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Impact of processed earwigs and their faeces on the aroma and taste of 'Chasselas' and 'Pinot Noir' wines

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Summary

The abundance of the European earwig *Forficula auricularia* L. (Dermaptera, Forficulidae) in European vineyards increased considerably over the last few years. Although earwigs are omnivorous predators that prey on viticultural pests such as grape moths, they are also known to erode berries and to transfer fungal spores. Moreover, they are suspected to affect the human perception of wines both directly by their processing with the grapes and indirectly by the contamination of grape clusters with their faeces. In this study we artificially contaminated grapes with *F. auricularia* adults and/or their faeces and determined the impact on aroma and taste of white 'Chasselas' and red 'Pinot noir' wines. Whereas the addition of five living adults/kg grapes affected the olfactory sensation of 'Chasselas' wines only marginally, 0.6 gram of earwig faeces/kg grapes had a strong effect on colour, aroma and the general appreciation of 'Chasselas' wines. Faeces-contaminated wines were less fruity and less floral, the aroma was described as faecal and they were judged to be of lower quality. The contamination of 'Pinot noir' grapes with four different densities of living earwig adults (e.g. 0, 5, 10 and 20 individuals/kg grapes) showed that only wines contaminated with more than 10 earwigs/kg grapes smelled and tasted significantly different than the uncontaminated control wine. Earwig-contaminated 'Pinot noir' wines were judged to be of lower quality. The descriptors "animal", "reductive", "vegetal", "acidic", "bitter" and "tannic" characterised their sensory perception. In conclusion, our results show that there is a real risk of wine contamination by *F. auricularia*. In particular, earwig faeces and earwig adults at densities above a threshold of 5 to 10 individuals/kg grapes have the potential to reduce the quality of wines. The evolution of earwig populations in vineyards should therefore be monitored carefully in order to anticipate problems during vinification.

Key words: *Vitis vinifera*, common earwig, wine making, sensory analysis, organoleptic tests.

Introduction

The European earwig *Forficula auricularia* L. (Dermaptera, Forficulidae) is native to Europe (Wirth *et al.* 1998). It spends the day time in cool and dark places such as wood crevices and fruits and is primarily active at night (Weyrauch, 1929). Earwigs seek food ranging from mould fungi, plant detritus, pollen, fruit flesh to arthropod prey (Huth *et al.* 2009 a). They are omnivorous predators preying also on viticultural pests such as the European vine moth, *Lobesia botrana*, the grape berry moth, *Eupoecilia ambiguella*, and the leaf-rolling tortrix, *Sparganothis pilleriana* (Buchholz and Schruft 1994). As a result, earwigs were considered as beneficial insects in vineyards in the past. Recently, however, this view has been put into question (Schruft *et al.* 1995, Mohr 2005, Huth *et al.* 2010 a). In several viticultural regions, the abundance of earwigs increased considerably over the last few years and densities occasionally reached levels that were no longer tolerated by winegrowers (Huth *et al.* 2009 a; Huth *et al.* 2010 b). Earwigs are not only known to erode berries and to transfer fungal spores (Huth *et al.* 2009 b), but winemakers also suspect that the wine made of earwig-contaminated grapes is of lower quality. Indeed, when disturbed or crushed during vinification, earwigs may release 2-methyl-1,4-benzoquinone and 2-ethyl-1,4-benzoquinone into the must (Schildknecht and Weis 1960, Walker *et al.* 1993). Moreover, these compounds with a smoky aroma are also found in their faeces (Huth *et al.* 2010 a). *Forficula auricularia* has therefore the potential to affect aroma and taste of wines directly by their processing during vinification as well as indirectly by the contamination of grape clusters with their faeces as it was partly shown by Schruft *et al.* (1995) and Huth (2011). As a result, European winemakers are worried about the impact of earwigs on the quality of wines.

