preferred by panelists compared to their conventional counterparts [34, 35], organically grown Trebbiano wines from Italy were described as unbalanced and acidic compared to conventional Trebbiano wines from the same trial [34]. Investigation of the influence of biodynamic viticultural practices on wine quality and wine sensory characteristics has been a topic in current research, especially as compared to organic management. In several studies on *Vitis vinifera* L. cv. Grüner Veltliner, Cabernet Sauvignon, and Sangiovese, no differences in wine sensory characteristics were observed [29, 33, 36, 37]. In contrast, Meißner [5], Ross et al. [38] and Parpinello et al. [39] detected differences in the preference or in the sensory properties of biodynamic and organic Riesling, Merlot and Sangiovese wines, respectively.

A recent study from Italy shows that the winemaking process (conventional vs. biodynamic) highly influences wine quality. Conventional and biodynamic winemaking protocols for Sangiovese red wines were compared over two consecutive seasons resulting in a higher intensity of cherry and floral odors in the biodynamic wines. The latter were produced without addition of industrial yeast or bacteria [40].

The grape juices, constituting the wines of the present study, have been thoroughly researched in previous studies. Herein the image-forming methods proved to be sensitive indicators for the effects of different growth conditions [25, 41]. Therefore, the hypothesis for the present study was: (i) image-forming methods generate different and complementary information compared to sensory analysis and (ii) with the image-forming methods, wine from the cultivation methods integrated, organic and biodynamic can be differentiated, characterized and classified, as growth processes influenced by site conditions have a significant impact on the product quality of wine.

Materials and methods
Experimental site and management
Wine samples from the vintage 2010 were taken from a long-term field trial comparing different cultivation systems at Hochschule Geisenheim University, Geisenheim,

Germany ([2]; see Tab. 1). The experimental site is a 0.8-ha vineyard (*Vitis vinifera* L. cv. Riesling, clone Gm198–30, grafted on *Vitis berlandieri* Planch. × *Vitis riparia* Michx. cv. SO4 and *Vitis riparia* Michx. × *Vitis cinerea* Engelm. cv. Börner rootstock, respectively) at Geisenheim (49° 59′; 7° 56′), Germany. The vines were planted in 1991 at a spacing of 1.2 m within rows and 2 m between rows. The pruning system is single guyot with about 6–8 buds m^{-2}. The vineyard was managed using good agricultural practice (GAP) until 2005. Since January 2006, the vineyard has been divided into replicate plots of integrated (GAP), organic and biodynamic viticulture (both according to EU regulations 834/07 and 889/08). The experiment was setup as a complete block design, where the three factor levels of the main effect management system were replicated in four blocks. Each main plot for the factor management system consisted of two subplots, within which the two different rootstocks were equally distributed. Each plot included four rows with 32 vines each. Only the inner two rows of each plot were used for sample collection. The outer rows were considered as buffer rows. The main characteristics of the different treatments are specified in Table 1.

Wine samples

Grapes were hand-harvested on 10/13/2010 and transported to the Department of Oenology at Geisenheim University in boxes containing 25 kg each. Grapes from the different subplots (central rows without buffer rows) and field replicates were blended together in order to obtain three samples from the respective management systems. Wine samples were obtained by contemporaneous pressing of 300 kg grapes from the three management systems on EUROPRESS Px3 (EUROPRESS Umwelttechnik GmbH, Lathen, Germany). Juices were sedimented overnight, racked and stored in two 25-L carboys per management system on 10/14/2010. Industrial yeast (*Saccharomyces cerevisiae* Oenoferm® Klosterneuburg,

Erbslöh, Geisenheim, Germany) was added to each sample (30 g * 100 l^{-1}), and fermentation was controlled by regularly measuring relative density with a digital density meter (DMA 35 Basic, Anton Paar, Graz, Austria). Before samples were analyzed, they were degassed for 3 min in an ultrasonic bath. Samples from all three management systems showed similar fermentation patterns (Fig. 1).

After alcoholic fermentation was completed, wines were racked and the two replicates per management system were blended together in order to obtain one sample per management system. These samples were then analyzed using Fourier-transform infrared spectroscopy (FTIR) (FT2 Winescan, FOSS, Hillerød, Denmark), with the results presented in Table 2.

The wine samples for performing image-forming methods were obtained from the integrated, organic and biodynamic management systems before bottling. By the staff of Geisenheim University nine samples were coded (three samples per farming system). Using the three image-forming methods copper chloride crystallization, capillary dynamolysis and circular chromatography, the samples were analyzed in the laboratory of the Department of Agroecology and Organic Farming at the University of Bonn. Nine samples (three repetitions per farming system) were assessed. All samples were delivered in wine bottles.

The wine was not filtered. In the laboratory, the wine was aged by opening the bottles and storing them at 20 °C. For the first 48 h, the bottle was open without a cap. Afterwards, from the 2nd to the 6th day of aging, the bottle had a vacuum closure (brand "vacuvin wine saver concerto"). From the 6th to the 114th day of aging the bottles were closed with a handle cork (natural cork). Each wine series was analyzed in a sequence with varying mixing ratio of wine and diluted metal salts as described below. By varying both aging times and mixing ratios of wine and diluted metal salts, the spectrum of images for the analysis of every sample was extended. 412 images

Table 1 Characterization of the different viticultural management practices (integrated, organic and biodynamic) used within the experimental trial (taken from [25])

	Integrated	Organic	Biodynamic
Perennial cover crops	Grass mixture	Diverse cover crop mixture (Wolff Mixture)	
Annual cover crops	Rye + vetch	Diverse cover crop mixtures	
Under vine management	Herbicides	Mechanical	
Fertilization	Compost + mineral + legumes from annual cover crops	Compost + legumes from perennial and annual cover crops	
Plant protection	Organic fungicides	Copper (max 3 kg/ha and year), sulfur, plant strengtheners	
Biodynamic preparations			Horn manure, horn silica, compost preparations

