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Sensory impact of skin contact on white wines characterized by descriptive analysis, time–intensity analysis and temporal dominance of sensations analysis

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ABSTRACT

In white wine fermentation, extended skin contact of crushed grapes is frequently used to increase the varietal aromas of white Riesling and Gewürztraminer wines. At the same time, phenolic compounds are extracted which can yield significant increases in bitterness and/or astringency. Descriptive analysis (DA), time–intensity analysis (TI) and temporal dominance of sensation (TDS) analysis were used to evaluate the changes in flavor of Riesling and Gewürztraminer wines made with varying skin contact times. DA showed that Riesling wines differed only in bitterness and color. In contrast, Gewürztraminer wines varied significantly in bitterness, sweetness, sourness, and astringency as well as for several aroma notes and color. 2009 and 2010 Gewürztraminer wines increased in intensity of honey/caramel, floral, and lemon aromas as well as yellow color, whereas peach/apricot was only significant in 2009 and apple and green grass/green banana only in 2010. Regarding the temporal properties of orally perceived modalities, bitterness TI curves recorded from Gewürztraminer differed significantly in maximum intensity and area under the curve, while Riesling showed no significant differences in any TI parameter. Increasing skin contact altered the dominance of orally perceived attributes. Fermenting the grapes completely on their skins produced a wine, which was significantly more bitter than all other wines according to TI and DA. However TDS analysis showed that the dominating sensation in this wine was not the bitter taste but the astringent mouth feel. TDS revealed further subtle differences caused by botrytized grape material, altering sourness and astringent perception.

Introduction

Improving wine quality

Sensory properties of wines are determined by grape variety and geographic heritage but to a large extent also by oenological treatments applied during grape processing and winemaking. To enhance varietal wine aroma in white wines, extended skin contact of grapes is often applied to facilitate a better extraction of skin constituents such as free and bound aroma compounds, which will enhance floral and fruity characters in subsequent wines and thus improve wine quality (Cabaroglu et al., 1997; Fischer, Trautmann, Binder, Wilke, & Göritz, 2001; Gómez-Míguez et al., 2007; Marais & Rapp, 1986; Palomo, Pérez-Coello, Díaz-Maroto, González Viñas, & Cabezudo 2006).

Benefits and drawbacks of skin maceration

While Gewürztraminer, Riesling, and Muscat varieties most likely benefit from skin contact due to a high amount of extractable aroma precursors in their skins, other varieties such as Chardonnay, Sauvignon Blanc or Airén benefit to a lesser extent. Wines may exhibit lower fruitiness or even negative spicy attributes masking varietal characters (Cejudo-Bastante, Castro-Vázquez, Hermosín-Gutiérrez, & Pérez-Coello, 2011; Marais, 1998; Marais & Rapp, 1986; Test, Noble, & Schmidt, 1986). Furthermore, the impact of skin contact on wine quality also depends on grape processing variables such as contact time, storing temperature, addition of sulfur dioxide (SO_2) or use of pectolytic enzymes (Arnold & Noble, 1979; Cheynier, Rigaud, Souquet, Barillère, & Moutounet, 1989; Hernanz et al., 2007; Marais & Rapp, 1986; Ough, 1969; Ramey, Bertrand, Ough, Singleton, & Sanders, 1986; Reynolds, Wardle, & Dever, 1993). This is mostly rationalized by the concurrent extraction of potassium and polyphenols from

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grape skins and seeds, which both affect sensory properties of wine.

Extended up-take of potassium enhances potassium bi-tartrate precipitation and thus reduces tartaric acid concentration. As a consequence, titratable acidity drops, pH increases, and perceived sourness is diminished (Boulton, 1980; Ough, 1969; Palomo et al., 2006; Ricardo-da-Silva, Cheynier, Samsom, & Bourzeix 1993). Extensive focus was directed towards the extraction of phenols during skin contact of white grapes. While concentrations of the skin and seed derived flavonoids catechin and epi-catechin increased, the flesh derived non-flavonoids, such as caftaric acid, were affected much less (Arnold & Noble, 1979; Cejudo-Bastante et al., 2011; Cheynier et al., 1989; Fuleki & Ricardo-da-Silva, 2002; Gómez-Míguez et al., 2007; Hernanz et al., 2007; Ramey et al., 1986). Some authors welcome the enrichment of total phenols due to their anticipated health benefits (Darias-Martın, Rodríguez, Dıaz, & Lamuela-Raventós, 2000; Fuhrman, Volkova, Suraski, & Aviram, 2001) while other point out the negative impact caused by enhanced bitterness and astringency (Arnold & Noble, 1978).

Impact of skin contact on taste properties

Chardonnay wines varying in skin contact treatments between 0 and 24 h exhibited no significant differences in bitterness and astringency based on pair-wise comparison tests (Test et al., 1986) or descriptive analysis (Arnold & Noble, 1979). In both cases, authors assumed that an increase of 110 mg/L total phenols (expressed as gallic acid equivalents, GAE) was too marginal to cause linear differences in bitterness or astringency. However, according to Singleton, Zaya, and Trousdale (1980), bitterness was rated significantly higher in a Chardonnay wine made with a skin contact period of 24 h, presumably due to a larger increase in total phenols, while the same treatment exhibited no effect for French Colombard or Chenin Blanc. After skin fermentation of a white wine, total phenols rose more than 200 mg/L GAE, which enhanced astringency and, to a smaller extent, bitterness (Singleton, Sieberhagen, De Wet, & Van Wyk, 1975).

It is surprising that no study has thus far investigated the modulation of temporal perceptions in wine due to skin contact. Noticeable bitterness in white wine has a negative connotation among consumers, partially due to its lingering taste which frequently dominates the aftertaste of the particular wine. The objective of this study is thus to apply sensory techniques to determine the temporal evolution of taste attributes for wines prepared with varying skin contact treatments.

Time related sensory methods

Oral perceptions such as bitterness and astringency are commonly evaluated in a static mode when applying descriptive sensory analysis (DA). To gain further temporal information about the sensory impact of polyphenols, time–intensity analysis (TI) was the method of choice for decades (Brossaud, Cheynier, & Noble, 2001; Fischer, Boulton, & Noble, 1994; Peleg, Gacon, Schlich, & Noble, 1999). However, if more than one attribute has to be studied, TI is a rather time-consuming technique as only one attribute is commonly evaluated at a time (Cliff & Heymann, 1993). Furthermore, TI analysis bears the risk of bias due to halo-dumping effects (Clark & Lawless, 1994). To circumvent this limitation, TDS was developed. TDS records, over time, which attribute is currently viewed as the dominant one by the panel and judges make the choice from a given list of orally perceived traits (Labbe, Schlich, Pineau, Gilbert, & Martin, 2009; Meillon, Urbano, & Schlich, 2009; Pineau et al., 2009). In contrast to TI analysis where one sole attribute is assessed, TDS monitors all oral perceptions parallel. Thus, TDS curves are also accounting for interactions among taste properties (Le Révérend, Hidrio, Fernandes, & Aubry, 2008). Applying DA, TI and TDS to the same set of wines, it could be further demonstrated that each of the methods provided unique information regarding the temporal perception of bitterness and its interaction with major wine constituents such as ethanol and sugar (Sokolowsky & Fischer, 2012).

The objective of this study is to (1) evaluate the sensory impact of commonly used skin contact on two cool climate varieties namely, Riesling and Gewürztraminer, by applying DA, TI and TDS analyses to the same set of wines, (2) to correlate wine composition with orally perceived intensities recorded by DA and parameters extracted from TI and TDS curves and (3) to investigate which complementary knowledge could be gained by each applied sensory technique.

Material and methods

Participants

Panelists for the sensory evaluation of the wines were selected based on interest, availability and prior experience in sensory analysis of wine. The panels for descriptive analysis (DA) of the experimental wines consisted of 16 judges for the 2009 vintage and 17 judges for the 2010 vintage (see Table 1). Nine of the 17 judges on the 2010 panel were also judges on the 2009 panel. After completion of the DA tasks for both vintages, a subset of the panels participated in the TDS analysis. TI analysis of bitterness in wines of vintage 2010 followed the TDS analysis in order to avoid bias for bitterness during the TDS analysis due to the explicit focus on bitterness during TI analysis. The panel for TI analysis was identical to the one used for the TDS analysis, except for one female judge that was excluded. Thus, all judges participating in TI analysis have already had the experience of preceding TDS and DA analysis of the same 2010 wines.

