Available online at www.sciencedirect.com
SCIENCE DIRECT®
Food Quality and Preference 16 (2005) 345–349
Food Quality and Preference
www.elsevier.com/locate/foodqual

Estimating a "consumer rejection threshold" for cork taint in white wine

John Prescott [a,*], Leslie Norris [b], Madeleine Kunst [c], Sandra Kim [c]

[a] School of Psychology, James Cook University, Cairns QLD 4870, Australia
[b] FlavorSense, San Rafael, CA, USA
[c] Sensory Science Research Centre, University of Otago, Dunedin, New Zealand

Received 26 January 2004; received in revised form 18 May 2004; accepted 23 May 2004
Available online 19 July 2004

Abstract

Cork taint in wine produced by 2,4,6-trichloroanisole (TCA) is characterised by generally unacceptable *musty* or *earthy* odours. Estimates of TCA threshold in wine have been reported in the low parts per trillion (ppt) range, although it is not clear at what levels TCA begins to render a wine unacceptable. We conducted two studies to address this question by using a method that combined a paired preference test with a method of constant stimuli threshold procedure. The aim was to determine the point at which wine consumers would begin to reject a wine containing TCA, which we termed the *consumer rejection threshold* (CRT). Regular white wine consumers (Ss) received pairs of samples of white wine—one spiked with TCA in eight ascending concentrations—and were asked to indicate which of the samples was preferred. Detection thresholds (DT) for TCA in wine were also determined using triangle tests. The CRT and DT were 3.1 and 2.1 ppt, respectively. CRT and DT were significantly positively correlated with one another, and negatively correlated with TCA knowledge. A replication provided a similar CRT value, and suggested that a percentage of consumers are either highly insensitive to TCA or do not find it objectionable. These results suggest that the use of this method may provide a rational basis on which to assess the real impact of TCA in white wine.

1. Introduction

It has been estimated that 2–5% of all bottled wines are affected by "cork taint" (Fuller, 1995; Pollnitz, Pardon, Liacopoulos, Skouroumounis, & Sefton, 1996). This *musty*, *mouldy* quality results from contamination of the wine by 2,4,6-trichloroanisole (TCA), arising primarily from wine closures made from the cork oak, *Quercus suber* (Amon, Vandepeer, & Simpson, 1989; Buser, Zanier, & Tanner, 1982; Pollnitz et al., 1996; Silva Pereira, Figueiredo Marques, & San Romao, 2000). A major cause of rejection of wines by consumers, cork taint has considerable economic impact. The cost of cork taint to the wine industry worldwide has been estimated at in excess of US$10 billion annually (Fuller, 1995).

To date, the majority of sensory studies of TCA have been concerned with determining the threshold at which TCA can be detected. Such threshold values are potentially able to provide a reference point, above which consumer preferences may be affected, and are used by both wine and cork manufacturers as criteria for judging that a wine is suitable for public release, even if some level of TCA is present. However, reported values of the detection threshold for TCA in wine have varied considerably, from as low as 1.4 ng/L (parts per trillion; ppt) in pinot noir (Duerr, 1985) to as high as 210 ppt in sauvignon blanc (Suprenant and Butzke, 1997), although this latter value was derived using inexperienced tasters. When using a more experienced panel, their threshold estimate was 17.4 ppt. TCA threshold values below 10 ppt have been reported using trained/experienced panellists in both white and red wines (4 ppt: Amon et al., 1989; 2–5 ppt: Liacopoulos et al., 1999). Although not assessing thresholds, panellists used by Peña-Neira et al. (2000) were able to rate TCA levels lower than 10 ppt, suggesting that TCA produced characteristic sensory qualities that were apparent at these levels. Similarly, at least 40% of a group of experienced wine assessors were able to identify TCA-produced taint in a range of wines when the TCA concentration was above 3 ppt (Pollnitz et al., 1996).

* Corresponding author.
E-mail address: john.prescott@jcu.edu.au (J. Prescott).

0950-3293/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodqual.2004.05.010

Within the wine industry, trained/experienced panellists are commonly used to assess threshold values for TCA. However, because experience or training acts to increase odour sensitivity, it can be expected that values obtained using such panels represent thresholds much lower than the point at which the majority of wine consumers will detect TCA. In other words, such values will lead to "false alarms" if used to make decisions about the concentration at which the TCA influences the consumer's liking for the wine, and ultimately the decision to accept or reject it. Moreover, even using appropriate consumer panels, detection thresholds themselves can be expected to be lower than, and thus a poor estimate of, the point at which consumer acceptability is affected. Providing a more accurate and direct estimate of the point at which TCA influences consumer liking for a wine should provide a more rational basis on which to establish guidelines for wine quality control for the impact of TCA.

