Food Quality and Preference 92 (2021) 104230

Contents lists available at ScienceDirect

Food Quality and Preference

journal homepage: www.elsevier.com/locate/foodqual

How does wine ageing influence perceived complexity? Temporal-Choose-All-That-Apply (TCATA) reveals temporal drivers of complexity in experts and novices

Qian Janice Wang [a,*], Tadas Niaura [a], Kevin Kantono [b,c]

[a] Department of Food Science, Aarhus University, Denmark
[b] Arla Innovation Centre, Arla Foods amba, Aarhus N 8200, Denmark
[c] Department of Food Science, Faculty of Health and Environment Sciences, Auckland University of Technology, Private Bag 92006, Auckland 1142, New Zealand

ARTICLE INFO

Keywords:
Complexity
TCATA
Madeira
Temporal evolution
Wine expertise

ABSTRACT

Complexity is an important component of food and drink, especially for experience/hedonic goods such as wine. However, the contribution of the temporal aspects of the tasting experience to such top-down cognitive evaluations of wine is not well-understood. In this study, we assessed how the length of wine ageing influenced the perceived complexity and temporal evolution of flavours, as judged by wine experts (N = 22) and novices (N = 60). A total of six Madeira wines, from two grape varieties and three ageing points, were served blind. Participants first rated the complexity of each wine before using Temporal-Check-All-That-Apply (TCATA) methodology to evaluate eight taste and flavour attributes over 120 s. Finally, participants provided free-text descriptions of wine complexity. Results demonstrated that wine experts, but not novices, were able to discriminate between wines according to complexity. Moreover, TCATA results mirrored the complexity results showing experts were able to better discriminate between the samples, with older wines exhibiting different flavour trajectories and longer aftertaste durations compared to younger wines. For both novices and experts, complexity ratings were associated with the total number of attributes, flavour duration, and overall intensity, but not how much the wine changed during the tasting experience. Free-text results revealed having multiple flavours as the most important self-rated feature of wine complexity, although experts reported temporal factors more than novices. Taken together, our results indicate previously uncharted differences in how experts and novices use temporal aspects in their evaluation of wine complexity.

1. Introduction

The sensory identity of food and beverages has an important temporal component. The process of eating releases volatiles from the food and leads to a variety of sensations due to chewing, breathing, salivation, tongue movements, and swallowing (Lawless & Heymann, 2010, Chapter 8). This is especially relevant for complex gustatory stimuli such as wine, which have often been described in terms of their flavour evolution. Just take this tasting note from noted wine critic Julia Harding MW on a cask sample of fine Riesling:

"*In the mouth, the orange notes are dominant at first but give way to wild herbal depths, dried grasses and the purest of fresh, ripe acidity. There's richness too, a fullness and weight in the mouth yet balanced by the intense freshness. Then full circle to the sour-fruited intensity on the finish, which goes on for ever*." (jancisrobinson.com, Weingut Keller Piesporter Schubertslay Grosses Gewäches 2018).

Reflecting the evolving nature of sensations during product evaluation, a variety of temporal sensory methods have been proposed recently to capture the evolution of in-mouth sensations over time (Castura et al., 2016). One method that is perhaps particularly well-suited to the complexity of wine is Temporal Check-All-That-Apply (TCATA), a relatively new temporal method that allows panellists to select multiple product attributes on a moment-by-moment basis (Castura et al., 2016). TCATA, therefore, provides a more comprehensive overview of the temporal evolution of the sensory characteristics of products than other methods such as Temporal Dominance of Sensations (Ares et al., 2015). In the world of wine, TCATA has been used to, amongst others, discriminate between carbonation levels in sparkling wines (McMahon

* Corresponding author at: Department of Food Science, Aarhus University, Agro Food Park 48, DK-8200 Aarhus, Denmark.
E-mail address: qianjanice.wang@food.au.dk (Q.J. Wang).

https://doi.org/10.1016/j.foodqual.2021.104230
Received 21 January 2021; Received in revised form 4 March 2021; Accepted 4 March 2021
Available online 15 March 2021
0950-3293/

et al., 2017), categorise wines by mouthfeel and texture (Kemp et al., 2019), and study the interaction between alcohol, sweetness, and acidity (Poveromo & Hopfer, 2019). In the present study, we use TCATA to understand how temporal elements of the tasting experience is related to the assessment of complexity in both novices and experts.

1.1. What makes a wine complex?

Complexity is a term that people often use to describe quality wines, although just what exactly people mean by complexity is not always clear (Spence & Wang, 2018b). While complexity can refer to both "objective" chemical complexity in the bottle as well as "subjective" psychological complexity in the mind of the taster, in the present paper, we will only focus on perceived complexity as evaluated by the taster.

The most intuitive explanation for complexity, regardless of whether pertaining to the chemical senses or otherwise, is that of having multiple distinguishable components (Berlyne 1960, pp. 38–39). This has been partially supported through research, showing that at least those with some expertise in wine associates, implicitly or explicitly, wine complexity with having multiple flavours (Parr et al., 2011; Schlich et al., 2015; Wang & Spence, 2018). Furthermore, the multiple elements may be apparent all at once (see Spence & Wang, 2018a, for a description of this snapshot approach), or they may unravel over time, such as described in the tasting note above.

On the other hand, complexity might be expressed via a single element. For instance, the overall flavour intensity of the wine is used as an indicator of complexity (Schlich et al., 2015; Wang & Spence, 2019), as well as the more abstract notions of balance and harmony (Schlich et al., 2015). In fact, the notion of "integratedness" has been raised by some as an alternative interpretation of complexity, defined by a unitary seamless sensation that is difficult to break down into its component parts (Parr 2015).

In contrast to the abovementioned configural viewpoint, where we experience a perceptual fusion of the sensations without necessarily attending to its component parts (Jinks & Laing, 2001), evidence shows that complexity may be indicated by the presence of specific flavours. Wang & Spence (2019) revealed via linguistic analysis that, for young red wines made from Bordeaux grapes (Cabernet Sauvignon, Cabernet Franc, Merlot), the descriptors that most predicted a higher complexity rating were coconut, toast, and vanilla, flavours that are associated with oak ageing (Fielden, 2009). Similarly, Wang & Spence (2018) found that flavours associated with winemaking and ageing (i.e. secondary and tertiary flavours) were more often used to describe more wines that participants rated as more complex.

Complexity can also be expressed via a single dynamic element; length, or the duration of lingering flavours in the mouth after the wine has been swallowed, has been shown to be significantly correlated with complexity for both consumers and experts (Schlich et al., 2015).

In summary, factors driving wine complexity can be categorised by the presence of single or multiple elements and whether these elements are perceived at a single moment in time or dynamically over time (Table 1). Moreover, many non-sensory factors have been associated with complexity, such as familiarity, liking, and perceived wine quality (Parr et al., 2011; Schlich et al., 2015; Wang & Spence, 2018; 2019).

1.2. The relationship between wine ageing and complexity

Wine ageing/maturation is a winery procedure that can drastically alter the complexity of the resulting product. During ageing, the wine is stored in a vessel which can be either inert (e.g. concrete tank) or more commonly, prone to trace levels of oxygen ingress (e.g. oak barrel) (Robinson & Harding, 2015). In terms of flavour characteristics, ageing results in the loss of fruity, floral, and fresh vegetable aromas – so-called primary aromas – and leads to the development of earthy, dried fruit, and nutty oxidation aromas – so-called tertiary aromas (Waterhouse et al., 2016, p. 309–312). Moreover, the use of new oak barrels can also contribute smoky, spicy, vanilla aromas (known as secondary aromas, deriving from the winemaking process) as a byproduct of oak staves being toasted during the barrel making process (Waterhouse et al., 2016, p. 304-305). Keeping in mind the multi-component of complexity, it is clear that wine ageing therefore adds to the complexity of the finished wine by adding entirely new groups of tertiary (and potentially secondary) aromas and flavours.