Wines

All experimental wines from both vintages are listed in Table 2 including the applied treatments and their varying skin contact time. Identical sound grape material was used for each variety, which was hand-harvested from vineyards of the Staatsweingut Neustadt located in the Pfalz viticultural region in Germany. In 2009, Gewürztraminer was harvested at a high ripeness level (104 Oechsle/25 Brix) while the grapes from the cooler 2010 vintage had less sugar (87 Oechsle/21 Brix) and more acidity (see Table 7). Riesling was only included in the 2010 vintage (95 Oechsle/23 Brix). All grapes were destemmed, except for the whole cluster treatment. Skin contact was realized in replicates for each maceration time at 15 °C. To prevent microbial spoilage, SO_2 was added (50 mg/L). To enhance the release of aroma precursors from berry skins and to accelerate juice clarification after pressing, two pectolytic enzymes were added at 2 mg/kg (Lallzym HC, Lallemand Inc., Rexdale, Canada and SIHA Panzym Claire rapid, E. Begerow GmbH & Co., Langenlohnsheim, Germany). In 2010, additional treatments included the incorporation of 30% grape material which was infected with the grey rot fungus, *Botrytis cinerea* and a complete fermentation of the crushed grapes on the skins, similar to red wine making. Conditions for pressing, clarification and fermentation (yeast strain Lalvin R-HST Riesling Heiligenstein, Lallemand Inc., Montreal) were kept identical for each treatment and vintage. Two weeks after completion of fermentation, wines were separated from the lees and SO_2 (100 mg/L) and ascorbic acid (150 mg/L) were added. Fermentation replicates were kept separate.

Table 1
Participants and timing of the sensory experiments.

Sensory task	Vintage wines	Number of judges	Age range	Female	Male	Time of assessment	Replicates
DA	2009	16	21–51	4	12	August 2010	3
TDS	2009	11	23–38	2	9	September 2010	3
TI	2009	–				–	–
DA	2010	17	21–52	12	5	May–June 2011	3
TDS	2010	13	21–47	7	6	August 2011	3
TI	2010	12	21–47	6	6	September 2011	3

Table 2
Experimental treatments.

Experimental treatment	Grape variety	Gewürztraminer		Riesling
	Vintage	2009	2010	2010
	Length of skin contact			
Whole cluster pressing, no crushing	0 h	X	X	X
Skin contact of crushed grapes	0 h	X	X	X
	8 h	X	X	X
	8 h + 30% *Botrytis cinerea*	–	X	–
	24 h	X	–	X
	35 h*	–	X	–
Fermentation on the skins	6 days	–	X	–

* Deviation from anticipated 24 h duration due to temporary breakdown of the press.

Prior to bottling, bench testing of the 2010 wines revealed a very strong sourness due to a cold ripening period which impeded acid degradation in the grapes. Similar to commercial winemaking in 2010, an acidity adjustment was applied using potassium bicarbonate ($KHCO_3$) aiming for a final titratable acidity of 8 g/L in Riesling and 7 g/L in Gewürztraminer. Diminishing the excessive sourness prevented a confounding effect on bitterness perception due to dumping effects during TI analysis and overwhelming dominance of sourness during TDS analysis. Potassium bicarbonate (Kalinat, Erbslöh Geisenheim AG, Geisenheim, Germany) was chosen for acidity adjustment instead of the more common calcium carbonate, because its use is recommended for acid adjustments in the wine stage, while treatment with calcium carbonate should be done at the juice stage. An early acid adjustment in the juice was not feasible, as we could not predict further precipitation of potassium bi-tartrate during fermentation caused by the ethanol increase and varying potassium content due to different skin contact times. Furthermore, calcium salts of acids such as lactate or gluconate exhibited a bitter taste (Laweless, Rapacki, Horne, & Hayes, 2003) which would have confounded our investigation of bitterness, while potassium salts are tasteless. Wines remained at their natural residual sugar levels of 0.6–2.5 g/L, in order to limit the bitterness masking effect of glucose and fructose. Wines were bottled in 750 mL glass bottles closed by MCA screw caps and stored at 15 °C until chemical and sensory analysis.

Chemical analysis

Grape juice and bottled wines were analyzed by FT-MIR (FT 120 GrapeScan, FT 120 WineScan, FOSS, Hillerød, Denmark) for all chemical parameters except for potassium, calcium, magnesium and total phenols. Determination of alkaline metals was carried out with atomic absorption spectroscopy (AAnalyst 700, PerkinElmer, Rodgau, Germany). Total phenols were analyzed via the Folin–Chiocalteau-method which was conducted on an automatic analyzer (Konelab Arena 30, Thermo Fischer Scientific, Vantaa, Finland).

Procedures

Presentation of sensory samples

Sensory analysis took place in a sensory room according to the prescription of DIN 10962 equipped with individual booths (DIN 10962, 1997). Wines were assessed under white light at 12 °C in transparent DIN 10960 glasses (Sensus, Schott Zwiesel, Germany) (DIN 10960, 2000), coded by three digit random numbers. Transparent glasses were utilized to facilitate the impact of skin contact of wine color. For descriptive analysis, glasses contained 30 mL and were covered with plastic lids. For TDS and TI analysis, only 10 mL aliquots were presented because judges were requested to take the whole volume in one sip, slurp the wine twice and expectorate when requested by the software. This protocol ensured maximum reproducibility regarding size and oral processing of the stimulus among judges. After evaluation of in-mouth attributes, the software forced judges to cleanse the mouth with tap water and to take a two-minute break for palate recovery. Data acquisition for all sensory experiments was carried out using FIZZ software (FIZZ network, version 2.46 A, Biosystemes, Courtenon, France).

Preliminary tests of processing replicates

Before bottling, wines originating from duplicated grape processing and fermentation were subject to bench testing. Applying a non replicated triangle procedure focusing on taste alone by using nose clips, 14 (2010) and 15 (2011) judges could not detect any significant differences between corresponding replicates of the four (2010) and ten (2011) experimental variants. In addition, none of the variants showed any fermentation related off-flavors. Thus, fermentation duplicates were blended prior to bottling in order to reduce the number of samples for subsequent sensory analysis.

Descriptive analysis

Odor and taste attributes listed in Table 3 were derived through panel discussion after tasting a subset of wines representing maximum sensory variance. Standard solutions were developed to define the chosen sensory descriptors and the maximum intensity

Table 3
Standard solutions for the descriptive analysis prepared in white wine.

Attribute	Definition	Standard[a]
Smell		
Lemon	Smell of fresh lemons	100 mL/L freshly pressed lemon juice
Peach/apricot	Smell of peach and apricot	40 mL/L peach nectar (granini); 22 mL/L apricot nectar (granini)
Apple	Smell of ripe apples	300 mL/L cloudy apple juice (Ameckes)
Green grass/ green banana	Smell of fresh, green grass and green, unripe bananas	8 g/L fresh grass, cut into small pieces;(6 g/L slices of green, unripe banana; both extracted for 10 min)
Rose	Smell of roses	500 μL/L stock solution roses (18 μL essence of roses (pharmacy)/50 mL ethanol (96% vol.))
Floral	Smell of flowers	300 μL/L stock solution roses (18 μL essence of roses (pharmacy)/50 mL ethanol (96% vol.)) 150 μL stock solution linalool (40 μL linalool/50 mL ethanol (96% vol.))
Honey/caramel	Smell of honey (and caramel)	4 tea spoons of honey (Langnese)/L and 0.4 g/L caramel cream candy (Werther's Original))
Buttery/yeasty	Lactic smell, smell of growing yeasts	400 μL diacetyl stock solution/L (1 mL diacetyl in 100 mL ethanol (96% vol.)); 1.2 g/L dried yeast (Begerow)
In-mouth attributes		
Sweet	Sweet taste	3 g/L fructose (2009: 4 g)
Sour	Sour taste	4 g/L tartaric acid (2009: 1.5 g)
Bitter	Bitter taste	1 g/L caffeine
Astringent	Puckering, drying mouth feel	0.4 g/L aluminium sulfate/L

[a] Prepared in 1 L base wine.

on the scale. For each training session, standards solutions were freshly prepared in a dry Riesling wine from the Staatsweingut Neustadt matching the vintage of the experimental wines. Each tasting booth was furnished with a complete set of sensory standards. During four training sessions, judges were familiarized with the standard solutions which were presented solitary and in binary mixtures of varying strength. Instant feed-back was given after completion of each task by the computer program and re-tasting was possible. Evaluation of bitterness was assessed as "bitter intensity" and "bitter persistency". To broaden the molecular base for bitterness, panelists were trained with caffeine and ethyl gallate standards which were presented in equi-bitter concentrations and subsequent dilutions.

During descriptive analysis, six wines were presented in randomized order following a Latin square design. Replicates were served in different sessions as well as varieties. Attribute intensities were rated on a 10 cm unstructured line scale labeled with "not noticeable" on the left end and "very strong" on the right. Odor descriptors were assessed in a comparative set-up, rating the intensity of one attribute in all wines before assessing the next attribute. In contrast, orally perceived attributes were evaluated monadically, assessing all descriptors in one wine before moving to the next sample after a two-minute break.

Temporal dominance of sensations analysis

For TDS analysis, the four in-mouth attributes used during DA (sweet, sour, bitter and astringent) were selected plus the hot sensation, as requested by the panel. Retronasally perceived attributes were omitted from TDS analysis due to the focus on taste-related modifications and panel consensus. Three training sessions were conducted presenting different standard dilutions to ensure that each modality was recognized correctly. To familiarize panelists with the time course of perceived sensory stimuli, judges listened to an audio track consisting of two sounds (195 and 440 Hz) at increasing and decreasing intensities. Judges were requested to assess the dominance of one sound over the other and the correct results were presented immediately after finishing the audio task. Finally, TDS assessments of wines were done followed by group discussion of the results.