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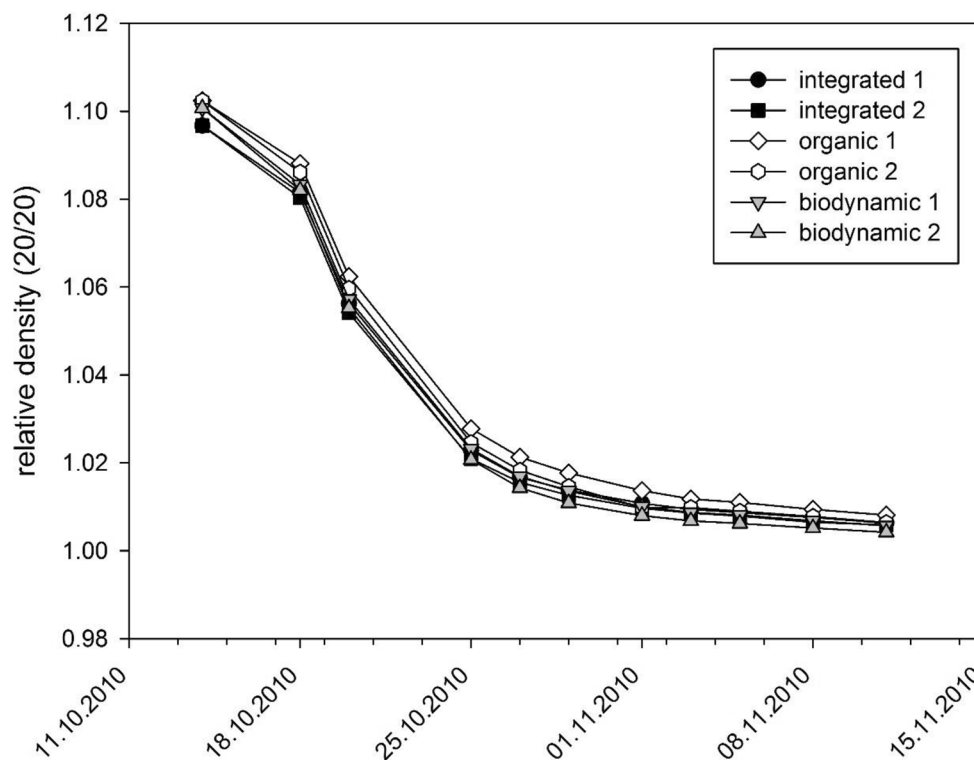
Fig. 1 Development of relative density (20/20) of juice samples deriving from different viticultural management systems during fermentation (vintage 2010). In order to be able to identify possible variations in wine production, fermentation was carried out in two different containers

Table 2 Chemical analysis of wines derived from the different management systems (vintage 2010) by FTIR

Parameter	Integrated	Organic	Biodynamic
Relative density (20/20)	1.0016	1.0022	1.0006
Alcohol (% vol.)	11.5	12.1	12.3
Residual sugars (g/l)	14.0	14.7	11.2
Glucose (g/l)	2.1	2.2	1.3
Fructose (g/l)	7.5	7.3	5.1
pH	3.1	3.2	3.1
Total acidity (g/l)	12.7	13.5	13.4
Tartaric acid (g/l)	1.9	1.7	1.6
Malic acid (g/l)	8.3	8.8	8.6
Lactic acid (g/l)	n. n	n. n	n. n
Volatile acidity (g/l)	0.8	0.7	0.6
Glycerol (g/l)	9.6	11.4	10.9

were produced and evaluated. For an overview of mixing ratios, wine aging times and reagent composition in the images, see Table 3.

Circular chromatography
Filter paper discs (Whatman No. 1) with a total diameter of 15 cm were saturated to a diameter of 8 cm with 0.5 ml of a 0.5% silver nitrate solution. The filter papers were then dried for 2–3 h. 0.45 ml, 0.50 ml, 0.55 ml and 0.60 ml of wine were diluted with distilled water (water distilling devices Muldestor Wagner & Munz) to a total volume of 0.77 ml. The samples were set at 20 °C with 0.48 ml 0.8% NaOH solution for 1 h (for mixing ratio see Tab. 3). The extract solution migrated through a central filter paper wick and the filter paper discs from the center to a diameter of 12 cm. To maintain sufficient humidity, the paper was covered with a glass container. The images developed to full color within 48 h in diffuse daylight (not direct sunlight). From each of the nine samples, 16 circular chromatography images were made and evaluated.

Capillary dynamolysis
In the first phase, 0.45 ml, 0.5 ml 0.55 ml, and 0.6 ml of wine were diluted with distilled water to a total volume of 0.6 ml. These liquids were applied to standard-sized chromatography paper (Schleicher & Schuell 2043A) in Kaelin dishes and left to rise [42]. In the second phase, 0.7 ml of a 0.25% silver nitrate solution rose to 1 cm across the line formerly formed by the juice. In the third phase, 2.0 ml of a 0.25 percent iron sulfate solution rose to a total height of 12 cm (for mixing ratio, see Table 3). During the second and third phase, the chromatograms

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Table 3 Extract setting times, mixing ratio and reagent composition of the image-forming methods circular chromatography capillary dynamolysis and copper chloride crystallization

Method	Series	Open bottle at 20 °C	Per image						
			Wine (ml)	H_2O dest. (ml)	NaOH 0.80% (ml)	$AgNO_3$ 0.25% (ml)	$AgNO_3$ 0.50% (ml)	$FeSO_4$ 0.25% (ml)	$CuCl_2$ 10% in H_2O (ml)
Circular chromatography	A	0 d	0.45	0.32	0.48		0.50		
	B	1 d	0.50	0.27	0.48		0.50		
	C	2 d	0.55	0.22	0.48		0.50		
	D	4 d	0.60	0.17	0.48		0.50		
Capillary dynamolysis	A	0 d	0.45	0.15		0.70		2.00	
			0.50	0.10		0.70		2.00	
			0.55	0.05		0.70		2.00	
			0.60	0.00		0.70		2.00	
Copper chloride crystallization	A	0 d	1.0	2.0					2.0
	B	1 d	1.2	1.8					2.0
	C	2 d	1.4	1.6					2.0
	D	6 d	1.6	1.4					2.0
	E	9 d							
	F	16 d							
	G	23 d							
	H	38 d							
	I	43 d							
	J	114 d							

Copper chloride crystallization mixing ratio:

- Serie 0 d and 1 d: 1.0 ml; 1.2 ml; 1.4 ml wine

- Serie 2 d–114 d: 1.2 ml; 1.4 ml; 1.6 ml wine

were covered with tall beakers to maintain sufficient humidity. The drying time between the individual phases was 2 hours at 20 °C and 50% humidity. From each of the nine samples, 4 capillary dynamolysis images were made and evaluated.