In this study grapes were artificially contaminated with *F. auricularia* and the impact on the aroma and taste of white 'Chasselas' and red 'Pinot noir' wines, the two main varieties in Switzerland, was determined. In order to distinguish between the effect of direct and indirect contamination 'Chasselas' grapes were processed with adults and their faeces. 'Pinot noir' grapes were processed with four different densities of living *F. auricularia* adults to specify the perception of earwig adults. The organoleptic properties of the finished wines were first analysed by conventional two-out-of-five discrimination tests in order to examine if the wines can be distinguished from each other. Thereafter, aroma and taste were characterised by sensory profiles.

Material and Methods

Contamination with adults and faeces: The aim of this experiment was to test the effect of a contamination of the vintage with living earwigs and their

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faeces on the quality of processed wines. In September 2009, adults of *F. auricularia* were collected in vineyards of Western Switzerland. They were kept in aerated plastic boxes at ambient temperature and were regularly fed with dry cat food, apples and salad until their use. Faeces of earwigs were collected in vineyards or originated from a laboratory culture (Matthias Kölliker, University of Basel). The two types of faeces were combined and the final mixture contained 70 % field-collected faeces. White 'Chasselas' grapes were harvested at the beginning of October 2009.

The experiment was conducted using a 2x2 factorial design with the two factors being "earwig adults" (presence vs. absence) and "earwig faeces" (presence vs. absence). Harvested 'Chasselas' grapes were randomly contaminated with either 5 earwigs/kg grapes, 0.6 g faeces/kg grapes, 5 earwigs along with 0.6 g faeces/kg grapes or nothing at all (= "uncontaminated control"). Living earwig adults and their faeces were crushed in a horizontal pneumatic bladder press (maximum pressure: 5.5 bars) together with 25 kg destemmed grapes. After pressing, the musts of the four different treatments were sulphited, cleared and inoculated with selected yeast of the species *Saccharomyces cerevisiae*. After the alcoholic fermentation, the four wines were inoculated with *Oenococcus oeni*. After the completion of the malolactic fermentation, the wines were racked and subsequently stabilised chemically and physically. In February 2010, the four wines were filtered and bottled.

Influence of adult density: This experiment aimed to examine the effect of the number of processed earwigs on the sensory quality of wines. Earwig adults were collected and stored as described above. At the end of September 2009, red 'Pinot noir' grapes were harvested and destemmed. Four vats with 20 kg of grapes were contaminated with four different densities of living adults of *F. auricularia* (0 [= "uncontaminated control"], 5, 10 and 20 individuals/kg grapes). After sulphitation and inoculation with selected yeast of the species *S. cerevisiae*, grapes underwent six days of skin fermentation. Thereafter, they were pressed in a pneumatic tank press (maximum pressure: 5.5 bars). The malolactic fermentation was induced by the inoculation with *O. oeni*. Subsequently, the wines were racked, stabilised chemically and physically, filtered and bottled in February 2010.

Assessment of wine quality: At filling, the basic chemical properties of the wines (SO_2, pH, acidity, ethanol; see Tab. 1 for details) were analysed by standard methods. Two months later, bottled 'Chasselas' and 'Pinot noir' wines were tested in two-out-of-five discrimination tests (ISO 6658) by 14 and 13 tasters, respectively, in order to examine if wines can be distinguished from each other. Data were recorded using Fizz software (Biosystemes ®, Couternon, France). The sensory profiles of the wines were established by trained tasters of two independent panels. Panel I consisted of 9 and 8 judges for the four 'Chasselas' and the four 'Pinot Noir' wines, respectively. The judges rated the sensory descriptors on a continuous linear scale ranging from 1 (bad/weak) to 7 (excellent/high). Panel II consisted of 10 judges who rated the sensory descriptors of the wines on a continuous linear scale from 0 (bad/weak) to 10 (excellent/high). Individual judges of both panels sampled wines in random orders and were uninformed of the tested product.