Each TDS descriptor was represented by one button on the computer screen. The sequence of attribute buttons differed from judge to judge to compensate for order effects. However, each judge worked with the same sequence of attributes to ease the search for the appropriate button. Sample assessment was started by clicking the start button parallel to sipping the wine and judges were requested to click on the button, representing the currently dominating oral sensation. Assessment was stopped automatically after 180 s or individually by the judges, when no attribute was perceived any longer. TDS evaluation of the wines was done in a monadic order and data were collected in 0.5 s intervals. Five wines were presented per session in a randomized order by mixing experimental treatments and grape varieties (only for 2010 wines), but not replications. Dominance rates were calculated according to the method of Pineau et al. (2009) yielding a set of TDS curves for each wine and each repetition. To facilitate statistical analysis of the TDS results for each attribute, the parameters "maximum dominance rate" (D_{max}), "duration of dominance" and "area under the curve" were extracted from the curves for each wine and repetition. To exclude noise, the parameters were only calculated for the curves above the chance level (p = 1/number of attributes; here: p = 20%).

Time–intensity analysis

Panelists were trained in three sessions to introduce them to the TI scale and varying bitter intensities. During three training sessions, judges familiarized themselves with the continuous evaluation of a sensory stimulus on the TI scale by listening to an audio signal increasing and decreasing in loudness. After completion, judges could compare their recorded TI curve versus the true audio curve and had the chance to repeat the task. Training was completed with three additional session in which the time course of diluted and undiluted bitter standards (caffeine, ethyl gallate) were assessed followed by a direct feedback. Panelists started the TI assessment by clicking on the scale simultaneously to sipping the complete wine sample. Recording of the TI signal stopped when the panelists reached zero intensity or automatically after 180 s. Prior to evaluation of the wine samples, a warm-up sample for bitterness was served representing the intensity at the right end of the scale. As for TDS analysis, five wines were served per session mixing both grape varieties within a session, but not sensory repetitions.

To enable statistical comparison for each wine and its replicate, the parameters "maximum intensity" (I_{max}), "duration of bitter taste" and "area under the curve" were extracted from the TI curves. Area under the curves was calculated directly from start to end of the curves as skeleton curves could not be built of all judges' data sets.

Statistical analysis

Results from descriptive analysis and extracted parameters from TI curves were compared by means of a three-way mixed

model analysis of variance (ANOVA) in which judges were treated as a random effect while wine and replications were fixed. *F*-values of the interactions were compared versus their corresponding single factors as proposed by Næs, Brockhoff, and Tomic (2010) to determine their importance. For TDS curves, expressing the percentage of judges indicating the particular attribute as the dominating one, the factor "judge" was not available any more. Thus, a two-way ANOVA was conducted with wine and repetition as sources of variation (Sokolowsky & Fischer, 2012). For all sensory methods, separate ANOVAs were calculated for Gewürztraminer and Riesling wines. Least significant difference test (LSD) was applied for comparison of means among the wine samples (significance level $\alpha = 0.05$). Sensory results were correlated to chemical data using Spearman's rank correlation. All statistical analyses were performed using XLSTAT (XLSTAT version 2011.1.02, Addinsoft, Paris, France).

Results

Descriptive analysis

According to the *F*-values from a three-way mixed model ANOVA displayed in Table 4, seven out of twelve and eleven out of thirteen descriptors varied significantly among four treatments for 2009 and 2010 Gewürztraminer, respectively. By excluding the two extreme treatments namely "skin fermentation" and "30% Botrytis-infected grapes" in a second ANOVA, only yellow color, rose, honey and bitter intensity remained significant in 2010 Gewürztraminer. The 2010 Riesling varied only significantly for yellow color, rose (floral) and bitter intensity.

Yellow color increased with skin contact time presumably due to a better extraction of carotenoids. The majority of the wines differed between an intensity of 3.2 and 5.5, only 24 h skin contact in the 2009 Gewürztraminer (6.3), 35 h skin contact in the 2010 Gewürztraminer (6.6) and fermentation on the skins in case of the 2010 Gewürztraminer (8.6) showed elevated intensities. Judges were not informed regarding oenological treatments and according to Table 4 no clear correlation could be observed between color enhancement and increase in bitter or astringency, except for the skin fermented trial. The same is true for odor attributes such as peach/apricot, apple, honey or buttery/yeasty, for which a possible color-driven bias could be discussed. Morrot, Brochet, and Dubourdieu (2001) reported a strong impact of white versus red color on odor perception which would rationalize the use of black glasses for wines varying in color. Ballester, Abdi, Langlois, Peyron, and Valentin (2009) however could not find any significant sensory differences when six white wines were tasted by experts or novices in transparent versus black glasses, corroborating our decision, to utilize transparent glasses in this study.

For both varieties of the cool 2010 vintage, no significant differences occurred for odor attributes among whole cluster pressing, 0 and 8 h of skin contact. Extending the skin contact of Riesling and Gewürztraminer to 24 or 35 h, respectively, the rose odor which is typical for both varieties, was enhanced significantly. The addition of 30% botrytized grapes to the 8 h skin contact treatment of Gewürztraminer increased both the honey and apple odors. The strongest impact could be observed due to fermentation on the skins, yielding a threefold increase in rose intensity. This strong smell presumably masked perception of lemon, apple and green grass/green banana, which decreased significantly (Fig. 1a and b, Table 4). For wines from the much warmer 2009 vintage, the flavor enhancing effect of skin maceration was more pronounced, yielding a significant increase after 8 h of skin contact for the attributes lemon, peach, rose and honey. Most probably, more aroma precursors could be formed in the skins during the warmer ripening period, enhancing the sensory effect of skin contact.

Regarding the in-mouth attributes, only bitterness varied among the experimental wine from both grape varieties in the 2010 vintage. Riesling wine (Fig. 1c) processed by whole cluster pressing was significantly less bitter than the wines prepared with skin contact for 8 and 24 h. Among the Gewürztraminer wines, the sample fermented on skins showed the highest bitter intensity, bitter persistency, astringency and sourness, but also a significantly lower sweetness. Among the other treatments, no significant increase in bitterness or astringency could be linked with extended skin contact or the use of botrytized grape material. For the riper 2009 vintage, however, sweetness and sourness were modified significantly by skin contact, but no effects were observed for bitter and astringency. In 2009, the acidity had not been adjusted to the same level prior to bottling as it was the case in 2010, thus enhancement of sweetness and diminution in sourness could be linked to a decline in acidity and rise in pH due to extended skin contact.

Table 4
Post hoc test (LSD, $\alpha = 0.05$) for those attributes from descriptive analysis which were significantly different among the wines in vintage 2009 and 2010.[a]

	Visual attribute	Odor attributes							In-mouth attributes				
	yellow color	Lemon	Peach/ apricot	Apple	Green grass/ banana	Rose (flowery)	Honey	Buttery/ yeasty	Sweet	Sour	Bitter intensity	Bitter persistency	Astringent
Gewürztraminer 2009													
Whole cluster pressing	b	a	b	Only	–	c	b	–	b	a	–	–	–
0 h skin contact	b	ab	b	used in	–	c	b	–	b	ab	–	–	–
8 h skin contact	a	a	a	2010	–	b	a	–	a	b	–	–	–
24 h skin contact	a	a	a		–	a	a	–	a	b	–	–	–
Gewürztraminer 2010													
Whole cluster pressing	e	a	–	b	a	c	c	–	a	abc	c	b	b
0 h skin contact	e	a	–	b	a	c	c	–	a	bc	b	b	b
8 h skin contact	d	a	–	b	a	c	bc	–	a	ab	c	c	b
8 h skin contact + Botryis	c	a	–	a	a	bc	a	–	a	c	bc	bc	b
35 h skin contact	b	a	–	b	a	b	bc	–	a	abc	bc	bc	b
Fermentation on skins	a	b	–	c	b	a	b	–	b	a	a	a	a
Riesling 2010													
Whole cluster pressing	c	–	–	–	–	b	–	–	–	–	b	–	–
0 h skin contact	b	–	–	–	–	b	–	–	–	–	ab	–	–
8 h skin contact	ab	–	–	–	–	a	–	–	–	–	a	–	–
24 h skin contact	a	–	–	–	–	b	–	–	–	–	a	–	–

The difference between levels with the same letter is not significant. Not significant results are denoted with '–'.
[a] Tests were calculated separately for the wines of each grape variety and vintage.