Copper chloride crystallization

For the crystallization method, wine, distilled water and a 10 percent copper chloride solution were mixed (for mixing ratio, see Table 3). The solution was placed into Petri dishes (100 mm × 15 mm steriplan soda-lime-glass Duran Group) and crystallized in a crystallization chamber at 30 °C with 50% humidity for 12–15 h [41]. From each of the nine samples, 30 copper chloride crystallization images were made and evaluated.

Analysis of wine samples with image-forming methods

The visual image evaluation of the wine samples was based on reference images of grape juice and exemplary images of wine with (i) different levels of juice or wine quantity per plate and (ii) different levels of degeneration/ageing due to different periods of storage in open wine bottles. The calibration procedure also described in Fritz et al. [41] for grape juice was as follows: in the reference grape images and exemplary wine images, characteristic changes in the image structures that occurred (i) with increasing juice and wine quantity per plate and (ii) with increasing juice and wine deterioration were described using the criteria listed by Huber et al. [16].

These comparative series formed the basis for characterizing the images from the three production system as "strong–weak form expression" (wine-specific morphological features) and "fresh–deteriorated". Based on these characterizations, a qualitative assessment of the generated images was made, where (a1) wine with strong form expression and (b1) fresh opened wine bottle (wine exhibiting fewer decomposition features due to limited oxidative processes) was ranked higher than (a2) wine with weak form expression and (b2) a long time opened wine bottle. The encoded wine samples were grouped according to similar form expression and, based on experience from earlier investigations, assigned to cultivation methods (classification). The images were evaluated visually by 2 persons.

Statistical analysis of image-forming methods

For statistical analysis (see also [12]), the agreement between correct grouping/classification and the grouping/classification based on the results of the image-forming methods was tested. The test is based on a 3×3 contingency table, which compares a set of given categories to the ones determined in the investigation (see Tables 5 and 6). For the grouping test, Fisher's exact test was carried out. For the classification test, the agreement

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was determined with the simple Kappa coefficient. The methods are described by Agresti [43]. The statistical software 'R', version 2.10.1 (R Development Core Team, R Foundation for Statistical Computing, Vienna, Austria) was used for Fisher's exact test. Calculation of Kappa coefficients and exact p-values for testing agreement was carried out using PROC FREQ in SAS (SAS Institute Inc., Cary, NC, USA), version 9.3.

Sensory analysis of the wines

Sensory analysis of the wines from the vintage 2010 was performed on 04/09/2014 at Hochschule Geisenheim University within a Bachelor Thesis [44] with a trained panel consisting of students, staff of Hochschule Geisenheim University and winegrowers ($n = 24$). Descriptive analysis (attributes: acidity, freshness, fruit, aroma intensity, complexity, reduction, purity, typicity for variety Riesling, bitterness, body, ripeness) was performed. Before the tasting, fructose was added to the integrated and the biodynamic variant up to the same level of residual sugars as the organic variant. This was done to equalize sweetness in the wines and to prevent panelists from ranking according to levels of residual sugars. Samples were randomly encoded and the order of appearance of the samples was random for each panelist.

Statistics for the descriptive analyses were computed with the software R [45]. A mixed linear model with treatment as a fixed factor and panelist as random factor was applied. A likelihood ratio test was performed to test the significance of the factor treatment. If the treatment effect was significant ($p < 0.1$), a General Linear Hypothesis Test with Bonferroni–Holm adjustment was carried out to compare the factor levels.

Results and discussion

Grouping based on circular chromatography images

The grouping of the coded samples (i.e., the differentiation of the samples) was primarily done based on circular chromatography images. Characterization of the images with classification was carried out with the reference series of copper chloride crystallization images. In circular chromatography, three groups of images with similar characteristics were distinguished, each group consisting of three samples (Fig. 2):

- Group 1: clear brown outer ring; bright pink inner ring with some purple lines in the center of the pink inner ring.
- Group 2: paler brown outer ring; very bright pink inner ring with many purple lines in the center of the pink inner ring.

- Group 3: unclear brown outer ring; darker pink inner ring without purple lines; violet lines running towards the center of the white inner zone.

Quality assessment and classification based on copper chloride crystallization images

In the reference series for deterioration (Fig. 3), it was determined that

- with decreasing amount of wine per plate, the needle bundles turned from fine to coarse
- with increasing deterioration of the sample, the needle bundles turned from fine and even (fresh open bottle) to coarse, with wavy, brittle needle bundles, not uniformly structured from center to outside, partly with annular zones where needle coverage is low (bottle of wine that had been opened for 23 days).

In the different image series produced for comparing samples from the three production systems, the needle bundles in the images of the wine samples were increasingly coarser with less uniform needles in the following order:

- Series 1: 0 days < 1 day < 2 days open bottle (Fig. 4)
- Series 2: 9 days < 16 days < 23 days open bottle (Fig. 5)
- Series 3: 38 days < 43 days < 114 days open bottle (Fig. 6)
- Group 1 < Group 2 < Group 3 (in Figs. 4, 5, 6).