Statistical Analysis: Data obtained from the two-out-of-five discrimination tests were analysed using a simple binomial test (SMITH 1981). To specify the impact of earwig adults and their faeces on 'Chasselas' wines, the sensory profiles of each panel were first analysed by 3-way ANOVAs. The sensory descriptors were the dependent variables whereas judges, earwig adults and earwig faeces were independent factors. For each statistical test, the fulfillment of model assumptions was checked by visually inspecting the distribution of the residuals. Where required, the sensory descriptors were log-transformed prior to analysis. For a global analysis of the two datasets, the data of the two panels were normalised, pooled and analysed by multiple factor analysis (MFA) using SensoMineR (ESCOFIER and PAGÈS, 1998; LE and HUSSON, 2008). The core of this method consists in performing a weighted principal component analysis (PCA) computed on the mean scores of each panel. The similarity between the two panels was assessed by the computation of the RV coefficient, a multivariate generalisation of the Pearson correlation coefficient (ESCOUFIER 1973, JOSSE *et al.* 2008).

For the examination of the effect of adult earwigs on 'Pinot Noir' wines, the data of the two panels were first analysed independently with 1-way ANCOVAs. The vari-

Table 1

Chemical composition of 'Chasselas' and 'Pinot Noir' wines processed with either living adults of *F. auricularia* and/or their faeces

	Free SO_2 ($mg \cdot L^{-1}$)	Total SO_2 ($mg \cdot L^{-1}$)	pH	Total acidity ($g \cdot L^{-1}$)	Volatile acidity ($g \cdot L^{-1}$)	Ethanol (% vol.)
Chasselas processed with						
Uncontaminated control	36	90	3.22	6.41	0.25	11.89
Earwigs	34	83	3.16	6.43	0.31	11.88
Faeces	28	72	3.17	6.82	0.30	11.81
Earwigs + faeces	32	83	3.19	6.61	0.34	11.54
Pinot Noir processed with						
0 earwigs/kg grapes (= uncontaminated control)	30	58	3.86	4.60	x[1)]	13.38
5 earwigs/kg grapes	29	61	3.81	4.87	0.55	13.80
10 earwigs/kg grapes	33	62	3.82	4.99	0.46	13.84
20 earwigs/kg grapes	31	64	3.88	4.77	0.52	13.60

[1)] missing value.

ous sensory descriptors were treated as dependent variables, judges served as the factor and earwig density were included in the models as a covariate. The fulfillment of model assumptions was checked by the visual inspection of the distribution of residuals. The sensory descriptors were transformed logarithmically where required. The data of two panels were normalised, pooled and analysed by MFA.

Results

Contamination with adults and faeces: The addition of earwig adults and earwig faeces did neither affect the start nor the duration of the fermentation of the four white 'Chasselas' wines. Alike, their chemical properties, such as free and total SO_2, pH, total acidity, volatile acidity and ethanol, were similar among the wines (Tab. 1). However, the two-out-of-five tests showed that the contamination of grapes with faeces had a significant effect, since the panellists were able to discriminate aroma and taste of wines contaminated with earwig faeces from the uncontaminated control wine and the wine contaminated with earwigs only (Tab. 2). Yet, there were no significant differences between the latter two and between the wine contaminated with faeces only and the wine contaminated with both faeces and earwigs.

There were significant differences in the rating of the organoleptic descriptors among judges (Tab. 3). Likewise, the contamination of grapes with *F. auricularia* had a significant effect on the sensory profiles of the four processed 'Chasselas' wines (Fig. 1, Tab. 3). Whereas the addition of living adults affected the olfactory sensation only marginally, earwig faeces had a strong effect on colour, aroma and the general appreciation of finished wines. Wines contaminated with earwig faeces had a higher colour intensity and were less fruity and less floral (Fig. 1). Their aroma was described as faecal. The aroma of wines contaminated with living adults was more intense, but the wines smelled reduced and vegetal. The addition of adults did not or only slightly interact with the addition of faeces (Table 3). Overall, 'Chasselas'wines contaminated with faeces were disliked by both panels (Fig. 1, Tab. 3).