Here, we present the results of studies in which we measured a "consumer rejection threshold" for TCA in white wine. This novel approach is based on using a standard method for assessing preference—a paired preference test—within a method of constant stimuli threshold methodology ((Meilgaard, Civille, & Carr, 1991; ISO Standard 4120; ISO Standard 5495). Across a series of concentrations steps of TCA added to white wine, consumers were asked to indicate which of two wines—one with added TCA and one without—they preferred. To provide a point of comparison, we also measured these consumers' detection thresholds for TCA in the same wine.

2. Experiment 1

2.1. Methods

2.1.1. Subjects

Regular consumers of white wine (at least once per week) were recruited from among University of Otago staff and students and members of the public. Thirty-seven females and 21 males, aged between 20 and 55 years, participated. The majority (95%) were aged 20–30 years. In a screening questionnaire, 2% identified themselves as knowledgeable wine drinkers; 76% were interested in wines; and 22% were novice drinkers. The modal wine consumption frequency (98%) was 1–3 times/week. Thirty-eight percent of Ss were primarily Chardonnay drinkers, with the remainder distributed among other varietals such as Riesling, Sauvignon Blanc or blends. Ss were told that the study was a test of preference for different wines, and no mention was made of cork taint. Following the testing, Ss completed a brief questionnaire containing four multiple-choice items aimed at assessing knowledge of cork taint. These questions related to the meaning of cork taint, its incidence, prevention, and the characteristic flavour notes it produces.

2.1.2. Stimuli

A medium priced New Zealand white wine (2002 *Vidal* Chardonnay), selected partly on the basis that it was sealed with a screw cap, was used as the base wine. A 1% (10,000 ppm) solution of TCA (Aldrich) was prepared in ethanol (absolute) and, at least 24 h before testing, this solution was added to the base wine to achieve the following TCA concentrations (v/v):

- Assessment of consumer rejection threshold (CRT): 0 (diluent only), 0.5, 1, 2, 4, 8, 16, 32 ppt;
- Assessment of detection threshold (DT): 0 (diluent only), 0.125, 0.25, 0.5, 1, 2, 4 ppt.

These values were selected on the basis of the results of prior, unpublished studies. In both tests, the volume of each sample was 15 ml, served in clear wineglasses at 13 ± 1 °C.

2.1.3. Procedure

The CRT was measured using replicate series of eight paired comparison tests, one for each TCA level (including 0). Each pair consisted of a sample of the base wine alone and a sample of the base wine plus added TCA. In each test, Ss were required to taste both samples and indicate on a score sheet which sample of the pair they preferred. Ss received a new pair of coded samples every 2 min, with a 5 min break at the midpoint. TCA concentrations were presented in ascending order. Each S placed the whole sample in their mouth, moved it around for a few seconds, and then expectorated. After each pair, Ss rinsed four times with filtered water. Order of the TCA wine within each pair was randomised across each of the series.

In a second session at least one week later, DTs were measured using replicate series of triangle tests in which one of the three samples contained TCA. Ss were asked to identify the different sample. TCA concentrations were presented in ascending order, and the position of the TCA sample within each test was randomised across each series. All other serving and sampling details were the same as for the determination of CRT.

Criteria for significant detection or rejection as a function of TCA levels were based on binomial distribution tables for triangle tests and paired comparison, respectively (Roessler, Pangborn, Sidel, & Stone, 1978; Meilgaard et al., 1991; ISO Standard 4120; ISO Standard 5495). In addition, *best estimates thresholds* (BETs) were calculated as the group geometric mean (ISO Standard 13301).