In earlier studies it was found that organic and especially biodynamic products show fewer signs of aging and degeneration and a stronger form expression than samples from conventional or integrated production (e.g., beetroot: [27], wheat: [24, 26]; rocket lettuce: [22]; grapes: [25, 41]). Therefore, the group with the coarsest and least uniform needle bundles showing most signs of degeneration (group 3) was classified as from the integrated production system, the group with the finest needle bundles with the lowest degeneration (group 1) was classified as from the biodynamic production system and the group in between (group 2) was classified as from the organic production system.

Thus, in the present study, the cultivation methods showed a clear hierarchy of quality according to the criteria of strength of form expression and resistance to deterioration of biodynamic > organic > integrated (Table 4). Decoding showed that all samples were correctly grouped and classified (Tables 5 and 6).
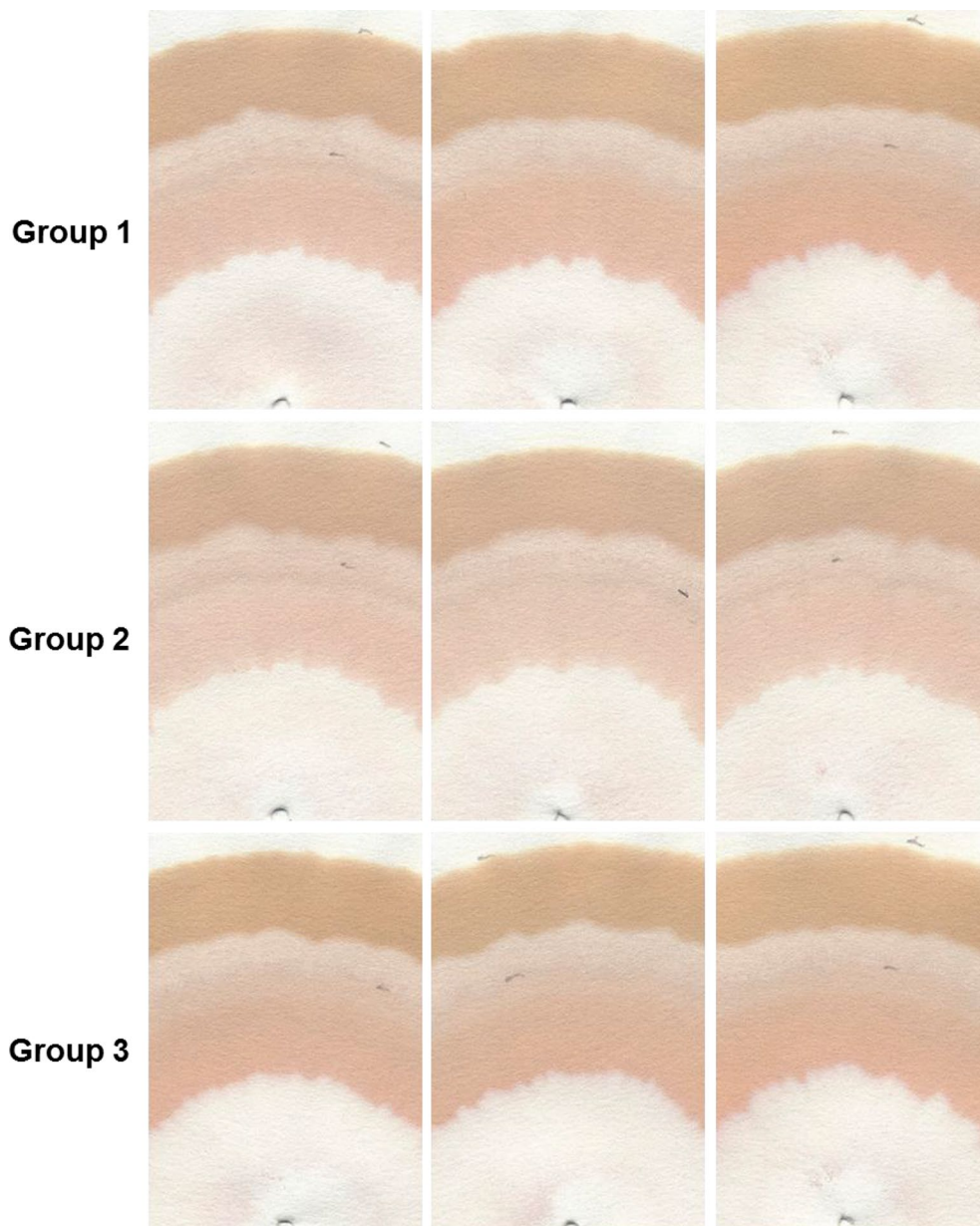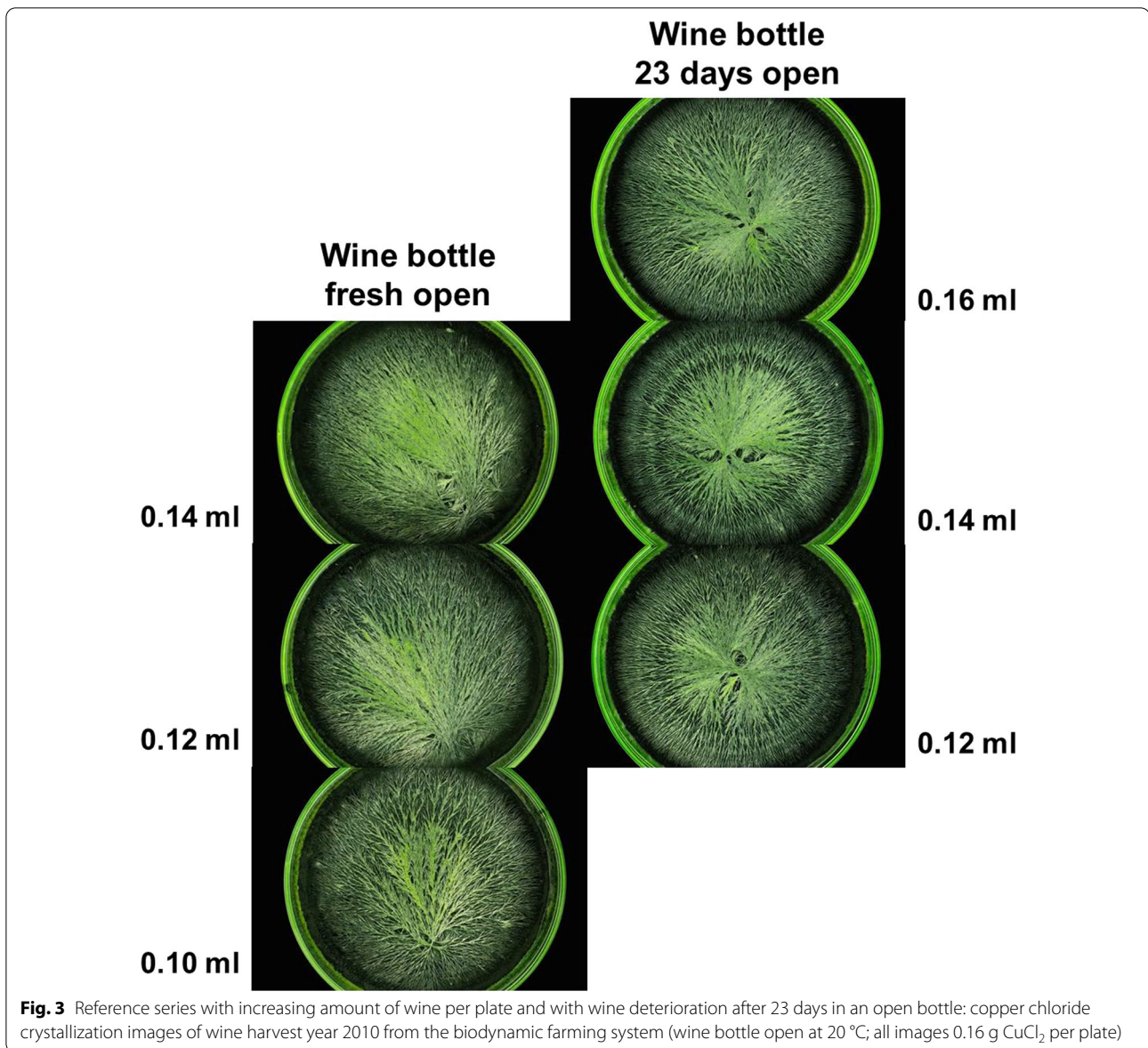
Fig. 2 Discrimination of 9 samples in 3 groups (*n* = 3) from biodynamic (group 1), organic (group 2) and integrated (group 3) farming systems: circular chromatography images of wine harvest year 2010 (wine bottle open 2 days at 20 ℃; all images 0.55 ml wine)