The global analysis of the two datasets showed that there was a very high agreement between the sensory pro-

Table 2

Olfactory and gustatory comparisons in the two-out-of-five tests

	Number judges	Olfactory perception		Gustatory perception	
		No. correct responses	P	No. correct responses	P
Chasselas					
"Uncontaminated control" vs. "earwigs"	14	3	0.158	1	0.771
"Uncontaminated control" vs. "faeces"	14	9	< 0.001	8	< 0.001
"Uncontaminated control vs. "earwigs + faeces"	14	8	< 0.001	8	< 0.001
"Earwigs" vs. "faeces"	14	7	< 0.001	4	0.044
"Earwigs" vs. "earwigs + faeces"	14	8	< 0.001	5	0.009
"Faeces" vs. "earwigs + faeces"	14	2	0.415	2	0.415
Pinot Noir					
"0 earwigs/kg" vs "5 earwigs/kg"	13	3	0.134	3	0.134
"0 earwigs/kg" vs "10 earwigs/kg"	13	4	0.034	5	0.007
"0 earwigs/kg" vs "20 earwigs/kg"	13	5	0.007	5	0.007
"5 earwigs/kg" vs "10 earwigs/kg"	13	2	0.379	1	0.746
"5 earwigs/kg" vs "20 earwigs/kg"	13	3	0.134	3	0.134
"10 earwigs/kg" vs "20 earwigs/kg"	13	2	0.379	4	0.034

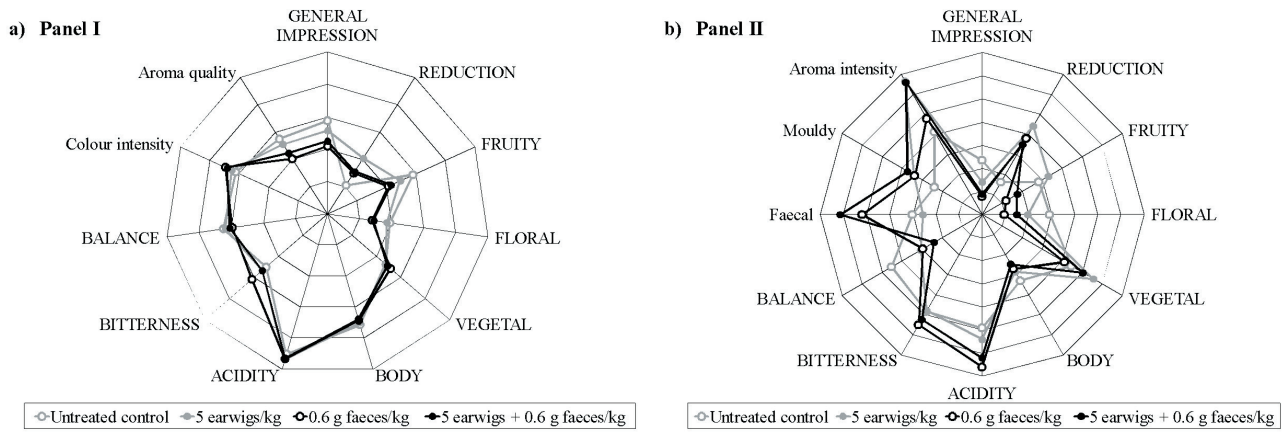

Fig. 1 : Organoleptic properties a) of panel I and b) of panel II for the four 'Chasselas' wines processed with either living adults of *F. auricularia* and/or their faeces. In capital letters: sensory descriptors that were assessed by both panels.

files of the two panels (RV = 0.950). The first two principal components of the MFA explained 95.7 % of the total variance (Fig. 2). The first component clearly opposed 'Chasselas' wines contaminated with earwig faeces to wines processed without faeces, whereas the second principal component opposed wines processed with living earwig adults to wines without adults (Fig. 2 a). The control wine was characterised by the sensory descriptors “floral”, “aroma quali-