Table 1
An overview of factors potentially leading to wine complexity, with definitions and examples.

Category	Definition	Example
Single static	Complexity is based on one single thing which can be measured if the wine was tasted for only one moment	Flavour intensity
Multiple static	Complexity is based on the presence of multiple elements, which can be measured if the wine was tasted for only one moment	Multiple flavours in the wine, balance, integration
Single dynamic	Complexity is based on one single thing that can only be assessed over time	Length (of aftertaste)
Multiple dynamic	Complexity is based on the presence of multiple elements, which can only be assessed over time	Multiple flavours in the wine that evolve over time
Other	Non-sensory related	Liking, familiarity

Research has shown that wine experts associate complexity with a wine's ageing ability (Langlois, Dacremont, Peyron, Valentin, & Dubois, 2011; Parr et al., 2011; Sáenz-Navajas et al., 2015). Interestingly, Wang & Spence (2018) demonstrated that, even for social drinkers, flavours associated with the process of winemaking and ageing (such as smoke and vanilla) were more often attributed with those wines perceived to be more complex. This is why, in the present study, we focused specifically on wines which have been aged for different periods of time, to ensure that the wines would display a range of complexity levels.

1.3. Effect of wine expertise on complexity evaluation

A body of research has demonstrated differences in how wine experts and novices evaluate wine complexity. For instance, an interview with wine professionals and consumers from Australia and New Zealand revealed that while experts focused on the process with which the wines were produced, novices gave more weight to their hedonic appreciation for the wine itself (Parr et al., 2011). A consequence of this difference is that, sometimes the same flavour descriptor can be thought of as more or less complex depending on the taster. Using a machine learning model, Wang & Spence (2019) demonstrated that wine experts associated descriptors such as coconut and toast with higher complexity, whereas novices associated the term cedar with lower complexity. While both sets of descriptors refer to the effect of oak ageing, only experts were able to make the connection between flavour and production, therefore inferring that oak aged wines have more complexity.

In terms of dynamic factors, evidence shows that only experts associate temporal factors such as "evolving complexity" (Parr et al., 2011) or duration of aftertaste (Schlich et al., 2015) with complexity.

Finally, it should be kept in mind that the consistency of experts with regard to complexity (Schlich et al., 2015) is likely due to their training. For instance, the Wine and Spirits Education Trust, one of the biggest wine educational organisations in the world, defines complexity as the wine having multiple flavours that span different multiple aroma clusters (Fielden, 2009). While this seems like a "snapshot" approach at first, since different types of flavours (e.g. those from the grape versus those from ageing) are often perceived during different time points (e.g. Meillon et al., 2009), it is probable that describing the full flavour spectrum of a wine is in fact a dynamic process.

1.4. Hypothesis development and contributions

Based on the research summarised above, we hypothesize the following:

H1: Longer aged wines are rated as more complex.
H2: Compared to novices, experts are better able to discriminate between wines of different ageing times.
H3: Complexity is associated with multiple factors, both static (e.g. number of flavours) and dynamic (e.g. length). However, experts are more likely to focus on dynamic factors than novices.

The present study aims to link temporal sensory data to reported wine complexity evaluations from both wine experts and novices. It is worth highlighting that the use of TCATA, or any temporal methods for that matter, is a novel approach to the study of complexity. Moreover, previous wine complexity studies have been limited in terms of 1) a lack of consistency in the makeup of the expert population and 2) no well-defined manipulations of complexity in the wine samples studied. Therefore, the present study contributes to the literature by demonstrating how experts (from the same wine education) and novices use temporal aspects in their evaluation of complexity for wines with specific ageing periods.

2. Methods and materials

2.1. Participants

A total of 82 participants were recruited at two levels of wine expertise: experts and novices. Wine experts were defined as those who had completed the Wine & Spirit Education Trust (WSET) Level 4 Diploma. This two-year qualification conveys both theoretical and practical expertise via the study of wine regions and analytical tasting practice, with a focus on how and why wine production and business factors influence the style, quality, and price of wines (https://www.wsetglobal.com/qualifications/wset-level-4-diploma-in-wines). Unlike most previous research involving wine expertise, where expertise was defined using a wide-ranging criteria e.g. (Parr, Heatherbell, & White, 2002), we specifically recruited WSET graduates to ensure they have comparable background knowledge and training. These experts were recruited via social media, for example the WSET Diploma alumni Facebook group, in the week leading up to the annual WSET Diploma graduation ceremony in January 2020 (where graduates were around the world travelled to London to attend the ceremony). Wine novices were people without any formal wine training, and were recruited via social media in the Aarhus region.

Results were collected from 22 experts (9 female) with an age range of 25 to 63 years (mean age = 41.2, SD = 11.2) and 60 novices (35 female) with an age range of 20 to 60 years (mean age = 30, SD = 9.4). Self-reported wine-expertise on a 3 point scale (1 = "I drink socially but don't know much about wine", 2 = "I know which wines I like and have been to some classes", 3 = "I work in the wine trade and/or have 5 + years' experience tasting wine formally") revealed that out of 60 novices, 47 self-reported level 1, and the remaining 13 self-reported level 2. Self-reported familiarity with Madeira wines on a 4-point scale (1 = "not at all", 2 = "a little", 3 = "moderately", 4 = "very") tracked with expertise level: for experts, average familiarity was 3.1 ($SD = 0.6$); for novices, average familiarity was 1.5 ($SD = 0.6$). The study was carried out in according with the Declaration of Helsinki, and all participants gave informed consent at the beginning of the study.

2.2. Wine samples

Six different wines from Justino's Madeira Wines were used in the study. Madeira wines were selected as examples of wines which regularly undergo long periods of cask ageing at the winery before being bottled, which makes it ideal for studying the influence of ageing on complexity. The wines consisted of three ageing points (3, 10, and 20 years) and two grape varieties (Tinta Negra, Malvasia). The ageing points were selected to cover the typical range of commercially available aged Madeira wines (Liddell, 2014). The two grape varieties were selected to have similar levels of residual sugar. To eliminate variations in bottling, all wines were obtained directly from barrel at the winery and shipped to the testing sites. Table 2 shows the chemical analysis of the wines (WineScan, FOSS, Denmark).

2.3. TCATA setup

TCATA procedure was set up in Compusense (Compusense Cloud, Academic Consortium, Guelph, CA). Attributes were selected based on a pre-study involving a group of sensory specialists and WSET diploma holders (N = 6), who came up with eight descriptors after tasting and discussion. Descriptors consisted out of three basic tastes (sweet, sour and bitter), two primary wine flavour descriptors (apple and orange zest) and three tertiary wine aroma descriptors (ground coffee, burnt caramel and roasted walnuts). We limited the number of attributes to eight, in line with previous TCATA studies involving wine (e.g. Jaeger et al., 2018; McMahon, Culver, Castura, & Ross, 2017; Poveromo & Hopfer, 2019). Attribute fading was set to 5 s after pilot testing.

All participants received training on the TCATA method directly making the TCATA evaluation. Training consisted of multiple stages: first, participants read a description of the TCATA methodology. Next, they heard a 60 s piece of music (Manchester Orchestra – The Silence) and practised using TCATA to select different elements they heard in the music (the attributes were: drums, voice, piano, violin, bass, electric guitar, flute). Afterwards, they completed a TCATA evaluation using a practice wine sample (Justino's Tinta Negra, 5 year old). The practice sample was selected to be similar, but not identical, to the actual wines being evaluated, to ensure that participants would get used to using the same list of attributes as for the actual evaluation.