Each of the image-forming methods shows different aspects of the examined samples. Therefore, all three methods were used in parallel. In this study, circular chromatography was used to differentiate the samples into groups (sample repetitions). Copper chloride crystallization was especially well suited for quality assessment and sample classification (differences in strength of form expression and resistance to deterioration). In the present study, capillary dynamolysis did not further

support the accuracy of the results. However, in other studies [12, 22], sample characterization relied strongly on this method. Therefore, the combined use of all three methods is recommended for investigations.

Sensory analysis

In the descriptive sensory analysis, the wines derived from biodynamic, organic and integrated viticulture were perceived to be slightly different. The wine from

Fig. 3 Reference series with increasing amount of wine per plate and with wine deterioration after 23 days in an open bottle: copper chloride crystallization images of wine harvest year 2010 from the biodynamic farming system (wine bottle open at 20 °C; all images 0.16 g $CuCl_2$ per plate)

the biodynamic treatment showed a significantly higher aroma intensity compared to the wine from the integrated treatment ($p < 0.1$) (Fig. 7). The wine from the biodynamic treatment was also perceived as being the fruitiest and the freshest, but differences were not significant.

Role of image-forming methods in wine quality assessment

In the INBIODYN systems comparison trial, the three production systems systematically influenced growth and development of the vines, with low vegetative growth and low yield, loose grape structure and little acetic acid infestation in the organic and especially in the biodynamic treatment, and strong vegetative and generative growth with high shoot length of primary shoots, high pruning weight, single berry weight and grape yield, but also compact bunch structure and a higher share of sour rot on bunches in the integrated treatment [2, 4]. These differences were consistent in the period of conversion from 2006–2009 described in Meißner et al. [2] and the following 3 years 2010–2012 described in Döring et al. [4]. Even though the different fertilization strategies in the two biological treatments