Table 3

ANOVA-table on the effect of adults of *F. auricularia* and/or their faeces on the organoleptic properties of 'Chasselas' wines. In capital letters: sensory descriptors that were assessed by both panels

	Judges	Earwigs	Faeces	Earwigs x faeces
Panel I				
Colour				
Intensity	***	ns	***	(*)
Aroma				
REDUCTION	(*)	*	ns	(*)
FRUITY	**	ns	**	ns
FLORAL	***	ns	**	ns
VEGETAL	***	ns	ns	ns
Overall quality	**	ns	**	ns
Taste				
BODY	***	ns	ns	ns
ACIDITY	***	ns	ns	ns
BITTERNESS	***	ns	ns	ns
BALANCE	**	ns	(*)	ns
GENERAL IMPRESSION	**	ns	***	ns
Panel II				
Aroma				
REDUCTION	ns	ns	ns	(*)
FRUITY	**	ns	*	ns
FLORAL	***	ns	**	ns
VEGETAL	***	*	ns	ns
Faecal	ns	ns	***	ns
Mouldy	***	ns	ns	ns
Intensity	ns	**	ns	ns
Taste				
BODY	***	ns	ns	ns
ACIDITY	*	ns	(*)	ns
BITTERNESS	*	ns	ns	ns
BALANCE	***	ns	ns	ns
GENERAL IMPRESSION	*	ns	**	ns

ns: P > 0.10, (*): P ≤ 0.10, *: P ≤ 0.05, **: P ≤ 0.01, ***: P ≤ 0.001.

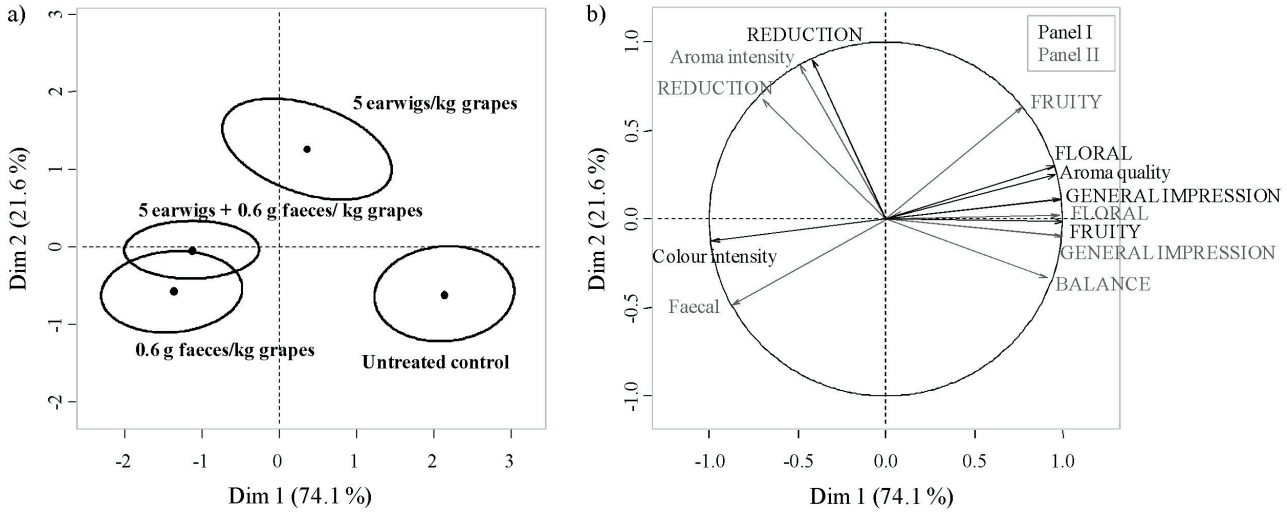

Fig. 2: MFA plots of the four 'Chasselas' wines processed with either living adults of *F. auricularia* and/or their faeces. **a**) First two factors product map inclusive their 95 % confidence interval, **b**) first two factors circle of correlation. In capital letters: sensory descriptors that were assessed by both panels.

ty", "general impression", "fruity" and "balance", whereas the terms "colour intensity" and "faecal" described the two wines contaminated with earwig faeces (Fig. 2 b). The descriptors "reduction" and "aroma intensity" were attributed to the wine processed with living earwig adults. Overall, the global MFA strongly confirmed the results obtained by the holistic two-out-of-five tests and the ANOVAs.