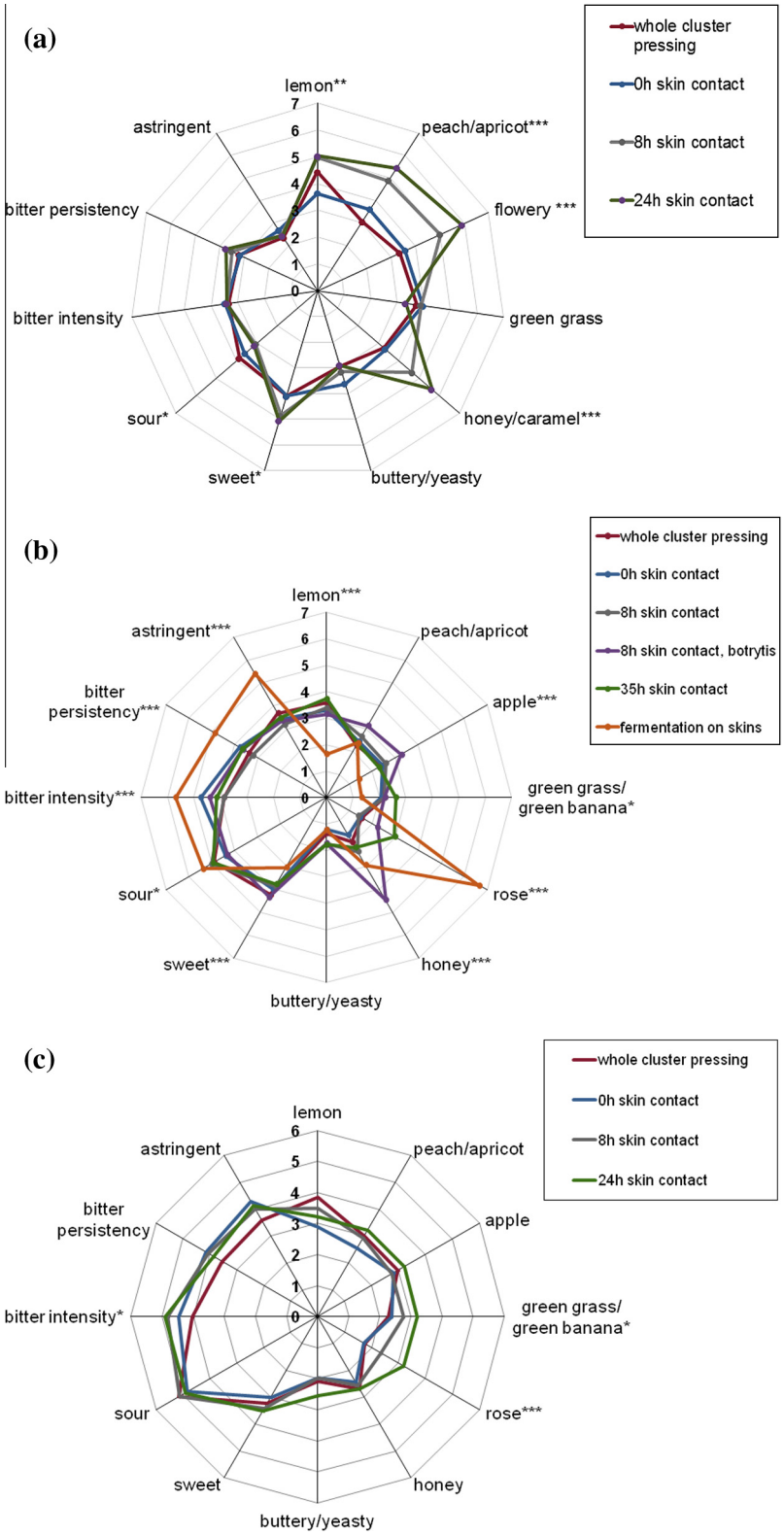

Fig. 1. Smell and in-mouth attribute mean scores from descriptive analysis displaying wines varying in skin contact time. (a) 2009 Gewürztraminer, (b) 2010 Gewürztraminer and (c) Riesling (16 or 17 × 3 Rep, respectively; levels of significance: $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$).

Time–intensity analysis of bitterness

TI curves of bitterness were compared regarding maximum intensity (I_{max}), duration and area under the curves (see Table 5). For Gewürztraminer, I_{max} and area under the curve differed significantly among treatments, while all TI parameters did not vary significantly among Riesling wines. A three-way mixed model ANOVA of Gewürztraminer revealed high significance for the factor wine for I_{max} ($F = 11.7$) and area under the curve ($F = 9.9$). Although bitter persistency varied significantly during DA, duration of bitter

Table 5
F-values from analysis of variance with levels of significance and mean values for parameters extracted from time–intensity curves for bitterness with post hoc test (LSD, $\alpha = 0.05$).[a]

	I_{max}	Duration	Area
Gewürztraminer 2010			
F-value wine	11.7***	1.1	9.9***
Whole cluster pressing	5.4 c	41.6 –	137.1 c
0 h skin contact	5.8 bc	44.2 –	149.2 bc
8 h skin contact	5.3 c	44.2 –	132.6 c
8 h skin contact + Botryis	6.2 b	44.5 –	152.0 bc
35 h skin contact	6.2 b	44.4 –	176.2 b
Fermentation on skins	7.9 a	47.8 –	230.2 a
Riesling 2010			
F-value wine	0.3	0.8	0.9
whole cluster pressing	6.6 –	44.4 –	163.5 –
0 h skin contact	7.0 –	45.7 –	180.5 –
8 h skin contact	6.7 –	47.3 –	180.6 –
24 h skin contact	6.9 –	49.4 –	192.5 –

Levels of significance: $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$. The difference between levels with the same letter is not significant. Not significant results are denoted with '–'.

[a] Tests were calculated separately for the wines of each grape variety.

taste was not a significant parameter in the TI analysis for both grape varieties. It is interesting to note that the addition of botrytized grapes raised the bitter I_{max} in the same significant way than extending skin contact from 8 to 35 h did. In general, Gewürztraminer wine made by fermentation on skins had the highest I_{max} and area under the curve, whereas whole cluster pressing and 8 h of skin contact yielded wines with the lowest I_{max} and area under the curve among all samples.

Temporal dominance of sensations analysis

According to the TDS curves of the 2009 Gewürztraminer in Fig. 2a–d, sweetness was the first dominating taste whose prevalence lasted for eight to twelve seconds. Only for whole cluster pressing, sourness appeared slightly above the chance level, which may be due to the higher acidity and lower pH (Table 7). Extending skin contact diminished sourness and increased the dominance of hot perception. The mid-palate and aftertaste was dominated by bitterness. Overall longer skin contact time enhanced domination of sweetness in frequency and duration, while the time course of bitter dominance did not change much. Due to the application of extended skin contact (35 h) and even fermentation on the skins, TDS curves of the 2010 Gewürztraminer wines in Fig. 3a–f differed to a larger extent than for the 2009 wines. Again, sweetness dominated first, followed shortly by sourness. Skin contact, occurring either during three hours of pressing in the 0 h maceration treatment and during the eight hours skin contact treatment, enhanced the sweetness perception, although related chemical compounds such as glucose, fructose, glycerol or ethanol did not increase (Table 7). However, extending skin contact further to 35 h or even 6 days during fermentation on the skins, diminished the dominance of sweetness again (Fig. 3e and f). The aftertaste of the wines was either dominated by sourness (whole cluster pressing, 8 and 35 h of skin contact), bitterness (0 and 8 h skin contact plus botrytized grape material) or astringency (fermentation on the skins). Comparing 8 h skin contact with and without 30% botrytized grape material, it seems that infection with *B. cinerea* enhanced the bitter taste as shown by the dominance of bitterness between 15 and 30 s. At the same time, sourness perception was either lower or masked by the bitter taste. Astringency dominance was also slightly elevated due to infection with *B. cinerea*.

TDS curves for 2010 Riesling wines in Fig. 4a–d revealed sourness as the most dominating sensation during the first 10 s, eventually accompanied by a dominating sweetness in the whole cluster pressing and 24 h skin contact treatment. The aftertaste was characterized as sour or bitter in combination with an astringent impression.

Post hoc tests of the parameters extracted from the TDS curves are shown in Table 5. In contrast to the DA and TI results, TDS