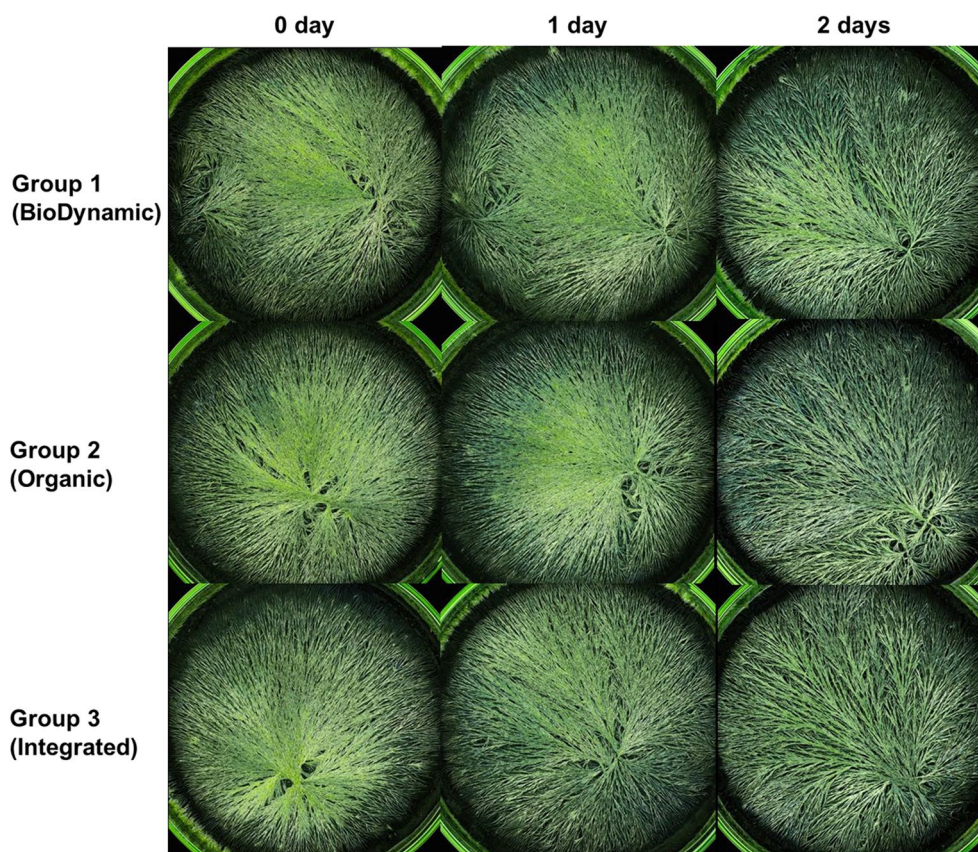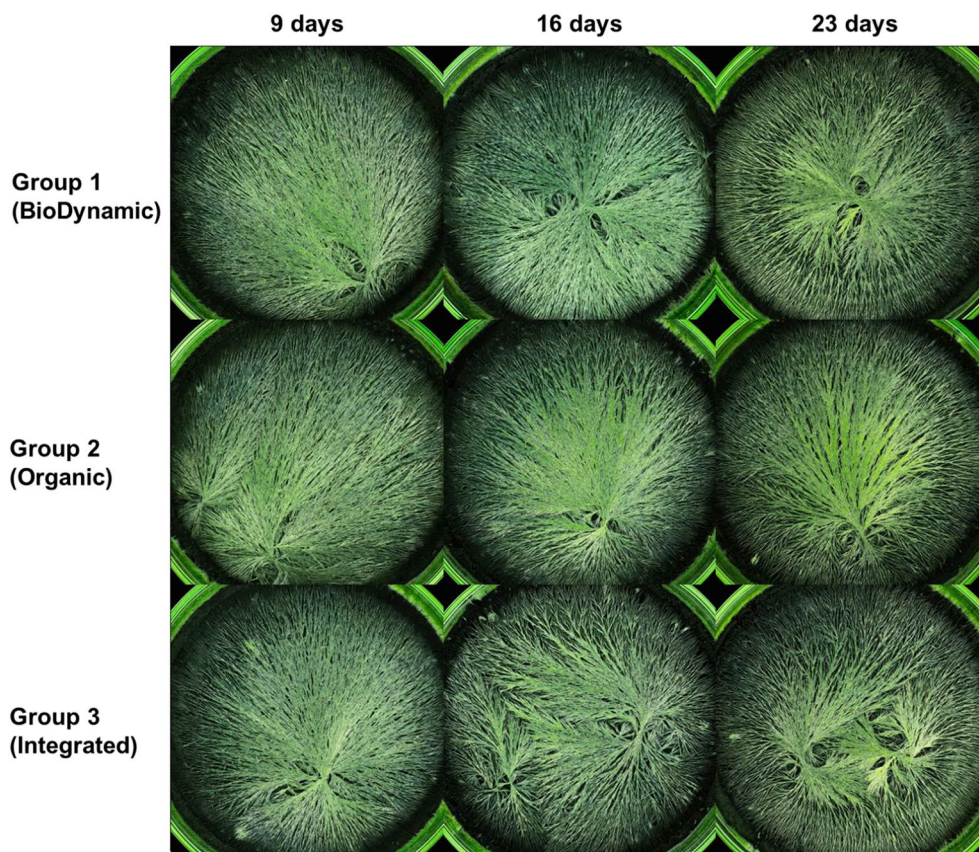
Fig. 4 Crystallization images of wine deterioration 0, 1, 2 days (open bottle) of integrated, organic and biodynamic farming systems (sample identity was not known at the time of investigation): copper chloride crystallization of wine samples harvest year 2010, open bottle aged at 20 °C (all images 0.12 ml wine and 0.16 g CuCl$_2$ per plate)

(with compost and legume-rich intercrops) and the integrated treatment (compost, mineral nitrogen and mostly non-leguminous intercrops) resulted in lower contents of soil mineral nitrogen in the period of conversion in the biological treatments, but in the following 3 years it was vice-versa. Consequently, the effect of the production method on the chemical composition of wood, leaves and grapes differed between the period of conversion (lower total acidity in must, high total soluble solids in juice and comparatively high contents of carbon-based wood constituents in biodynamic and organic as compared to integrated treatment) and the following three years (higher nitrogen content in leaves at veraison, higher content of yeast assimilable nitrogen in berries in biodynamic as compared to integrated treatment).

In the current study, the hypotheses were confirmed that (i) the image-forming methods used generate different and complementary information compared to sensory analysis and (ii) with these image-forming methods, wine from the cultivation methods integrated, organic and biodynamic can be differentiated, characterized and classified, as growth processes influenced by site conditions have a significant impact on the product quality of wine. Reduction in vegetative growth, resulting in a slightly higher leaf-area-to-fruit-weight-ratio in the organic and biodynamic treatment when assessed in 2012 [4], is a characteristic trait of organic and biodynamic systems both in the INBIO-DYN trial and worldwide [3] and likely influences juice and wine quality [46]. Therefore, this trait might partly account for differences in wine quality among systems assessed in the current study by image-forming methods and sensory analysis.