2.2. Results

Figs. 1 and 2 show the results for the CRT and DT, with the percent of Ss rejecting or identifying, respectively, the samples containing TCA. These data are

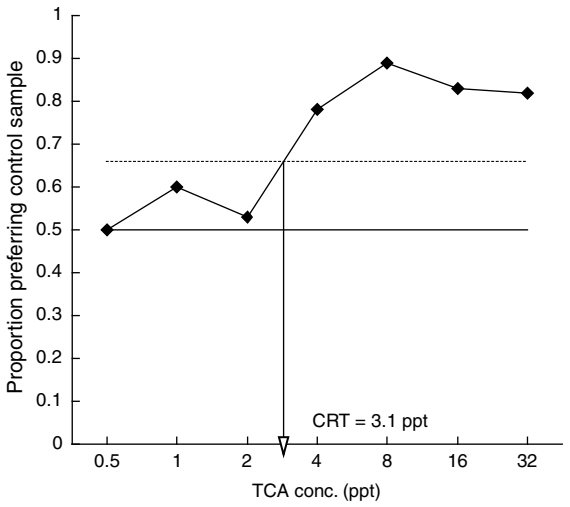

Fig. 1. Proportions of Ss in Experiment 1 choosing a wine without added TCA, averaged across duplicate paired preference tests, at each TCA concentration. The solid line (0.5) represents no preference, while the dotted line indicates the 5% significance criterion (0.66) using the binomial distribution for paired preference tests ($N = 58$), which is reached at ~3.1 ppt TCA (defined as the CRT value for these Ss).

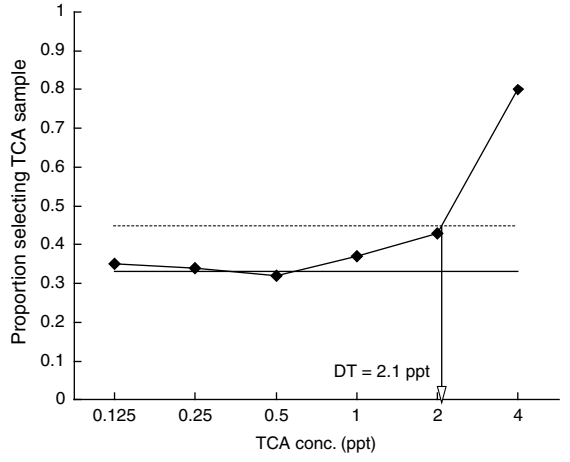

Fig. 2. Proportions of Ss in Experiment 1 identifying the wine with added TCA, averaged across duplicate triangle tests, at each TCA concentration. The solid line (0.33) represents chance responding, while the dotted line indicates the 5% significance criterion (0.45) using the binomial distribution for triangle tests ($N = 58$), which is reached at ~2.1 ppt TCA (DT: detection threshold).

averaged over both replicates, although the criterion for significance at the 5% level is based on the actual number of Ss ($N = 58$).

2.2.1. CRT

Extrapolating from the point at which the proportion of Ss rejecting the TCA sample reached the criterion for significance gave a value of 3.1 ppt. In contrast, the BET values were 6.46 and 6.08 ppt for the first and second replicates, respectively. This discrepancy reflects the fact that the BET is strongly influenced by the small number of Ss who did not reject the TCA sample at any concentration. As such, it represents a much more liberal estimate of the CRT.

2.2.2. DT

The extrapolated value for a significant proportion of Ss identifying the TCA sample was, as expected, lower than the CRT, at 2.1 ppt. In contrast to the CRT data, the DT BETs were similar to this value: 2.83 ppt for replicate 1 and 2.73 ppt for replicate 2. This greater degree of agreement between the two estimates could be expected if it was the case that some individuals did not find TCA objectionable, even if they were able to detect it.

The BET values for the CRT and DT were significantly positively correlated (Spearman's rho = 0.34; $p < 0.05$). Significant negative correlations were found between number of questions correctly answered regarding cork taint and both CRT (Spearman's rho = −0.38; $p < 0.05$) and DT (Spearman's rho = −0.31; $p < 0.05$). Thus, those with greater awareness/knowledge of cork taint also were more likely to be sensitive to TCA, and to reject wines containing it, at lower concentrations. The modal response rate for the cork taint questions was two out of four questions correct (39.7%), with only 8.6% of Ss correctly answering all four questions.

3. Experiment 2

If TCA in wine was universally disliked, then it might be expected that continuing to increase the concentration in a wine would eventually result in 100% of all consumers choosing the wine without TCA. However, Fig. 1 shows that above 8 ppt TCA, the percentage of consumers rejecting the "spiked" wine remains between 80% and 90%. This suggests perhaps that some individuals are either highly insensitive to its presence, or do not find the odour unpleasant. While thresholds for many odours typically show considerable individual variation, the DT data are unable to indicate if this is the case here since the maximum concentration used was 4 ppt.

An additional possibility exists, however. Because we used an ascending series of TCA concentrations, carry over of the TCA odour from 4 ppt TCA and above may have reduced the ability of Ss to discriminate between each pair of wines at successive TCA levels, and thus altered the basis on which their preference decisions were made.