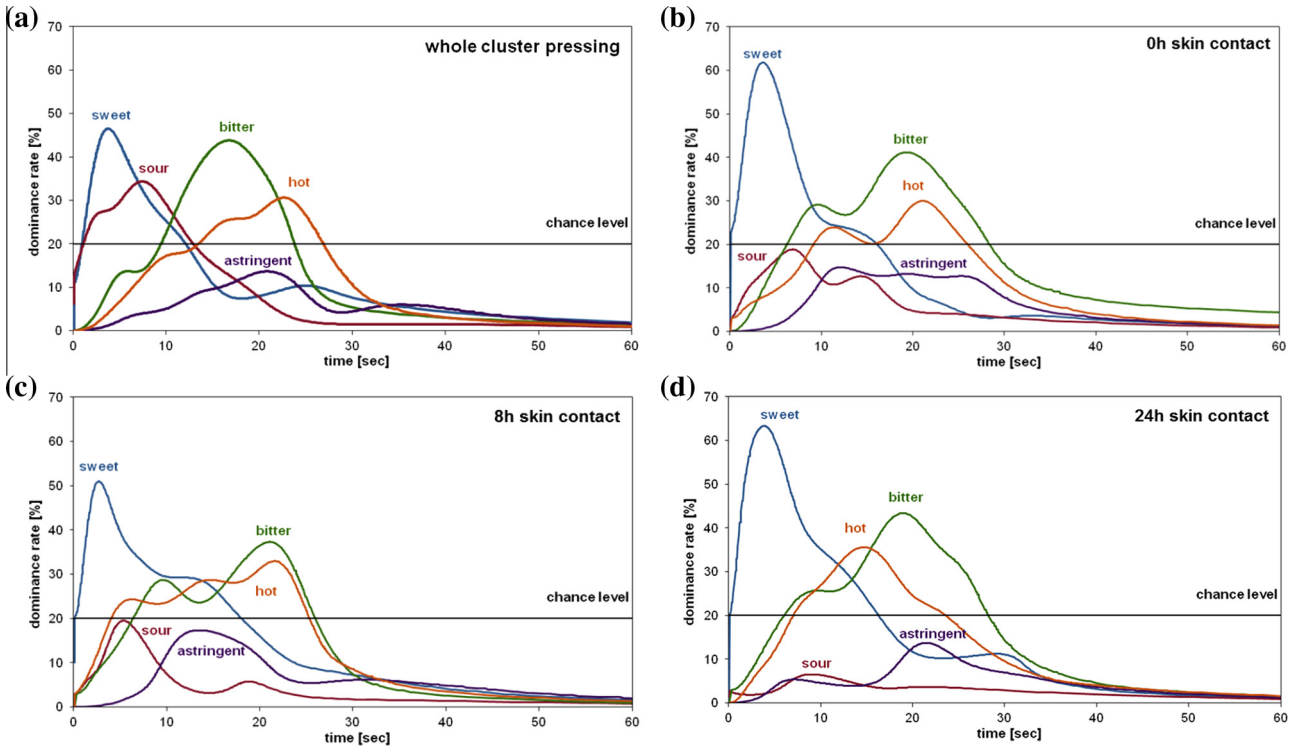

Fig. 2. TDS curves of 2009 Gewürztraminer wines made by (a) whole cluster pressing, (b) 0 h skin contact, (c) 8 h skin contact, (d) 24 h skin contact (12 J × 3 Rep).

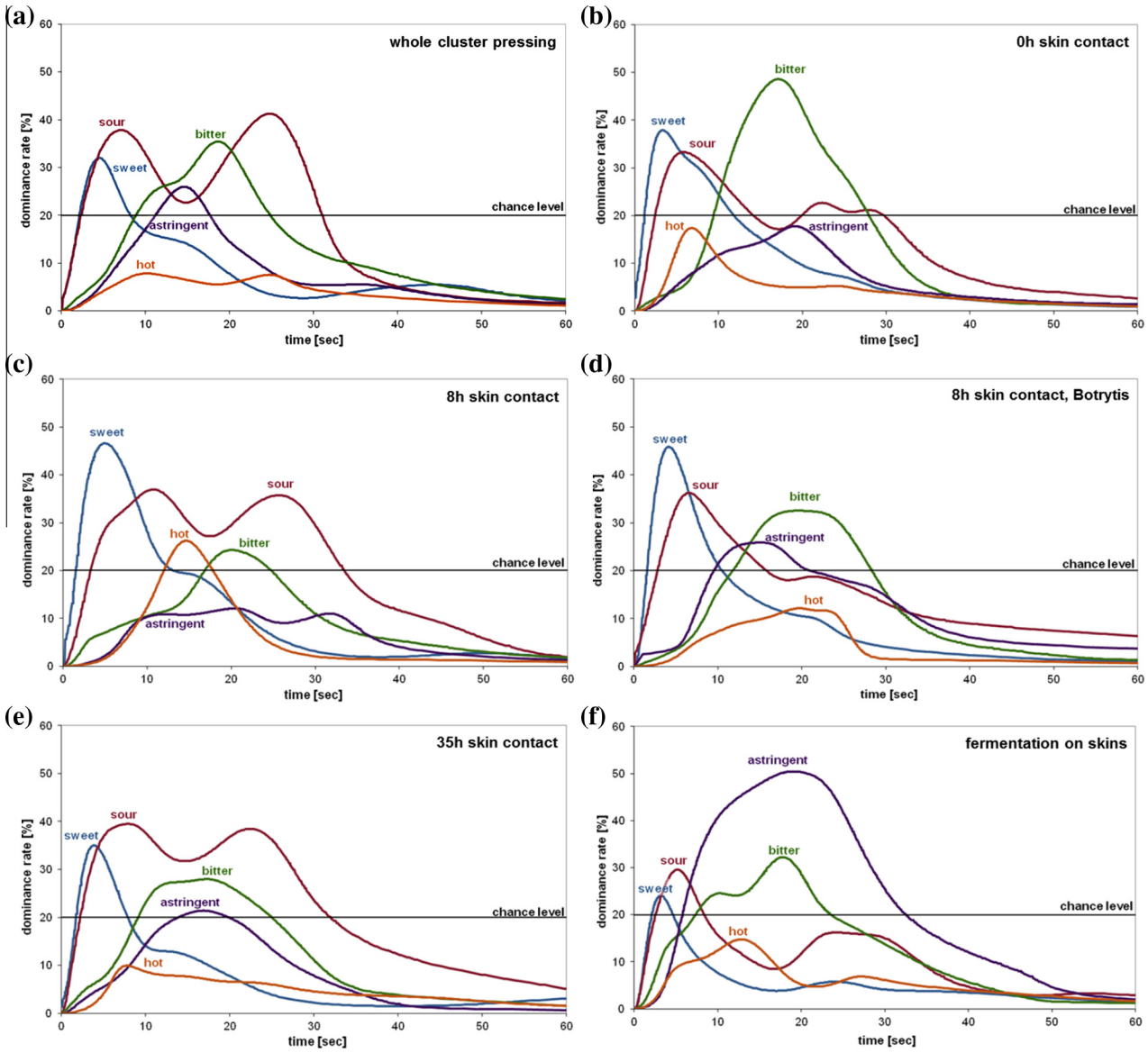

Fig. 3. TDS curves of 2010 Gewürztraminer wines made by (a) whole cluster pressing, (b) 0 h skin contact, (c) 8 h skin contact, (d) 8 h skin contact of botrytis infected grapes, (e) 35 h skin contact and (f) fermentation on skins (13 J × 3 Rep).

curves for bitterness did not differ significantly among the wines. Gewürztraminer wines from both vintages differed significantly regarding dominance of sour taste (duration, area). Additionally, 2010 Gewürztraminer wines varied significantly in the duration and area of the sweet and astringent TDS curves. The wine fermented on skins was described as least sweet and sour (duration and area) but most astringent (D_{max}, duration and area).

Correlation to chemical parameters

Examining chemical composition of the wines in Table 7, only subtle differences regarding residual sugar (glucose and fructose) as well as ethanol occurred, because all wines were fermented to dryness. The lower alcohol in the skin-fermented Gewürztraminer was mainly due to lower sugar content in the grapes (79 Oe or 19 Brix versus 87 Oe or 21 Brix in all other treatments). The lower values for tartaric acid and total acidity observed prior to acidity adjustments, prove the general diminution effect of skin contact. Riesling dropped from 5.0 to 3.1 g/L tartaric acid and 11.4 to 9.3 g/L total acidity; Gewürztraminer in 2010 from 4.9 to 3.8 g/L tartaric and 9.9 to 8.1 g/L total acidity. Parallel, the potassium concentration rose, although the potassium bi-tartrate precipitation, which caused the decline in acidity, already diminished the potassium content to some extent. Total phenols increased up to 72 mg/L GAE in Riesling after 24 h skin contact time and up to 92 mg/L GAE in Gewürztraminer after 35 h. While 8 h of skin contact with sound grapes did not yield much of a total phenol increase, the addition of 30% botrytized grape material raised total phenols during 8 h of skin contact similar to sound grape material during 35 h of skin contact. Fermenting the Gewürztraminer for 6 days on the skins yielded a threefold increase to 751 mg/L GAE, which is similar to the levels obtained during red wine making of a Pinot noir.

To investigate the relationship between the concentration of major wine constituents and all significantly modified in-mouth parameters, Table 8 displays coefficients of correlation derived from Riesling and Gewürztraminer wines.