With regard to the chemical ingredients, Granato et al. [47] was only able to differentiate between

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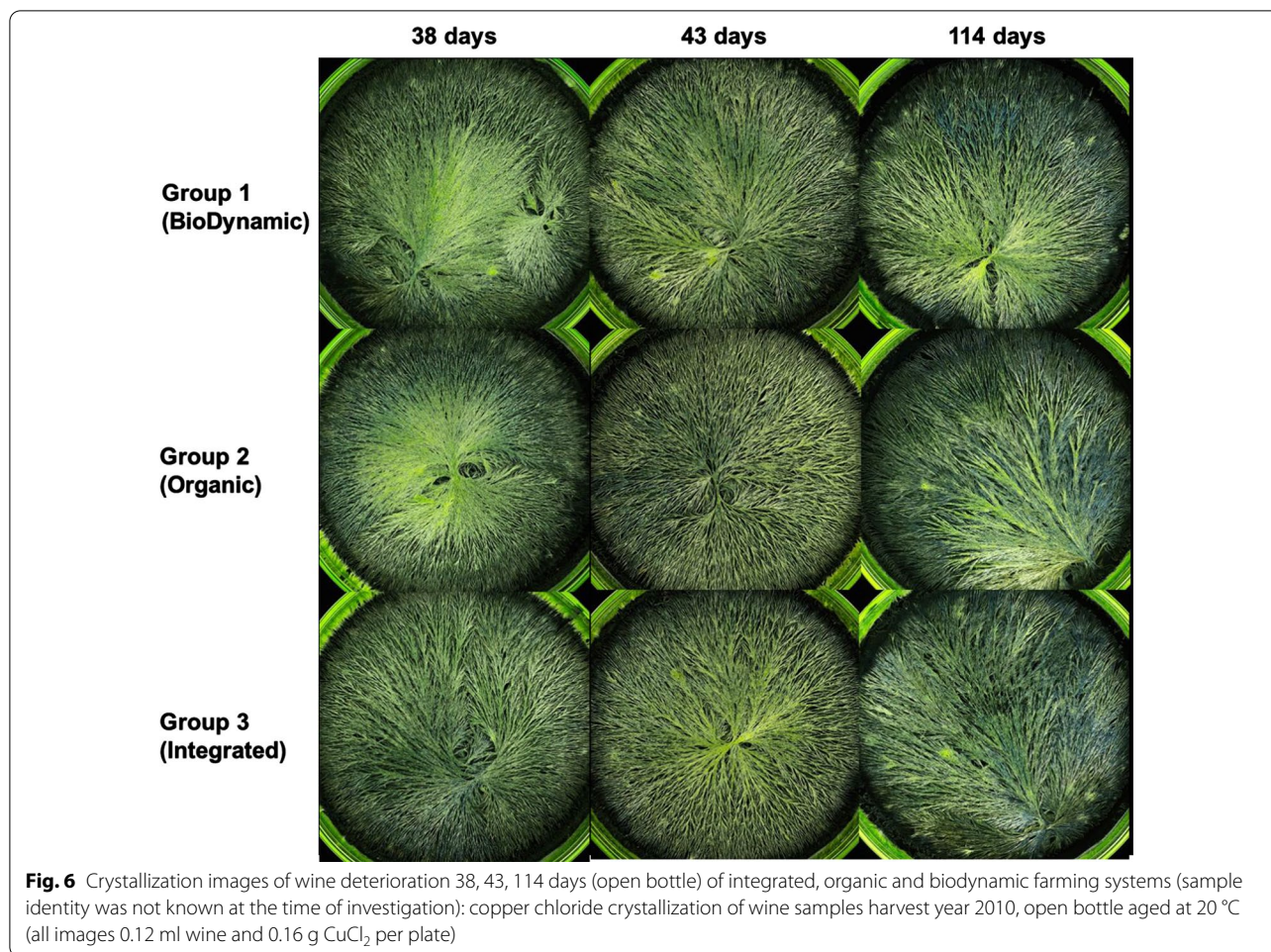
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Fig. 5 Crystallization images of wine deterioration 9, 16, 23 days (open bottle) of integrated, organic and biodynamic farming systems (sample identity was not known at the time of investigation): copper chloride crystallization of wine samples harvest year 2010, open bottle aged at 20 ℃ (all images 0.12 ml wine and 0.16 g CuCl$_2$ per plate)

biodynamic and organic wines as a common group compared to conventional wines. Yañez et al. [48] were also able to differentiate between organic and conventional wines with ingredient analyses. In contrast, Tassoni et al. [49] and Plahuta et al. [50] did not differentiate the wines from the three cultivation methods according to ingredients. In Parpinello et al. [36] and Laghi et al. [51], a differentiation between organic and biodynamic wines from one location of two years each was possible by evaluating the chemical ingredients. A sensory differentiation of the organic and biodynamic cultivation methods was possible in Ross et al. [38] and not possible in Parpinello et al. [36], Bigler et al. [52] and Döring et al. [4].

As in sensory analysis, it is difficult to relate differences in structure formation in image-forming methods to the chemical composition of the wine. Wines from the organic and the biodynamic treatment had higher alcohol levels, a higher acidity and more glycerol (Table 2). As part of the main ingredients of the

matrix wine, i.e., the physical domain that contains or interacts with the individual chemical components, these parameters are likely to influence sensory evaluation of the wines. The panel ranked the wines in the correct order concerning their acidity, although results were not significant (Table 2, Fig. 7). The content of alcohol and glycerol did not influence the perception of the wines by the sensory panel concerning the descriptor "body".

Even though the food matrix has largely been neglected in food quality research, recent advances in food science show that it can have strong implications on bioaccessibility, bioconversion or bioefficacy in the human body [53]. Likewise, it is known that matrix properties, namely viscosity, influences structure formation in copper chloride crystallization and that viscosity is reduced when juice ages [9]. Therefore, future research should focus on effects of production systems on the food matrix and possible relations to structure formation in image-forming methods.