I n f l u e n c e o f a d u l t d e n s i t y : Neither the start, the duration of the fermentation nor the basic chemical parameters of 'Pinot Noir' wines were affected by the contamination of the grapes with the four different levels of living earwig adults (Tab. 1). The two-out-of-five tests showed that 'Pinot noir' wines contaminated with 10 and 20 earwigs/kg grapes smelled and tasted significantly different than the uncontaminated control wine (Tab. 2). The wine contaminated with only 5 earwigs/kg grapes could, however, not be distinguished from the control wine. Alike, the three wines contaminated with earwigs could, with one exception, not be distinguished from each other (Tab. 2).

The ANCOVAs showed that the sensory profiles were different among judges and that the addition of *F. auricularia* also had a significant effect on the organoleptic properties of 'Pinot noir' wines (Tab. 4). Panel I found that the fruitiness, the floral and the spiciness as well as the aroma quality decreased significantly with increasing earwig levels (Figure 3a). Wines contaminated with higher levels of earwig adults smelled more vegetal and more animal, and they tasted more bitter and had drier tannins. Panel II described the four wines less consistently, but the judges noted that earwig-contaminated wines smelled reduced (Fig. 3 b). Overall, the judges of both panels did not appreciate 'Pinot noir' wines contaminated with high levels of earwigs (Fig. 3, Tab. 4).

Despite some differences, there was a good correlation between the two panels (RV = 0.804). The first two principal components of the MFA on the pooled datasets explained 93.3% of the total variance (Fig. 4). The first principal component opposed wines with increasing earwig population levels (Fig. 4 a). The second principal component opposed the wine contaminated with 10 earwigs/kg grapes to the three other 'Pinot noir' wines. The uncontaminated wine was described by the terms "spicy",

T a b l e 4

ANCOVA-table on the effect of levels of *F. auricularia* adults on the organoleptic properties of 'Pinot Noir' wines. In capital letters: sensory descriptors that were assessed by both panels

	Judges	Level of earwigs
Panel I		
Colour		
Intensity	***	(*)
Aroma		
FRUITY	**	**
VEGETAL	***	(*)
ANIMAL	***	***
Floral	***	**
Spicy	***	*
Overall quality	**	**
Taste		
BODY	***	ns
ACIDITY	***	(*)
BITTERNESS	***	*
DRY TANNINS	***	**
SOFT TANNINS	*	ns
Hard tannins	***	ns
Tannin intensity	***	ns
Tannin quality	***	*
GENERAL IMPRESSION	*	**
Panel II		
Aroma		
Reduction	***	*
FRUITY	*	ns
VEGETAL	ns	ns
ANIMAL	ns	ns
Lactic	**	ns
Intensity	ns	ns
Taste		
BODY	***	ns
ACIDITY	***	ns
BITTERNESS	(*)	ns
DRY TANNINS	***	ns
SOFT TANNINS	***	ns
GENERAL IMPRESSION	ns	*

ns: $P > 0.10$, (*): $P \leq 0.10$, *: $P \leq 0.05$, **: $P \leq 0.01$, ***: $P \leq 0.001$.