Sweetness of the wines, measured by DA and TDS, was related to the wines' glucose and fructose contents, while sourness parameters correlated best with low pH and higher total acidity. Bitter intensity and bitter persistency from DA were significantly

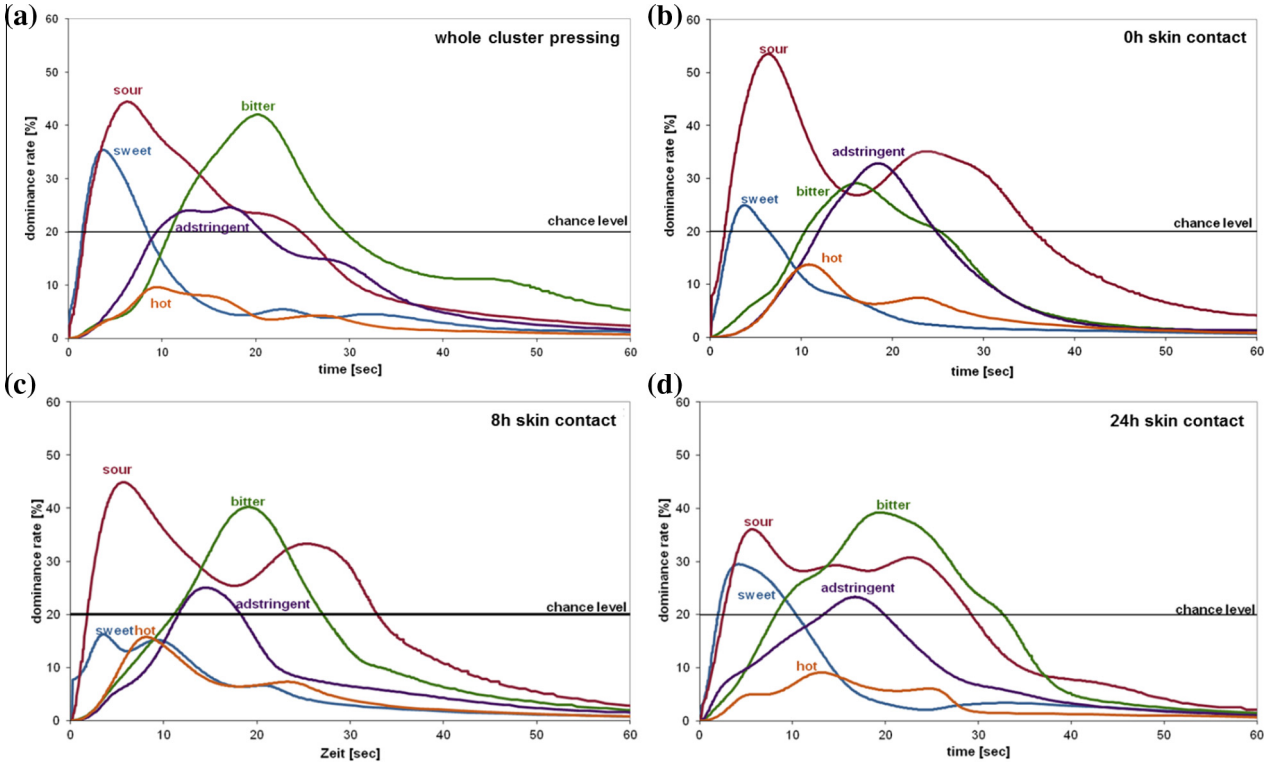

Fig. 4. TDS curves of 2010 Riesling wines made by (a) whole cluster pressing, (b) 0 h skin contact, (c) 8 h skin contact, (d) 24 h skin contact (13 J × 3 Rep).

correlated with low fructose content. These correlations slightly improved when the data of the skin fermented wine were excluded due to its leverage effect on the correlations. Bitter intensity and bitter persistency from DA were also significantly correlated with increasing total phenols, which was also the case for all parameters extracted from TI curves for bitterness. A negative correlation was observed between tartaric acid for the astringent dominance regarding D_{max} and area under the curve as well as the bitter intensity during TI analysis. Higher perceived sourness might have masked the perception of bitterness and astringent dominance.

When excluding the skin-fermented Gewürztraminer with its abnormally high total phenols level in the new correlation analysis, 16 coefficients of determination decreased. Some became even insignificant, most notably the correlation between total phenols and bitter intensity, bitter persistency and astringency determined by DA. However, other correlations increased by excluding the extreme wine, such as the correlation between ethanol and I_{max} in the TI analysis for bitterness and the perception of astringency during TDS analysis.

Discussion

The discussion is structured according to the stated major objectives of this study to (1) evaluate the sensory impact of skin contact in the cool climate varieties by applying DA, TI and TDS analyses to the same set of wines, (2) to correlate wine composition with orally perceived intensities recorded by DA and parameters extracted from TI and TDS curves and (3) to investigate which complementary knowledge could be gained by each applied sensory technique.

Sensory impact of skin contact for cool climate varieties

For both Riesling and Gewürztraminer, intensity of rose odor was enhanced with increasing skin contact times which can be rationalized by increased enzymatic decomposition of the skin material and enhanced transfer of aroma precursors into the juice (Fischer et al., 2001; Reynolds et al., 1993). The effect of grape maturity could be demonstrated by comparing the warm 2009 vintage to the colder 2010 vintage. In 2009, skin contact of 8 and 24 h significantly enhanced lemon, peach/apricot, floral, and honey/caramel intensities, while the effect of skin contact in 2010 was limited to floral and apple flavor alone. Thus, the impact of skin contact on white wine aroma seems to increase with the degree of ripeness, at least in context of a cool climate. Under hot growing conditions, such as in South Africa, Marais could not detect any increase in floral characters in Gewürztraminer due to elongated skin contact (Marais, 1998) or in general among commercial Gewürztraminer wines (Marais & Rapp, 1986). Thus, too high temperatures during the growing season seems to diminish or even erase the positive sensory impact of skin contact and indeed warmer wine regions apply much less skin contact than colder ones.

B. cinerea infection is prone to wine regions with higher humidity during the ripening period, as the fungus needs moisture in order to grow on the grape skin. Adding 30% infected grape material to the 2010 Gewürztraminer with 8 h skin contact, honey and apple intensities increased significantly and in tendency also peach/apricot. The fungal attack by *B. cinerea* facilitates an early partial enzymatic maceration of the berries in the vineyards, which increases oxidation of phenolic compounds and changes berry color to brown. At the same time, oxygen ingress stimulates the lipoxygenase reaction, cleaving fatty acids and yielding C_6-compounds. These react with the tri-peptide glutathione, which contains the sulfurous amino acid cysteine. Further activity of a yeast derived cysteinlyase is able to liberate thiol-carbonyl compounds from these precursors, which exhibit a powerful fruity odor reminiscent of grapefruit and passion fruit (Thibon, Dubourdieu, Darriet, & Tominaga, 2009).

A second objective to apply skin contact is to reduce perceived sourness, which receives more attention in cool climate growing

Table 6
Post hoc test (LSD, $\alpha = 0.05$) for those parameters extracted from TDS curves which were significantly different among the 2009 and 2010 Gewürztraminer wines.[a]

Sensory modalities	Sweet			Sour			Astringent		
Parameters from TDS curves	D_{max}	Duration	Area	D_{max}	Duration	Area	D_{max}	Duration	Area
Gewürztraminer 2009									
Whole cluster pressing	–	–	–	–	a	a	–	–	–
0 h skin contact	–	–	–	–	ab	b	–	–	–
8 h skin contact	–	–	–	–	b	b	–	–	–
24 h skin contact	–	–	–	–	b		–	–	–
Gewürztraminer 2010									
Whole cluster pressing	–	bc	bcd	–	b	a	bc	c	bc
0 h skin contact	–	abc	abc	–	c	b	bc	c	c
8 h skin contact	–	a	a	–	a	a	c	c	c
8 h skin contact + Botryis	–	ab	ab	–	c	b	b	b	b
35 h skin contact	–	cd	cd	–	a	a	bc	c	bc
Fermentation on skins	–	d	d	–	d	b	a	a	a

The difference between levels with the same letter is not significant. Not significant results are denoted with '–'.
[a] Tests were calculated separately for the wines of each grape variety and vintage.

regions characterized by higher acidity levels compared to the lower acidity levels of warmer regions Enhanced precipitation of potassium bi-tartrate due to skin contact (García-Romero, Pérez-Coello, Cabezudo, Sánchez-Muñoz, & Martín-Alvarez, 1999; Palomo et al., 2006) lowered sour intensities in the 2009 Gewürztraminer wines significantly according to DA and TDS results (Tables 4 and 6, respectively). However, extraction of skin constituents is not limited to aroma precursors and potassium alone, but includes also phenolic compounds triggering bitterness and astringency, which are both not desirable in white wines (Arnold & Noble, 1979; Singleton et al., 1980; Test et al., 1986). For Riesling wines, DA suggested significantly higher bitter intensity due to skin contact compared to whole cluster pressing, but neither TI curves for bitterness nor TDS results could support this hypothesis. It may be speculated that during TDS recording, other taste properties of the Riesling wines, most likely sourness, were more dominating than the weak bitterness signal.

Different to Riesling, skin contact applied for Gewürztraminer grapes modified both bitter TI parameters I_{max} and area under the curve (Table 5). With its low acidity and higher ethanol content, Gewürztraminer represents more a warm climate white wine style than Riesling. Thus, its tendency to become more bitter due to skin contact, rationalize the reluctance of warm climate winemaking to apply extended skin contact.

In contrast to other studies based on DA (Oberholster, Francis, Iland, & Waters, 2009; Schmidt & Noble, 1983), we could not detect any significant increase in astringency due to increasing skin contact times, except for the skin fermented 2010 Gewürztraminer wine. By applying TDS, a significant increase in astringency could also be detected for 30% botrytized grape material in combination with 8 h skin contact. Due to the persistent lingering of astringency, TDS seems to be more sensitive than DA to find differences. A practical implication of the results is to support the notion that botrytis-affected grapes subjected to skin contact may result in wines with increased astringency.

Correlation of wine constituents with their temporal sensory properties

Parallel to extraction of aroma precursors and phenols, skin contact enhances leakage of potassium from the skin into the juice (see Table 7) which favors precipitation of potassium bi-tartrate and subsequent loss in acidity and rise in pH. Indeed, for both vintages, perception of sourness in Gewürztraminer wines dropped significantly in intensity (DA, Table 4) and duration as well as area of the sour dominance curve (TDS, Table 6). This chemical modification of acids affected the perception of sweetness as well, which was enhanced significantly by 8 and 24 h of skin contact in the 2009 Gewürztraminer wines although residual sugar remained equal among the wines (Tables 4 and 7).