Before starting the practice evaluation, participants were presented with a list of the eight attributes to review (the same list as for the actual evaluations) and had the opportunity to ask the experimenter for clarification if they were not sure about the definition of any attribute. For the practice wine evaluation, participants were first instructed to cleanse their palate with water. They then took a sip of the practice wine and started the timer. They were instructed to select all the attributes that described the wine at each moment in time. A pop-up window appears at 30 s telling the participants to swallow the wine. Data collection continued for a total of 120 s (30 s in-mouth evaluation plus up to 90 s to post-swallow evaluation). Participants could not stop the timer early, but were instructed that they could simply stop clicking if they no longer perceived any sensations.

2.4. Procedure

The testing sessions were held in two different locations. The expert group was mostly recruited and tested in London, UK, while the novices were recruited and tested at the sensory facilities at Aarhus University, Denmark. Data collection was performed on the Compusense platform presented on an iPad. The wines were served in 20 mL portions in

Table 2
Measurements of ethanol, glucose/fructose, and pH levels in tested wines.

Wine	Variety	Age	Ethanol %	Glucose/Fructose (g/L)	pH
1	Malvasia	3	18.97	97.13	3.02
2	Malvasia	10	18.57	106.96	2.98
3	Malvasia	20	18.98	106.76	2.69
4	Tinta Negra	3	18.39	120.06	2.93
5	Tinta Negra	10	18.06	115.95	3.07
6	Tinta Negra	20	18.75	112.85	3.03

opaque black "Royal Leerdam" wine glasses to avoid any bias towards wine colour. Each glass was identified with a randomly-generated 3-digit code. Participants also were provided with water and headphones (Fig. 1A).

The study consisted of three blocks (Fig. 1B). First, participants evaluated all six wines in terms of their complexity. Wine complexity was measured on an unmarked visual analogue scale anchored by "not complex at all" and "very complex". Participants rinsed their mouths with water between each trial. The order of wines presented were randomised.

After participants have made the complexity ratings, the tray with wines were taken away and the experimenter switched the set of three-digit codes and randomised the placement of glasses on the tray. This was to ensure that participants wouldn't remember any previously rated wines. The experimenter then returned the tray together with a glass of practice wine. Meanwhile, participants completed the TCATA practice session as described above (Section 2.3).

After the TCATA practice session, participants then evaluated the six wines using TCATA methodology using the same procedure as in the TCATA wine practice. After every sample, participants were instructed to rinse their mouths with water. No time restrictions were given in between the samples. The wines were presented in random order.

Finally, participants answered a free text question "What makes a wine complex?", followed by demographic questions regarding their age, gender, level of wine expertise, and familiarity with Madeira wines.

2.5. Data analysis

Complexity evaluation data was recorded from 0 to 100, with 0 being not complex at all, and 100 being very complex. After checking for data normality (Shapiro-Wilk test), a repeated-measures analysis of variance (RM-ANOVA) was conducted with years of wine ageing (3, 10, 20) and grape variety (Malvasia, Tinta Negra) as within participant factors and wine expertise (novice, expert) as between participant factor (SPSS, version 25). For all ANOVA tests, the degrees of freedom were adjusted by using the Greenhouse-Geisser correction if the sphericity assumption was violated, and all follow-up post-hoc comparisons were Bonferroni corrected. TCATA data was evaluated in terms of the total number of citations per attribute/wine/participant, total citation duration per wine/participant, and dynamic sensory profiles. Citation proportions were calculated as the percentage of participants who selected a given attribute at each moment in time. Smoothed TCATA curves and product trajectory graphs for each product and wine expertise group were generated using TCATA sensory tool in XLSTAT 2020 (Addinsoft, Paris, France). Product trajectory plots were drawn based on correspondence analysis between TCATA data and wines.

To analyse the relationship between rated complexity and temporal sensory data, we first divided the TCATA data into beginning (1–15 s), middle (16–30 s), and end (31–120 s) reflecting the attack, mid palate, and aftertaste of a wine. We then calculated operationalisations of single/multiple static/dynamic factors (Table 1) as follows for each wine/participant:

- Single static: a) overall sum of all attribute citations as an operationalisation of total intensity
- Multiple static: b) the total number of attributes used
- Single dynamic: c) the total duration of time in which the participant was able to detect any attribute (i.e. the "length" of the wine)

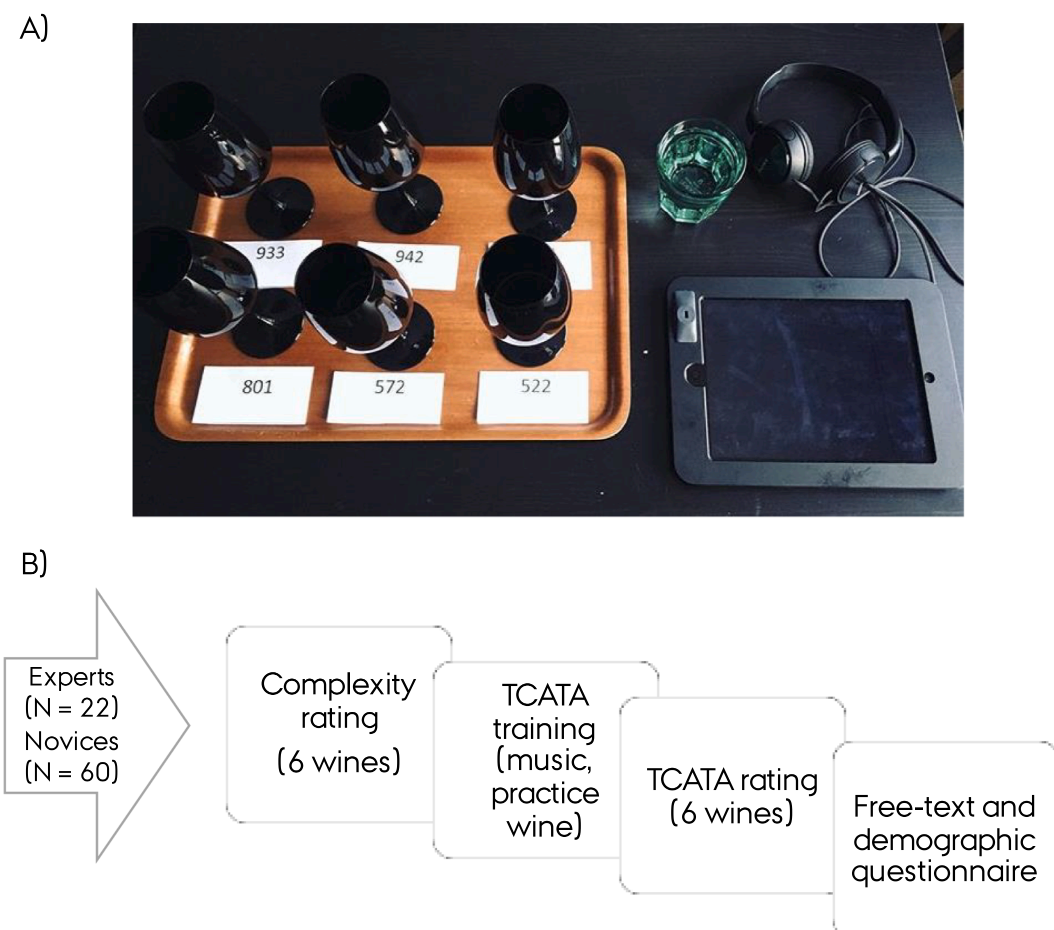

Fig. 1. A) Study setup: six wine samples served in black glasses with 3-digit identifiers, water, headphones, and an iPad. B) Schematic summary of testing procedure.