To assess if this factor was responsible for the flattening of the preference function at higher TCA levels, as well as to provide an indication of the reliability of the original CRT estimate, we conducted a second study

using a modified stimulus presentation and a separate group of Ss.

3.1. Methods

The Ss were 19 females and 11 males, aged 20–55 years old (mean: 24.6 yrs). All Ss consumed wine 1–3 times/week. In measuring the CRT, the methods were identical to those used in Experiment 1 with the following exceptions:

(a) there was no replication;
(b) sample pairs were presented in a balanced order over two sessions, a day apart—that is, only four sample pairs were assessed per session;
(c) Ss rinsed their mouths four times before and after each sample pair;
(d) Within each session, successive sample pairs were separated by 5 min.

3.2. Results

Fig. 3 shows the percentage of Ss choosing the wine without added TCA as a function of TCA concentration. The extrapolated CRT value of 3.7 ppt TCA was similar to, although somewhat higher than, the value in Experiment 1. This can perhaps be accounted for by the stricter criterion used because of a lower N. Once again, above this value, and despite the changes in methodology to substantially reduce the risk of carry-over of TCA across successive stimulus pairs, the function flattens out. Even at 32 ppt TCA, approximately 10% of Ss did not reject the wine containing TCA.

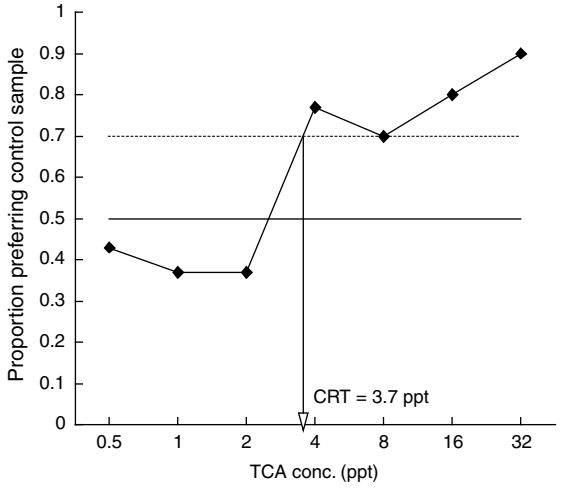

Fig. 3. Proportions of Ss in Experiment 2 choosing a wine without added TCA, averaged across duplicate paired preference tests, at each TCA concentration. The solid line (0.5) represents no preference, while the dotted line indicates the 5% significance criterion (0.7) for paired preference tests ($N = 30$), which is reached at ~3.7 ppt TCA (the CRT value).

4. Discussion

These data provide an apparently reliable estimate of the TCA concentration in white wine that is rejected by a majority of average wine consumers. Interestingly, it appears that a minority of consumers, either through insensitivity or preference, fail to reject levels of TCA at considerably higher levels. Preference tests have been shown to be sensitive measures of simple differences between samples (e.g., Macrae and Geelhoed, 1992). However, the use of a paired comparison procedure, and the fact that one of the wines was not identified as a standard, meant that an evaluation of the wine quality was a more likely basis for the CRT in the present studies. In turn, the concentration at which TCA was identified as present was lower than the CRT value. The DT measured here was also lower than some previously published values (e.g., Amon et al., 1989; Suprenant and Butzke, 1997). This is surprising, given the use of non-trained Ss in the present study, but may reflect the methods used here, in particular the use of "spiking" to achieve exact TCA concentrations in the wines.

Both sensitivity to TCA in wine and knowledge about cork taint were significantly associated with lower CRTs. In addition, cork taint knowledge was significantly negatively correlated with DTs, suggesting the possibility that knowledge of cork taint heightens sensitivity, perhaps mediated by a more effective awareness of the sensory properties that TCA produces. This is consistent with the likelihood that experienced wine consumers are much more likely to reject a wine if it is contaminated by cork taint. However, the selection of "average" wine consumers in the present study was a deliberate attempt to draw from the largest wine consumer group.

The present data are, of course, only estimates for a particular white wine, in this case, Chardonnay. Both grape variety and wine style will probably have a significant impact on the CRT for TCA. In particular, CRT values in red wines are likely to be higher, given the stronger flavours involved and the natural occurrence of "earthy" flavour notes in some red wine styles. Nevertheless, the approach taken here to establish a value that can be used in making decisions regarding possible rejections due to contamination is straightforward and can be easily repeated for other wine varieties or styles.