TDS further revealed that the wine made from *B. cinerea* infected Gewürztraminer grapes in 2010, was significantly less sour, although adjusted to a similar total acidity (9.0 and 8.7 g/L respectively; Table 7). Taking a closer look at the acid composition in Table 7, the wines made from sound grapes were lower in malic acid but higher in tartaric acid than the wine made from infected grapes. Thus, it seems that the difference of 0.9 g/L tartaric acid was able to trigger a significant lower duration and area of the sour dominance curve for the wine made from infected grapes.

Examining the molecular base for the significant modification of bitterness and astringency triggered by skin contact, phenol content in Table 7 was not able to explain the observed differences in a comprehensible manner. Comparing whole cluster pressing and 35 h of skin contact in the 2010 Gewürztraminer trial, the increase of 70 mg/L total phenols (Table 7) increased bitter I_{max} and area under the curve significantly, while an even larger difference of 92 mg/L total phenols between 0 and 35 h of skin contact, failed to be significant for the bitter TI parameters. It is also noteworthy that the huge increase of 500–600 mg/L total phenols due to skin fermentation only yielded a modest increase of 20–40% in the bitter TI parameters I_{max} and area under the curve.

Singleton et al. (1975) was even unable to detect any significant modification in bitterness by comparing wines made without any skin contact and wines fermented on the skins for five days. This could be rationalized by a much smaller increase in total phenols in Singleton's study, presumably due to larger berry diameters of Chenin Blanc and French Colombard grapes used by the authors versus the small berry diameters of Gewürztraminer in our study. Oberholster et al. (2009) could also not find any significant difference for bitter intensity among experimental wines, which were supplemented at the juice stage prior to fermentation with phenolic fractions derived from grape skins or seeds. Although catechin and epi-catechin were modified significantly in the finished wines, this was not sufficient to trigger a significant sensory signal.

Comparing bitter areas under the TI curve of Riesling versus Gewürztraminer, the Riesling was perceived as more bitter, except for the extreme skin fermented Gewürztraminer wine (Table 5). Not only higher total phenols may have triggered this difference (128–220 mg/L for Gewürztraminer and 185–281 mg/L for Riesling; Table 7) but also the fact that Riesling wines were, on average, 7 g/L or 0.8% vol. higher in ethanol than 2010 Gewürztraminer wines.

Examining the correlation coefficients for glucose, fructose and ethanol in the experimental wines in Table 8, sugars proved to

Table 7
Chemical composition of experimental wines.

Skin contact time	Glucose g/L	Fructose g/L	Ethanol g/L	Glycerol g/L	Malic acid g/L	Tartaric acid g/L Acidity adjustment*		Total acidity g/L Acidity adjustment*		pH	K^+ mg/L	Ca^{2+} mg/L	Mg^{2+} mg/L	Total phenols mg/L	SO_2 free mg/L	SO_2 total mg/L
						Before	After	Before	After							
Gewürztraminer 2010																
Whole cluster pressing	0.4	1.8	92.8	6.4	4.3	4.9	2.7	9.9	7.5	3.45	1339	39	47	146	33	82
0 h	0.4	1.2	93.5	6.8	4.1	4.2	2.6	8.7	7.2	3.43	1304	32	45	128	33	77
8 h	0.4	2.0	91.5	6.2	4.0	4.7	2.9	9.0	7.1	3.48	1379	44	50	149	28	71
8 h + 30% *Botrytis cinerea*	0.5	1.3	93.9	8.7	4.4	3.4	2.0	8.7	7.1	3.53	1575	50	52	213	34	143
35 h	0.4	1.4	90.4	6.9	4.0	3.8	3.2	8.1	7.2	3.49	1513	44	52	220	39	105
Fermentation on skins	<0.3	1.1	86.2	7.2	2.9	2.8		6.8		3.29	1055	35	47	751	18	96
Riesling 2010																
Whole cluster pressing	0.3	2.2	98.6	6.9	4.6	5.0	1.7	11.4	8.2	3.28	953	40	52	209	27	89
0 h	<0.3	0.6	101.5	7.3	4.2	4.2	1.8	10.3	8.1	3.24	980	38	53	213	32	104
8 h	0.3	1.1	98.3	6.9	4.7	3.8	2.1	9.9	8.3	3.34	1204	47	52	228	33	99
24 h	<0.3	0.7	98.0	6.9	4.7	3.1	1.7	9.3	8.3	3.35	1187	53	56	281	29	94
Gewürztraminer 2009																
Whole cluster pressing	0.3	2.2	117.6	7.2	2.3	2.0		5.8		3.40	916	26	50	185	40	87
0 h	0.3	1.0	102.3	6.8	2.1	1.8		5.1		3.62	878	24	49	216	52	87
8 h	0.3	1.3	114.8	6.5	2.3	1.4		4.8		3.76	1177	22	52	213	48	103
24 h	0.3	1.1	117.1	7.0	1.8	1.4		4.5		3.93	1340	22	55	219	37	93

* Prior bottling, 2010 wines were adjusted to the same total acidity of 7 g/L (Gewürztraminer) and 8 g/L (Riesling).

have a significant masking effect on bitterness, while ethanol showed an enhancing impact. This is remarkable, as both sugar and ethanol content varied only to a small extent among the experimental wines (Table 7).

Fructose was significantly correlated to lower bitter intensity and shorter bitter persistency evaluated by DA. Ethanol yielded a positive correlation to bitter I_{max} during TI recording in case of the data set which excluded the wine fermented on skins. This amplification of bitterness elicited by ethanol is in agreement with Fischer and Noble (1994) where an increase of 3% vol. ethanol from 8% to 11% and 11% to 14% v/v enhanced bitterness more than an increase in catechin from 100 to 1500 mg/L recorded by DA (Fischer & Noble, 1994). Similar results were measured by TI, where time to maximum, intensity at maximum, duration and area under the curve significantly increased bitterness due to increments of 6 and 7% v/v ethanol data in white model wines using the phenolic stimuli catechin or tannic acid (Arnold & Noble, 1978).

Applying DA, TI and TDS to a set of dry commercial and explicitly bitter white wines revealed that residual sugars, especially fructose, and ethanol correlated highly with bitterness, but not total phenols content (Sokolowsky & Fischer, 2012). This supports our findings in this study that increased total phenols due to skin contact does not necessarily lead to more bitter wines, while masking of bitterness by sugars play an important role.

Complementary knowledge gained by different sensory techniques

Evaluation by DA provides an intensity score of the particular attribute only at a point of time, which is individually chosen by the judge. Even TI assessment very seldomly yields more than one peak of maximum intensity, because the focus on one modality alone tends to suppress perception of other modalities. During TDS analysis, however, dominance of a particular attribute is always assessed in comparison with other attributes or modalities and

Table 8
Coefficients of correlation (Spearman) between significant sensory parameters and major constituents in 2010 wines ($N = 9$ or 10).[a]