- Multiple dynamic: d) to reflect how flavours changed over time, we calculated sum of absolute attribute-specific changes in citation rate from the beginning to the middle period, and from the middle to the end period.

In order to explore the drivers of complexity, we used a procedure similar to that used by Nguyen & Varela (2021): first, a PCA was produced based on the beginning, middle, end citation rates for all 8 attributes were plotted for all products. Ratings of complexity and the aforementioned *meta*-factors a)-d) were then projected onto the PCA as supplementary variables to show the driver of complexity and its relation to *meta*-factors a) to d) as well as to specific temporal sensory qualities over time.

Free text answers regarding the definition of complexity were independently coded by three judges (the first two authors and a WSET diploma holder) according to the following five categories: single static, multiple static, single dynamic, multiple dynamic, and other (see Table 1 for definitions). The coding process entailed reading each free text entry, then deciding which of the categories was mentioned. For example, the entry "Broad range of flavour and aromas, balance of basic tastes and structure, fruitiness, not too sweet, new flavours/things emerge and develop over time" was coded as single static ("not too sweet"), multiple static ("balance"), and multiple dynamic ("new flavours emerge and develop over time"). The proportion of each category mentioned overall was compiled separately for each wine expertise group.

3. Results

3.1. The effect of ageing and grape variety on complexity rating

Participants' ratings for madeira samples in all conditions are shown in Fig. 2. RM-ANOVA revealed a significant main effect of wine ageing ($F(2,79) = 9.28$, $p < .005$, *Wilks Lambda* $= 0.95$). We did not observe any main effect of grape variety ($F(1,80) = 0.26$, $p = .611$) or expertise ($F(1,80) = 0.11$, $p = .744$), nor any interaction effects between the three factors. Following up on the main effect, we see that, in a blind tasting with opaque black glasses, complexity ratings were significantly higher for wines with 20 years of ageing ($M = 56.03$, SE $= 2.19$) compared to wines with 10 years of ageing ($M = 49.23$, SE $= 2.16$, $p = .018$) and compared to wines with 3 years of ageing ($M = 43.14$, SE $= 2.48$, $p < .005$).

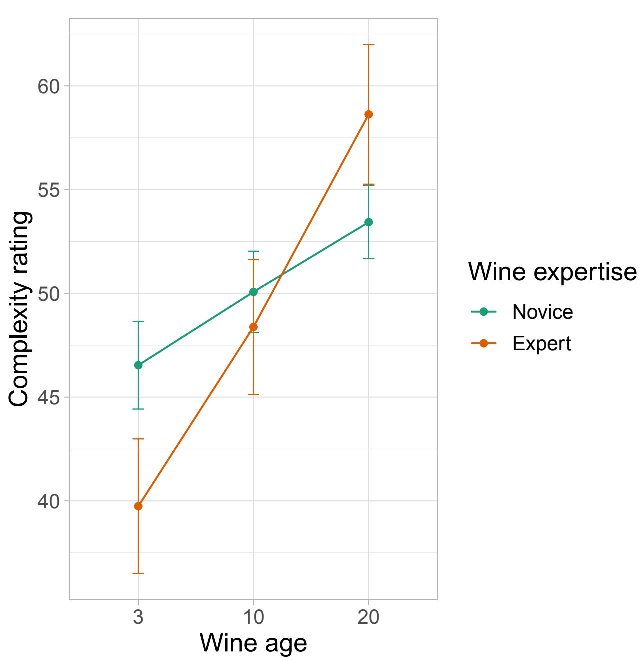

Fig. 2. Average complexity rating of wines at 3, 10, and 20 years of age for wine experts and novices. Error bars indicate standard error of the means.

As one of our hypotheses was to explore the role of wine expertise, we further assessed the interaction between wine expertise and wine ageing (Fig. 2). For novices, there were no significant differences in complexity between wines of different ageing points. For experts, complexity ratings were significantly higher for wines with 20 years of ageing ($M = 58.63$, SE $= 3.75$) compared to wines with 10 years of ageing ($M = 48.38$, SE $= 3.70$, $p = .046$) and compared to wines with 3 years of ageing ($M = 39.74$, SE $= 4.25$, $p = .001$). As seen from Fig. 2, experts also reported a wider range of complexity values compared to novices.

3.2. The effect of ageing and grape variety on temporal flavour evolution

3.2.1. TCATA visualisation

TCATA evaluations were aggregated and citation proportions were calculated in order to visualise general attribute patterns during the period of 120 s for all wines (Fig. 3). Overall, experts had higher citation proportions than novices across the entire evaluation period, suggesting that experts selected attributes more often than novices. Moreover, novices primarily selected the basic tastes (sour, bitter, sweet) during the 30 s in-mouth evaluation, whereas experts used a mixture of tastes and flavours. For experts, the ageing process for the same grape variety brought out notable changes in the wine, with 1) a general shift towards more tertiary flavours (walnut, caramel, coffee) and 2) longer aftertaste durations with more significant citations. The 3 year old Malvasia was distinctly lower in roasted walnut flavours during the in-mouth evaluation compared to other wines. The 10 year old Malvasia was characterised by clear orange zest flavours that develop in the mouth (20–30 s) and immediately after swallowing (40 s), followed by pronounced coffee flavours that remain throughout the finish (60–120 s). The 20 year old Malvasia is characterised by high acidity and orange zest on the entry (0–10 s), with high levels of acidity, orange zest, apple, and walnut interspersed throughout the finish (40–120 s). For Tinta Negra, the 3 year old sample is characterised by lower than average citation rates of roasted walnuts, and higher than average citation rates of bitterness, throughout the aftertaste evaluation period. The 10 year old Tinta Negra has notable sweetness both during the in-mouth evaluation (15–20 s) and after swallowing (40–45 s). The 20 year old Tinta Negra has notable sweetness during the in-mouth evaluation (around 10 s), followed by significantly higher citations of burnt caramel (30–80 s) and orange zest (35–45 s) post-swallowing.

For novices, the effect of ageing was less clear because there were fewer significant differences in attributes between products. The 3 year old Malvasia was characterised by apple flavours during the beginning of the aftertaste (40–50 s), the 10 year old Malvasia was only different for brief periods during the aftertaste in terms of orange zest and apple, and, similar to the expert evaluation, the 20 year old Malvasia was significantly different from the other samples due to the significant lack of sweetness on the palate and high acidity throughout the in-mouth and aftertaste evaluations. The 3 year old Tinta Negra was characterised by burnt caramel (around 10 s) and coffee notes (20 s) in the mouth, with significant apple flavours during the finish (60–100 s). The 10 year old Tinta Negra was characterised by notable sweetness around 30 s, and with significant burnt caramel flavours during the aftertaste (around 60 s and 90 s). The 20 year old Tinta Negra was characterised by brief periods of roast walnut during the first 15 s of evaluation, then immediately after swallowing (35 s).

3.2.2. Multivariate analysis of TCATA attributes

Symmetrical correspondence analysis biplots were used to visualise the temporal evolution of wines over the 120 s of evaluation for each expertise group (Fig. 4). An overview of the plot makes it clear that product trajectories are much closer together for novices than for

Fig. 3. Smoothed TCATA curves representing the citation proportions of attributes for each wine for A) experts and B) novices, with various colours representing each attribute. Thicker lines denote portions of an attribute curve which are significantly different from the same attribute in all other pooled products, where the reference line for that portion is displayed via a dashed line (using Fisher's exact test at 5% significance level). Time is expressed in seconds, with a vertical black line at t = 30 indicating the point at which participants were asked to swallow.