The CRT may also allow better estimate of the economic costs of cork taint, although it is likely to be a somewhat conservative estimate since consumers do not typically compare a corked and uncorked version of the same wine. However, the CRT should still be more closely related to consumers' behaviour in relation to wine than DT values, especially those calculated using trained panellists. The CRT may thus allow a more accurate calculation of that percentage of wines that

could be rejected, if the average TCA content is known through analytical testing.

Assessing whether or not the CRT is a generally useful technique, with wider applications beyond those reported here, requires further investigations. One possible application may be as a means of determining acceptance levels for food/beverage additives, or for other naturally occurring, but innocuous, food or beverage taints. Since quality assurance/quality control (QA/QC) sensory procedures are aimed primarily at ensuring that consumer preferences are satisfied (Munoz, 2002), the CRT might also be applied in assessing the impact of variations from control, either as a function of different product batches or over time. For example, the point at which consumers reject significantly above chance a stored, as compared to a fresh, product may be a useful criterion for establishing operating guidelines for acceptable storage times.

References

Amon, J. M., Vandepeer, J. M., & Simpson, R. F. (1989). Compounds responsible for cork taint in wine. *Australian and New Zealand Wine Industry Journal, 4*, 62–69.

Buser, H.-R., Zanier, C., & Tanner, H. (1982). Identification of 2,4,6-trichloroanisole as a potent compound causing cork taint in wine. *Journal of Agricultural and Food Chemistry, 30*, 359–362.

Duerr, P. (1985). Wine quality evaluation. In *Proceedings of the international symposium on cool climate viticulture and enology*. Eugene, USA, 25–28 June.

Fuller, P. (1995). Cork taint: Closing in on an industry problem. *Australian and New Zealand Wine Industry Journal, 10*, 58–60.

ISO (1983). Standard 4120: Sensory analysis—Methodology—Triangular test.

ISO (1983). Standard 5495: Sensory analysis—Methodology—Paired comparison test.

ISO (2002). Standard 13301: Sensory analysis—Methodology—General guidance for measuring odour, flavour and taste detection thresholds by a three-alternative forced-choice (3-AFC) procedure.

Liacopoulos, D., Barker, D., Howland, P. R., Alcorso, D. C., Pollnitz, A. P., Skouroumounis, G. K., Pardon, K. H., McLean, H. J., Gawel, R. & Sefton, M. A. (1999). Chloroanisole taint in wines. In R. J. Blair, A. N. Sas, P. F. Hayes, P. B. Høj (Eds.), *Proceedings of the 10th australian wine industry technical conference* (pp 224–226). Sydney, 2–5 August.

Macrae, A. W., & Geelhoed, H. (1992). Preference can be more powerful than detection of oddity as a test of discriminability. *Perception & Psychophysics, 51*, 179–181.

Meilgaard, M., Civille, G. V., & Carr, B. T. (1991). *Sensory evaluation techniques*. Boca Raton, FL: CRC Press.

Munoz, A. (2002). Sensory evaluation in quality control: An overview, new developments and future opportunities. *Food Quality and Preference, 13*, 329–339.

Peña-Neira, A., Fernández de Simón, B., García-Vallejo, M. C., Hernández, T., Cadahía, E., & Suarez, J. A. (2000). Presence of cork-taint responsible compounds in wines and their cork stoppers. *European Food Research and Technology, 211*(4), 257–261.

Pollnitz, A. P., Pardon, K. H., Liacopoulos, D., Skouroumounis, G. K., & Sefton, M. A. (1996). The analysis of 2,4,6-trichloroanisole and other chloroanisoles in tainted wines and corks. *Australian Journal of Grape and Wine Research, 2*(3), 184–190.

Roessler, E. B., Pangborn, R. M., Sidel, J. L., & Stone, H. (1978). Expanded statistical tables for estimating significance in paired preference, paired difference, duo-tro and triangle tests. *Journal of Food Science, 43*, 940–941.

Silva Pereira, C., Figueiredo Marques, J. J., & San Romao, M. V. (2000). Cork taint in wine: Scientific knowledge and public perception—A critical review. *Critical Reviews in Microbiology, 26*(3), 147–162.

Suprenant, A., & Butzke, C. E. (1997). Implications of odor threshold variations on sensory quality control of cork stoppers. *American Journal of Enology and Viticulture, 48*(2), 269.