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Fig. 6 Crystallization images of wine deterioration 38, 43, 114 days (open bottle) of integrated, organic and biodynamic farming systems (sample identity was not known at the time of investigation): copper chloride crystallization of wine samples harvest year 2010, open bottle aged at 20 ℃ (all images 0.12 ml wine and 0.16 g $CuCl_2$ per plate)

Table 4 Grouped and classified grape samples from different farming systems after decoding

Year	Grouping and classification
2010	D=D=D; O=O=O; I=I=I

From left to right (i) samples needed more wine per sample for similar form expression, and (ii) samples showed more pronounced structural features that indicate enhanced aging/deterioration (open wine bottle)

D biodynamic system, *O* organic system, *I* integrated system

Table 5 Contingency table of Fisher's exact test (test for grouping of encoded samples)

	Correct grouping		
	G1	**G2**	**G3**
Grouping of encoded samples			
G1	3	0	0
G2	0	3	0
G3	0	0	3
Significance	$p=0.004$		

G1–G3: sample group 1 to 3

Further research is also needed with respect to the mode of action of the biodynamic preparations, which may include bacterial regulation [54], resulting in greater rhizospheric activity [55, 56] or stimulation of natural defence substances [57, 58], possibly via plant hormones [54, 55, 59, 60]. When comparing biodynamic with conventional viticulture, Soustre-Gacougnolle et al. [61] found in their studies that biodynamic viticulture was associated with higher expression of silencing and immunity genes, and higher anti-oxidative and anti-fungal secondary metabolite levels. Soustre-Gacougnolle et al. [61] suggest that the sustainability of biodynamic practices is probably based on fine molecular regulation.

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Table 6 Contingency table of interrater agreement (test for classification of encoded samples)

	Correct classification		
	D	**O**	**I**
Grouping of encoded samples			
D	3	0	0
O	0	3	0
I	0	0	3
Significance	$p = 0.001$		

D biodynamic system, *O* organic system, *I* integrated system

Conclusions

The present study shows that the image-forming methods copper chloride crystallization, capillary dynamolysis and circular chromatography can detect quality differences in wine, which are consistent with differences in the physiological development of vines and grapes. The evaluation approach followed in the research presented here adds a new dimension to wine quality research and can make a significant contribution to a better understanding of how different cultivation systems influence plant physiology and thus product quality. With further research, the image-forming methods copper chloride crystallization, capillary dynamolysis and circular chromatography may become a complementary approach to sensory and chemical analysis in wine quality investigations. The image-forming methods can be seen as a resilience test that assesses ageing in terms of degeneration (presumably oxidation). The present experimental results of the image-forming methods lead to the hypothesis that differences in sensory analysis of different cultivation systems are more pronounced when the wine is more oxidized by prolonged air contact. This hypothesis should be tested in further studies.
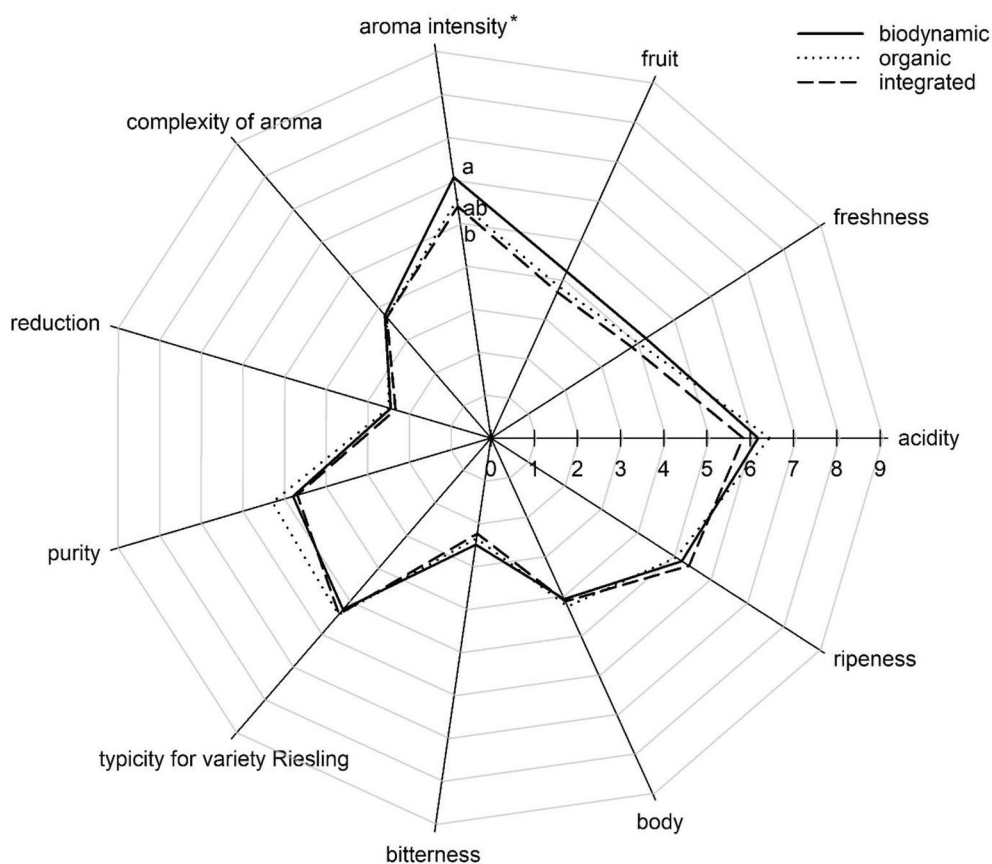
Fig. 7 Results of the descriptive sensory analysis of the wines derived from different management systems (vintage 2010) performed on 04/09/2014. *Indicates statistical significance ($p \leq 0.1$)

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Authors' contributions
JF and JD designed the work, interpreted the results and wrote the manuscript. MA interpreted the results and wrote the manuscript. GM, RK and HRS designed the work, interpreted the results and reviewed the manuscript. All authors read and approved the final manuscript.

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
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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