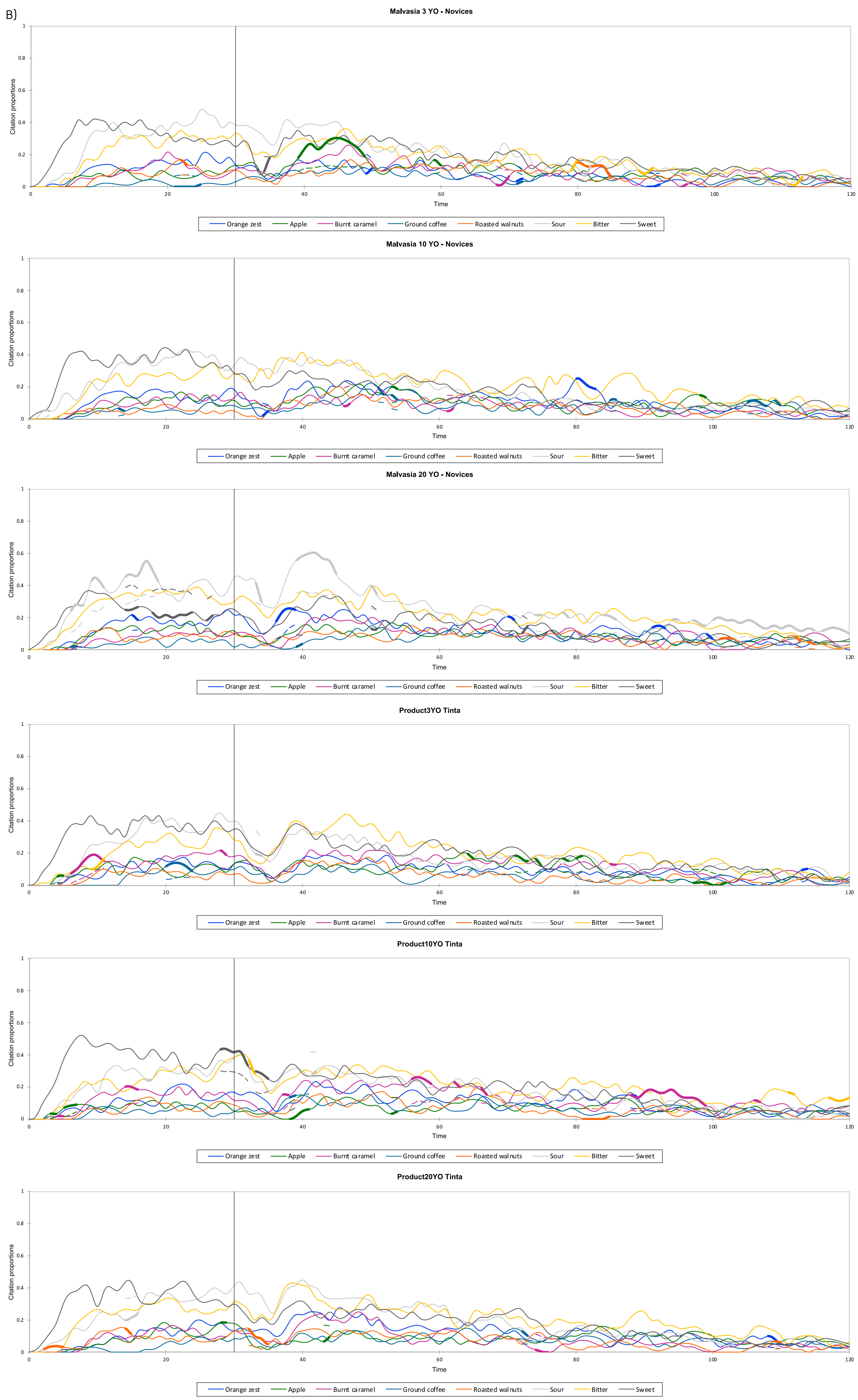

Fig. 3. (*continued*).

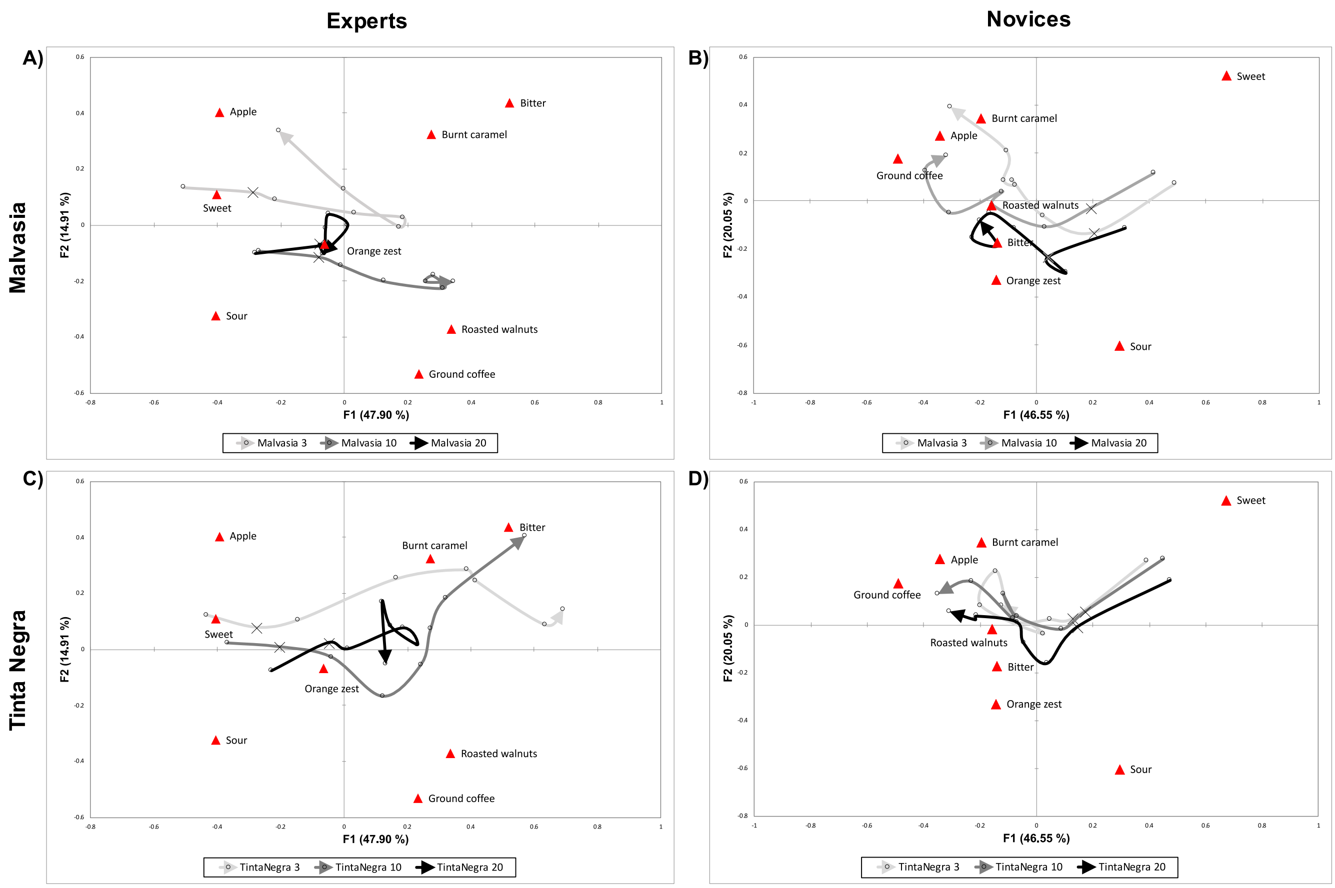

Fig. 4. Correspondence Analysis trajectories of TCATA evaluation for experts (A and C) and novices (B and D). Each trajectory indicates the flavour evolution over time for one wine. Three age points (3, 10, and 20 years) are shown in each graph for the same grape variety: Malvasia (A and B) and Tinta Negra (C and D). Attributes are represented by red triangles. Time markers (black circles) are positioned along each trajectory at 15 s intervals to show progression of evaluation time, with a X at the 30 s mark indicating when the participants were instructed to swallow the wine. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