		Glucose		Fructose		Ethanol		Total phenols		Glycerol		Tartaric acid		Malic acid		Total acidity		pH	
		Incl. SF [a]	Excl. SF	Incl. SF	Excl. SF	Incl. SF	Excl. SF	Incl. SF	Excl. SF	Incl. SF	Excl. SF	Incl. SF	Excl. SF	Incl. SF	Excl. SF	Incl. SF	Excl. SF	Incl. SF	Excl. SF
DA	Sweet	**0.87**[b]	**0.83**	0.43	0.30	−0.33	−0.68	−0.59	−0.50	−0.37	−0.28	0.43	0.49	0.03	−0.27	−0.30	**−0.69**	**0.88**	**0.85**
	Sour	−0.56	−0.40	0.21	0.43	−0.21	0.08	0.47	0.27	−0.13	−0.30	0.01	−0.02	−0.13	0.20	0.05	0.45	−0.42	−0.33
	Bitter intensity	−0.45	−0.24	**−0.80**	**−0.85**	0.06	0.46	**0.71**	0.59	0.49	0.45	−0.39	−0.48	0.11	0.53	0.12	0.55	−0.40	−0.36
	Bitter persistency	−0.59	−0.43	**−0.87**	**−0.92**	0.15	0.58	**0.71**	0.60	0.60	0.57	−0.33	−0.40	−0.02	0.34	0.13	0.57	−0.58	−0.55
	Astringency	**−0.89**	**−0.85**	**−0.66**	−0.63	0.20	0.65	**0.67**	0.55	0.41	0.33	−0.43	−0.53	0.12	0.54	0.34	**0.85**	**−0.75**	**−0.75**
TDS	Sweet-D_{max}	0.63	0.58	0.63	0.55	−0.15	−0.31	−0.49	−0.40	−0.16	−0.04	0.05	0.01	−0.07	−0.26	−0.39	−0.68	0.58	0.55
	Sweet-duration	0.55	0.45	0.36	0.27	−0.05	−0.33	−0.62	−0.52	−0.33	−0.30	0.05	0.05	−0.01	−0.25	−0.29	−0.63	0.53	0.48
	Sweet-area	0.60	0.52	0.45	0.38	−0.09	−0.38	−0.59	−0.47	−0.33	−0.29	0.06	0.06	−0.02	−0.26	−0.29	−0.64	0.56	0.53
	Sour-D_{max}	−0.23	−0.62	0.21	0.20	0.39	0.20	−0.34	−0.13	−0.31	−0.20	0.02	0.03	0.09	−0.20	0.42	0.21	−0.32	−0.48
	Sour-duration	−0.18	−0.62	0.21	0.18	0.42	0.20	−0.21	0.08	−0.17	−0.02	−0.07	−0.05	0.07	−0.29	0.42	0.19	−0.27	−0.47
	Sour-area	−0.18	−0.62	0.21	0.18	0.42	0.20	−0.21	0.08	−0.17	−0.02	−0.07	−0.05	0.07	−0.29	0.42	0.19	−0.27	−0.47
	Astringent-D_{max}	**−0.67**	−0.55	−0.34	−0.27	0.34	**0.85**	0.55	0.38	**0.79**	**0.78**	**−0.70**	**−0.84**	0.17	0.61	0.07	0.48	−0.63	−0.54
	Astringent-duration	−0.47	−0.27	−0.24	−0.17	0.09	0.50	0.56	0.40	**0.85**	**0.84**	−0.50	−0.59	−0.03	0.34	−0.20	0.10	−0.28	−0.10
	Astringent-area	−0.52	−0.33	−0.38	−0.33	0.26	**0.73**	0.56	0.40	**0.88**	**0.88**	−0.64	−0.76	0.16	0.60	−0.06	0.30	−0.43	−0.30
TI	I_{max}-bitter	**−0.79**	**−0.72**	**−0.70**	−0.68	0.28	**0.77**	**0.83**	**0.77**	**0.69**	**0.70**	−0.58	**−0.69**	0.12	0.55	0.26	**0.74**	**−0.71**	−0.68
	Area TI-bitter	**−0.70**	−0.58	**−0.70**	−0.68	0.14	0.57	**0.93**	**0.90**	0.61	0.61	−0.47	−0.55	0.16	0.61	0.28	**0.77**	−0.54	−0.50

[a] Incl. SF: data set with 2010 skin fermentation treatment; Excl. SF: data set with skin fermentation removed.
[b] Coefficients of correlation printed in bold were significant ($\alpha = 0.05$).

may increase or decrease constantly over time, yielding more than one maximum peak.

Temporal perception of sourness recorded by TDS in some Gewürztraminer and Riesling wines from 2010 revealed two maxima; one at the onset of tasting between two and twelve seconds and a second one starting after 25 s, dominating the aftertaste for most of the time (Figs. 3a, c, e and 4b and c). Extended skin contact seems to suppress the second sourness maximum and either bitterness or astringency dominates the aftertaste. This is also true for the 2009 Gewürztraminer, where sourness only exceeded the chance level for the whole cluster pressing wine, presumably due to lower acidity and higher ethanol levels which contribute to the dominance of sweet and bitter sensations. Due to these modifications of the second sourness maximum, sourness duration and area were significantly altered in case of the 2010 Gewürztraminer wines (Table 6). It may be speculated that the second sourness maximum did not affect sourness assessment during DA because judges had already terminated their evaluation procedure at this time. On the other hand, when astringency became the dominating taste after eight seconds in case of the skin fermented wine; sourness was still not perceived as dominating although it received the highest sourness rating among all wine in this trial during DA (Fig. 1b). Instead of artificially constructing a holistic profile from discretely evaluated DA attributes and their intensities, TDS creates a sensory profile over time, accounting for all relevant attributes at the same time.

Examining the impact of *Botrytis* infection in combination with eight hours of skin contact, the second sourness maximum was also suppressed and instead bitterness and astringency dominated the taste. However, it remains unclear if the dominance of astringency in the botrytized wine is due to the formation of new astringent compounds by the fungus, a better extraction of phenols due to the fungal enzymes or just a lack of sourness, which could have masked or at least dominated astringency.

For sweetness, the only significant difference detected by DA was a lower intensity in the skin fermented 2010 Gewürztraminer wine. Applying TDS instead, duration and area of sweet dominance were altered significantly among the six experimental wines (Table 6). Again the skin fermented wine showed the least sweet dominance due to the masking of astringency (Fig. 3f). While skin contact for 35 h and whole cluster pressing were perceived with less dominating sweetness, skin contact of 0 and 8 h revealed enhanced sweet dominance. Sweetness perception of the wines measured by DA and TDS correlated well with glucose and fructose content in the wines (Table 8). However, this correlation was only significant for glucose and not for fructose, although fructose content was higher and is sweeter than glucose at equal concentration. Thus, similar to bitterness, other wine constituents such as ethanol and glycerol and lowered sourness might have contributed to sweetness as well.

Our hypothesis that phenolic compounds are overestimated in their ability to enhance bitterness can be further supported by TDS analysis. Although the maximum frequency of bitter dominance (D_{max}) varied from 24% to 48% between the 2010 Gewürztraminer treatments (Fig. 3a–f), no significance was detected by a two-way-ANOVA with treatment and replication as fixed effects. However, examining the coefficients of correlation between total phenols and all significant sensory parameters provided by the three applied sensory techniques (Table 8), significant positive correlations were only observed for bitter I_{max} and area under the curve during TI analysis. When the extreme skin-fermented Gewürztraminer wine was included in the data set, intensity of bitter and astringency as well as bitter persistency obtained from DA became significant as well. In conclusion, except for the much focused TI analysis on bitterness, neither DA nor TDS could detect any significant correlation of total phenols with any evaluated sensory attribute in context of skin contact.

To our surprise, no significant differences could be detected for the bitter TDS parameter among the 2010 Gewürztraminer wines, although it included the most bitter wine of the entire study by applying skin fermentation. By examining the TDS curves, this unexpected result could be rationalized by the fact that not the bitterness, but astringency was dominating the taste and aftertaste of this particular wine (Fig. 3f). Thus, dumping effects elicited by astringency during TI analysis could be accountable for the significant increase in bitter I_{max} and area under the curve (Clark & Lawless, 1994). However, DA which is not susceptible to dumping effects, revealed a significant increase in both bitter and astringent intensities. The dominance curves for bitter and astringency follow a similar curvature, which could be explained by the fact that phenols in white wine indeed exhibit bitter and astringent properties (Noble, 1994). However, bitterness was always perceived less dominant than astringency. To conclude, wines may have differed in bitterness as indicated by DA and TI, but TDS was unable to detect these differences by focusing on the strongest perceived, dominating sensory modality, which was not bitterness, but astringency in this particular wines.

Bitter beverages such as beer and strong black coffee have been shown to be rejected because of their taste (Fallon & Rozin, 1983). Astringency, like bitterness, is often perceived as a negative attribute, such as in soy products, dairy products, nuts, and juices (Lesschaeve & Noble, 2005). However it is difficult to study the impact of bitterness and astringency on consumer preferences, as individuals who like bitterness and astringency in red wines would never describe the wine as bitter but use instead associations like "lot of character" or "long aftertaste". Vice versa, dislike of red wines is rationalized by the term bitter, including those wines which are more astringent or acidic (Lesschaeve & Noble, 2005). It can be speculated that preference ratings of consumers may be more strongly related to the attributes dominating the second half of the taste period such as astringency, sourness or bitterness. At this stage, less persistent retronasally perceived odors or taste attributes of shorter duration, such as sweetness, have already disappeared. Thus, TDS data should be taken into account when examining the effect of these modalities in wines on consumer preference by external preference mapping. According to Meillon et al.(2010) a Syrah wine in which alcohol was reduced by the highest rate (−5.5% vol.), not only showed an overwhelming dominance of astringency, but also the lowest overall liking of all wines. The authors rationalize this outcome not so much with a negative connotation to astringency, but a lack of other sensory attributes such as fruitiness of berries or woodiness. Finally and quite intriguing, Ng, Chaya, and Hort (2012) linked TDS dominance rates at different points in time with overall liking of black currant products and could predict consumer preference better with TDS than with DA data.

Conclusions

The objective of the paper was to demonstrate the versatility and power of temporal sensory techniques to reveal the sensory impact of skin contact during white wine making, a worldwide-used oenological treatment. It was demonstrated that TDS results helped to understand multidimensional sensory modifications due to altered extraction of bitter and astringent phenols as well as sourness attenuating potassium from berry skins. While assessment during DA relies on the intensity perceived at one point in time, TDS is monitoring all relevant in-mouth modalities simultaneously in a constant manner. Requesting all relevant sensory traits, TDS does not suffer from dumping effects such as TI analysis which focuses on one modality only. Furthermore, TDS helped to understand subtle differences caused by skin contact with healthy and botrytized grape material, which were not revealed by DA or TI

methodologies. Finally, it was speculated that dominance of taste modalities during the second half of the perception period may have a stronger impact on shaping consumer preference, because they stand alone and are not accompanied by other taste modalities as is the case during the first half of the evaluation process.

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