experts, which supports the observation from the TCATA curves that experts can discriminate between the wines better than novices. For experts, the correspondence analysis accounted for 62.81% of the variance. Factor 1 is (47.90% of variance) is defined roughly by the temporal nature of the data, with trajectories generally trending towards the right hand side of the plot. Factor 1 is also defined by primary/fruity attributes on the left, with tertiary flavours on the right hand side. Factor 2 (14–91% of variance) is positively defined by bitter taste and apple flavour, and negatively defined by roasted flavours and sour tastes. This seems to be driven by differences in the wines themselves, with the trajectories for the younger wines towards the top of the plot, and for older wines towards the bottom. For Malvasia, the youngest 3 year old sample clearly stays in the apple/sweet space, whereas the older wines are much more similar and move closer to the tertiary flavours on the finish. For Tinta Negra, it is clear that the younger wines (3 and 10 year old) drift towards bitter tastes and caramel flavours on the finish, whereas the 20 year old wine does not. Interestingly, for both Malvasia and Tinta Negra, the oldest wines show the least evolution over time, as demonstrated by the shorter trajectories. In fact, for both wines, the end of the trajectory is very close to the timepoint of swallowing, which suggests that the finish of the wine reflects the same flavours as in the mouth.

For novices, the correspondence analysis accounted for 66.60% of the variance. Factor 1 (46.55% of variance) is also defined by the temporal nature of the data, with trajectories moving towards the left side of the plot. Factor 2 (14.91% of variance) is positively defined by sweetness and negatively defined by sourness, and as for the experts, seems to be divided by age, with younger wines towards the top of the plot, and older wines towards the bottom. For Malvasia, the wines move from sweetness to more apple and burnt caramel on the finish, except for the 20 year old sample which is more associated with sourness and the finish remains defined by bitterness and roasted walnuts. For Tinta Negra, the trajectories are very similar for all three wines, moving from sweetness to walnuts, apple, and ground coffee. Compared to experts, there is a less clear pattern of the older wines showing a shorter trajectory (e.g. showing less evolution).

3.3. Static and dynamic drivers of complexity

The sensory description and complexity rating of all wines by experts can be seen in Fig. 5A. For experts, both the 20 year old wines and the 10 year old Malvasia are more aligned with complexity compared to the other wines. Complexity is closely related to the number of attributes, total citations, and length, but is orthogonal to the degree to which the wine changes in the mouth. In terms of sensory attributes, complexity is most associated with bitterness (including bitter tastes as well as flavours typically associated with bitter tastes) during in-mouth tasting (bitter beginning, ground coffee beginning, burnt caramel beginning and middle) as well as roasted walnut flavour as it develops in the mouth and lingers on the finish. In fact, most attributes were associated with complexity, with the exception of apple flavours and sourness on the midpalate.

The sensory description and complexity rating of all wines by novices can be seen in Fig. 5B. For novices, complexity appears to be based on grape variety more than ageing time. Specifically, the 20 year old Malvasia is most aligned with complexity, followed by the 3 and 10 year

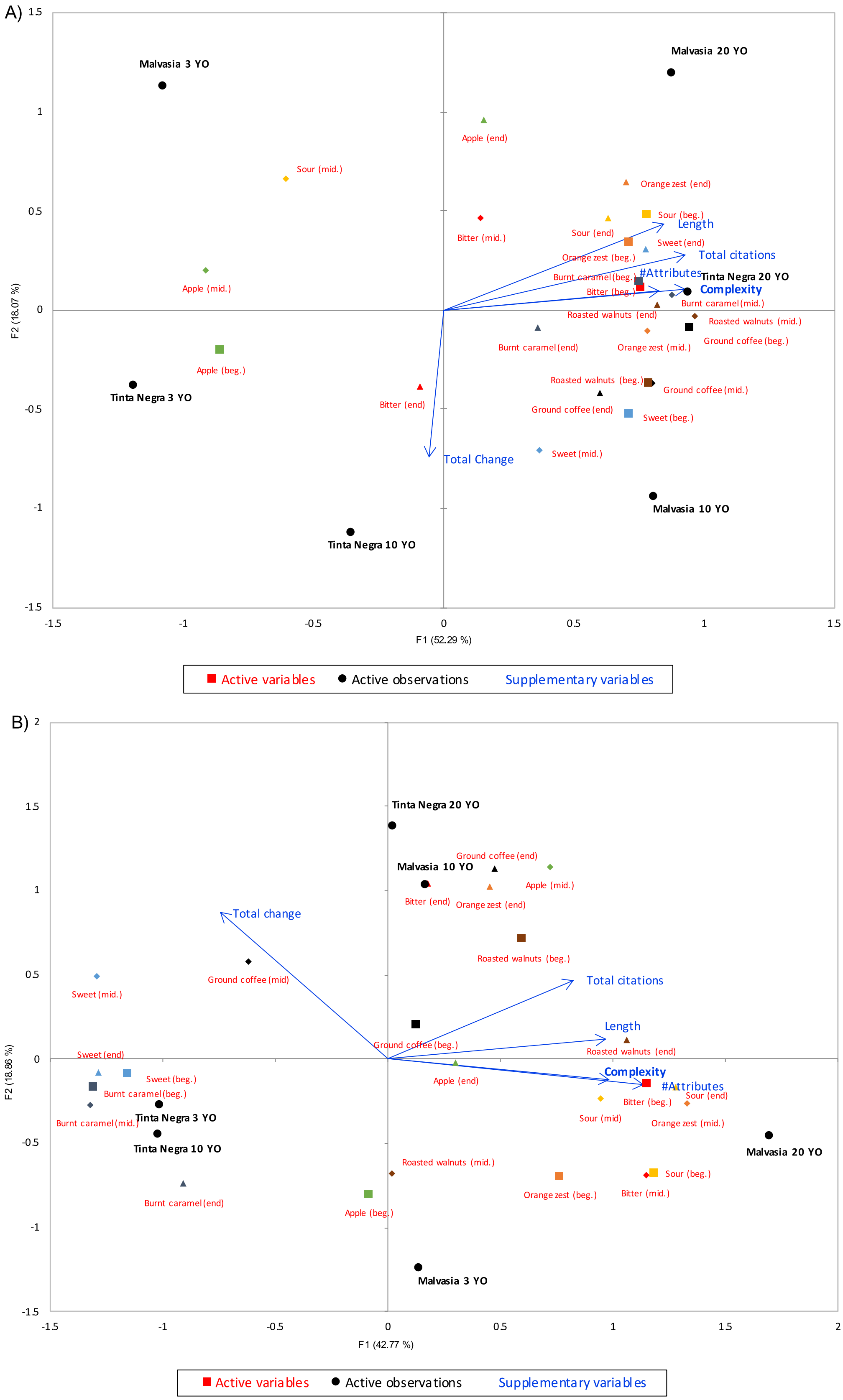

Fig. 5. Driver of complexity analysis based on TCATA temporal attribute citation rates (beginning, middle, end) projected on PCA product-space by both experts (A) and novices (B). Blue vectors (supplementary variables) show wine complexity ratings and *meta*-factors (# attributes, length, total intensity, total change over time). Product attributes at different points in time are represented by red text, with squares (■) indicating attribute citation rates at the beginning (1–15 s), diamonds (◆) indicating middle (16–30 s) and triangles (▲) indicating end (31–120 s) of the tasting experience. Products (wines) are shown by black circles. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

old Malvasia wines and the 20 year old Tinta Negra. Similar to for experts, complexity is closely related to the number of attributes, length, and total citations, but is opposite to the degree to which the wine changes in the mouth. In terms of sensory attributes, complexity is predominantly associated with sourness, both in terms of sour taste and flavours associated with sourness (sour beginning, middle, end; orange zest middle), and, like for experts, with bitterness in the beginning and roasted walnuts at the end. Most notably different from the experts is that novices considered sweetness and burnt caramel (at all stages of tasting) to be indicative of low complexity.

3.4. Free text analysis

The free-text answer to the question "what makes wine complex?" yielded a variety of responses (Table 3). Overall flavour intensity was prevalent in the single static category, with several novices naming a single predominant element (e.g. "smooth mouthfeel", "sweet tasting"). In the multiple static category, having different flavours was the predominant reason, followed by several mentions of balance and integration by both novices and experts. For the dynamic categories, the length of wine and flavour evolution were the only reasons in the single and multiple dynamic categories, respectively. In the "other" category, reasons involved the ability of the wine to age, cognitive difficulty ("needs a longer time to process and analyse", "a complex wine takes a lot of thinking and concentration"), and story-telling ("complex wine has a degree of expression that tells the story of its origins", "how the flavours gradually unfold…is like telling a story or listening to a song").

For experts, the most common reason for complexity involved the wine having multiple elements at any point, followed by having a single dynamic element (length) and multiple dynamic elements (flavour evolution). For novices, having multiple elements at a snapshot view was also the most common reason, followed by multiple dynamic elements and a single static element (predominantly overall flavour intensity).

4. Discussion

The present study aimed to evaluate the influence of wine ageing on the sensory and complexity evaluations from wine experts and novices, in order to gain a more complete understanding of static and dynamic drivers of complexity. Both ANOVA and TCATA results revealed that, compared to novices, experts were in fact better able to discriminate between wines of different ages (H2), both in terms of complexity ratings as well as sensory evaluations. For instance, TCATA visualisation showed that novices could not discriminate between wines of different age points as well as experts, when it came to using taste and flavour attributes, since there were much fewer flavour attributes with significant differences. Moreover, longer aged wines were indeed rated as more complex (H1), but only by experts. Keeping in mind that all wines were evaluated blind in black opaque glasses, our results validate the value of consistent training in our group of wine experts (Wang & Prešern, 2018). Furthermore, the fact that novices could not discriminate between the wines on a sensory level (H2) could help explain why novices could not discriminate between the different age points when it came to complexity ratings, since the wines perhaps did not fundamentally taste different.

Table 3
Percentage of coding categories that matched participants' free text responses for the question "what makes a wine complexity?"

Category	Experts (N = 22)	Novices (N = 60)
Single static	14%	23%
Multiple static	100%	85%
Single dynamic	41%	13%
Multiple dynamic	27%	28%
Other	23%	17%

To investigate H3, the relationship between complexity and sensory drivers were evaluated both via quantitative (TCATA) and qualitative (free-text) methods. Quantitative analysis demonstrated that both experts and novices associated complexity with the number of sensory attributes, length, and total intensity. However, the degree to which the wine changes during the tasting experience did not appear to be associated with complexity when it comes to Madeira wines. In comparison, free text analysis revealed that complexity was indeed associated with both static and dynamic factors, with experts giving more weight to dynamic factors (H3). Both groups considered a large number of simultaneously perceived flavours to be the predominant factor behind complexity. However, experts considered the dynamic elements of wine much more than novices, with length being a major contributor to complexity. Interestingly, PCA projections (Fig. 5) revealed that both novices and experts in fact associated complexity with length, even though only experts verbalised it.

Looking at the specific sensory drivers of complexity in Madeira wines, both experts and novices associated greater complexity with bitterness on the entry and roasted walnut flavours on the finish. This shows, once again, that novices do consider temporal elements of the wine tasting experience, even if they do not state it explicitly. The biggest difference between experts and novices was that, whereas experts associated sweetness with complexity, the novices clearly did not. This could reflect the general abhorrence of novices to sweetness in fine wines (Bruwer et al., 2011), whereas experts have learned to see sweetness as a desirable characteristic in fortified wines such as Madeira.

To address the question of why changes over time were not associated with complexity, we could look at the project trajectories (Fig. 4). Contrary to the idea that complex wines would show more evolution in the mouth (Spence & Wang, 2018b), the TCATA trajectories reveal that the oldest wines in fact showed the least evolution over time, as demonstrated by the shorter trajectories. In fact, for both 20 year old wines, the end of the trajectory is very close to the timepoint of swallowing, which suggests that the finish of the wine reflects the same flavours as in the mouth. This suggests that as wine ages, the flavours become more integrated, and the wine retains a tight-knit blend of primary and tertiary flavours from the beginning to the end.

One limitation of the present study is that only Madeira wines were investigated, making our results difficult to generalise for wines in general. Madeira, especially the Malvasia and Tinta Negra varieties used in the present study, is unique even in the world of fortified wines for having at once high levels of alcohol, sweetness, and acidity (Liddell, 2014). Therefore, factors behind evaluations of complexity may be different for dry, non-fortified wines which constitutes, after all, the majority of the wine market (Fielden, 2009). The relative obscurity of Madeira wines may also have been a surprise to novices, many of whom have never tasted Madeira before. This lack of prior experience could have led to the failure to discriminate between the wines for novices, especially since all wines had similar levels of alcohol, sweetness, and acidity (Table 2). As further evidence, self-reported familiarity with Madeira wine revealed a clear difference between novice and expert groups, with novices being less familiar with Madeira wines compared to experts. Therefore, the novices' inability to discriminate between the wine samples in terms of complexity ratings (Section 3.1) and TCATA trajectories (Section 3.2.2) could have been due to their relative unfamiliarity with the samples. Another limitation in the current study was that we could not control for the cultural differences between the expert and novice groups. While the experts were tested in the UK, many of them did not live in the UK, and had only travelled to London on the occasion of the annual WSET Diploma graduation ceremony. On the other hand, while novices were tested in Denmark, many were international students. Therefore, there could have been underlying cultural differences (e.g. habits regarding drinking fortified wines) that could have led to differences in complexity perception beyond those related to

WSET Diploma wine training.

Looking towards the future, the investigation into wine complexity can be deepened via the use of biometric sensors. One potential direction of investigation is provided by the free-text responses which mentioned cognitive difficulty as a measure of wine complexity (e.g. "a complex wine takes a lot of thinking and concentration"). If this were the case, neuroimaging, for instance with electroencephalography (EEG), could be incorporated to study how complexity corresponds to more cognitive load. Another important future direction is to link wine complexity with the taster's hedonic response. Both explicit and implicit measures of wine liking (e.g. via facial expressions or heart rate variability) can be combined with evaluations of complexity to better understand the extent to which complexity is truly desirable in wines. Previous studies have shown that, for instance, while complexity seems to be associated with liking (Parr et al., 2011), it does not necessarily translate to a higher willingness to pay (Wang & Spence, 2019).

5. Conclusion

The present study demonstrated that wine complexity, as produced by varying lengths of ageing time, is driven by both static and dynamic factors. While there were striking similarities in how novices and experts associated complexity with the total number of flavours, intensity, and length, only experts were able to discriminate between the wines using both complexity ratings and sensory evaluations.

Findings from the present study have important implications for researchers as well as wine producers and educators. Unlike previously thought, novices and experts both consider temporal aspects of flavour when it comes to complexity, even though novices may not verbalise it consciously. Moreover, wine ageing, a expensive process in the winery, is not necessarily recognised by novices as leading to more complex wines. Fortunately, wine education does in fact result in accurate discrimination (Owen & Machamer, 1979; Wang et al., 2021), even under strict blind tasting conditions. Faced with an increasingly knowledgeable consumer population, especially in growing wine markets, it is more important than ever for producers to consider viticultural and vinification factors contributing to wine complexity.

CRediT authorship contribution statement

Qian Janice Wang: Conceptualization, Methodology, Software, Formal analysis, Writing - original draft, Writing - review & editing, Visualization, Supervision. **Tadas Niaura:** Software, Formal analysis, Writing - review & editing. **Kevin Kantono:** Conceptualization, Methodology, Formal analysis, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by an AUFF starting grant from Aarhus University received by the QJW. The authors would like to thank Henrique Fernandes, Line Ahm Mielby, and Domen Prešern for helping with pilot testing; and Justino's Madeira Wines, SA, for generously providing the wine samples used in the study.

References

Ares, G., Jaeger, S. R., Antunez, L., Vidal, L., Gimenez, A., Coste, B., … Castura, J. C. (2015). Comparison of TCATA and TDS for dynamic sensory characterization of food products. *Food Research International, 78*, 148–158.

Berlyne, D. E. (1960). *Conflict, Arousal and Curiosity*. Eastford, CT: Martino Fine Books.

Bruwer, J., Saliba, A., & Miller, B. (2011). Consumer behaviour and sensory preference differences: Implications for wine product marketing. *Journal of Consumer Marketing, 28*(1), 5–18.

Castura, J. C., Antúnez, L., Giménez, A., & Ares, G. (2016). Temporal Check-All-That-Apply (TCATA): A novel dynamic method for characterizing products. *Food Quality and Preference, 47*, 79–90.

Fielden, C. (2009). *Exploring the world of wines and spirits*. London, UK: Wine & Spirit Education Trust.

Jaeger, S. R., Alcaire, F., Hunter, D. C., Jin, D., Castura, J. C., & Ares, G. (2018). Number of terms to use in temporal check-all-that-apply (TCATA and TCATA fading) for sensory product characterisation by consumers. *Food Quality and Preference, 64*, 154–159.

Jinks, A., & Laing, D. G. (2001). The analysis of odor mixtures by humans: Evidence for a configurational process. *Physiology and Behavior, 72*(1-2), 51–63.

Kemp, B., Trussler, S., Willwerth, J., & Inglis, D. (2019). Applying temporal check-all-that-apply (TCATA) to mouthfeel and texture properties of red wines. *Journal of Sensory Studies, 34*, Article e12503.

Langlois, J., Dacremont, C., Peyron, D., Valentin, D., & Dubois, D. (2011). Lexicon and types of discourse in wine expertise: The case of *vin de garde*. *Food Quality and Preference, 22*(6), 491–498.

Lawless, H. T., & Heymann, H. (2010). *Sensory Evaluation of Food Principles and Practices* (2nd ed.). New York, NY: Springer.

Liddell, A. (2014). *Madeira: The Mid-Atlantic Wine*. London, UK: Hurst Publishers.

McMahon, K. M., Culver, C., Castura, J. C., & Ross, C. F. (2017). Perception of carbonation in sparkling wines using descriptive analysis (DA) and temporal check-all-that-apply (TCATA). *Food Quality and Preference, 59*, 14–26.

Meillon, S., Urbano, C., & Schlich, P. (2009). Contribution of the Temporal Dominance of Sensations (TDS) method to the sensory description of subtle differences in partially deal- coholized red wines. *Food Quality and Preference, 20*(7), 490–499.

Nguyen, Q. C., & Varela, P. (2021). Identifying temporal drivers of liking and saitation based on temporal sensory descriptions and consumer ratings. *Food Quality and Preference, 89*, 1041043.

Owen, D. H., & Machamer, P. K. (1979). Bias-free improvement in wine discrimination. *Perception, 8*(2), 199–209.

Parr, W. V. (2015). Unravelling the nature of perceived complexity in wine. Practical Winery & Vineyard, January, 5-8.

Parr, W. V., Heatherbell, D., & White, K. G. (2002). Demystifying wine expertise: Olfactory threshold, perceptual skill and semantic memory in expert and novice wine judges. *Chemical Senses, 27*(8), 747–755.

Parr, W. V., Mouret, M., Blackmore, S., Pelquest-Hunt, T., & Urdapilleta, I. (2011). Representation of complexity in wine: Influence of expertise. *Food Quality & Preference, 22*(7), 647–660.

Poveromo, A. R., & Hopfer, H. (2019). Temporal Check-All-That-Apply (TCATA) reveals matrix interaction effects on flavor perception in a model wine matrix. *Foods, 8*, 641. https://doi.org/10.3390/foods8120641

Robinson, J., & Harding, J. (2015). Ageing. *The Oxford Companion to Wine* (4th ed.). Oxford, UK: Oxford University Press.

Sáenz-Navajas, M.-P., Avizcuri, J.-M., Ballester, J., Fernández-Zurbano, P., Ferreira, V., Peyron, D., & Valentin, D. (2015). Sensory-active compounds influencing wine experts' and consumers' perception of red wine intrinsic quality. *LWT – Food Science and Technology, 60*(1), 400–411.

Schlich, P., Medel Maraboli, M., Urbano, C., & Parr, W. V. (2015). Perceived complexity in Sauvignon blanc wines: Influence of domain-specific expertise. *Australian Journal of Grape and Wine Research, 21*(2), 168–178.

Spence, C., & Wang, Q.(J.) (2018). On the meaning(s) of complexity in the chemical senses. *Chemical Senses, 43*, 451–461.

Spence, Charles, & Wang, Qian Janice (2018). What does the term 'complexity' mean in the world of wine? *International Journal of Gastronomy and Food Science, 14*, 45–54.

Wang, Q. J., Fernandes, H., & Fjældstad, A. (2021). Is perceptual learning generalizable in the chemical senses? A longitudinal pilot study based on naturalistic blind wine tasting training scenario. *Chemosensory Perception.*. https://doi.org/10.1007/s12078-020-09284-x

Wang, Qian Janice, & Prešern, Domen (2018). Does blind tasting work? Investigating the impact of training on blind tasting accuracy and wine preference. *Journal of Wine Economics, 13*(4), 384–393.

Wang, Q. J., & Spence, C. (2018). Wine complexity: An empirical investigation. Food Quality & Preference, 68, 238-244.

Wang, Q. J., & Spence, C. (2019). Is complexity really worth paying for? Investigating the perception of wine complexity for single varietal and blended wines in consumers and experts. *Australian Journal of Grape and Wine Research, 25*, 243–251.

Waterhouse, A. L., Sacks, G. L., & Jeffery, D. W. (2016). *Understanding wine chemistry*. Hoboken, NJ: Wiley-Blackwell.