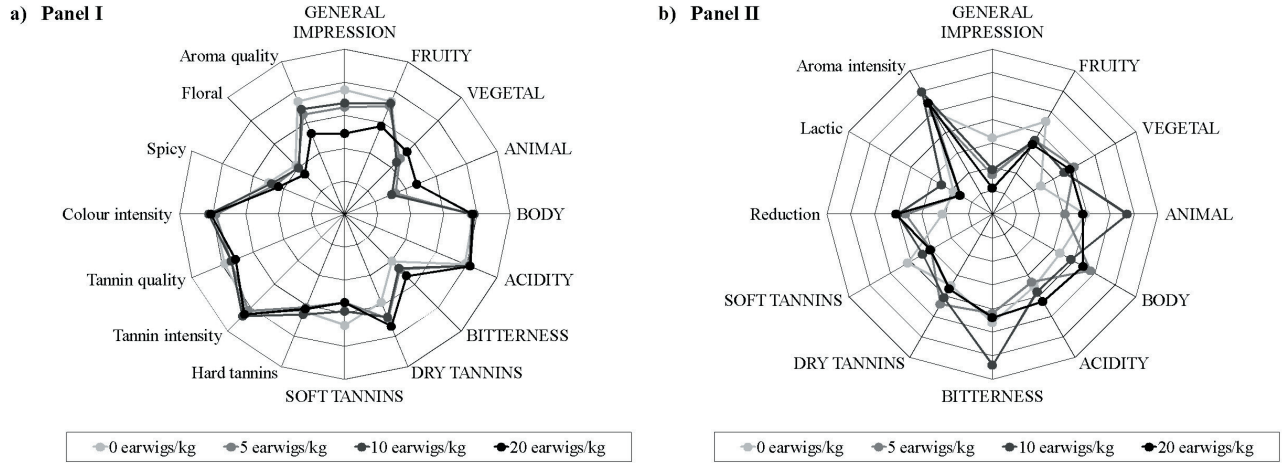

Fig. 3: Organoleptic properties **a**) of panel I and **b**) of panel II for the 'Pinot Noir' wines processed with four different levels of living *F. auricularia* adults. In capital letters: sensory descriptors that were assessed by both panels.

"fruity", "aroma quality", "soft tannins", "general impression", "floral" and "tannin quality", whereas the descriptors "reduction", "acidity", "dry tannins", bitterness" and "vegetal" were attributed to wines with high levels of earwigs (Fig. 4 b). While the descriptor "animal" as used by panel I was associated with an increase in earwig contamination, it was related to the wine contaminated with 10 earwigs/kg grapes by panel II. Apart from that, panel I characterised this wine by the descriptors "colour intensity" and "tannin intensity". Altogether, the findings obtained by MFA confirmed the results obtained by the discrimination tests and the ANCOVAs.

Discussion

Our artificial contamination of grapes with *F. auricularia* showed that their faeces as well as high densities of living adults have the potential to reduce the quality of finished wines. Whereas 0.6 g earwig faeces/kg grapes affected the olfactory sensation of 'Chasselas' wines significantly, 'Pinot Noir' grapes had to be contaminated with at least 5 to 10 earwigs/kg grapes for the contamination to be perceived in finished wines. These results are in accordance with previous studies of Schruft *et al.* (1995) and Huth (2011) and complement the current knowledge on the impact of earwigs on the aroma and taste of wines. It should, however, be noted that our wines were pressed at a higher maximum pressure than commonly used by commercial winegrowers, which might have accentuated the impact of processed earwigs (e.g. more stress, higher mortality etc.). Yet, the effect of the higher pressure on their processed faeces is probably marginal.

The contamination of 'Chasselas' with earwig faeces showed that excrement has the potential to significantly reduce the quality of finished wines. Wines contaminated with faeces were easily discriminated from the uncontaminated control wine by their faecal aroma and by their lower fruity and floral character. They were also for unknown reasons of higher colour intensity. Although it is known that the colour can influence the perception of wines, we are confident that the small differences observed among proceeded 'Chasselas' wines (Fig. 1 a) did not interfere with the organoleptic judgment of our well-trained panellists. Overall, faeces-contaminated wines were judged by both panels to be of poor quality. Such a negative impact of earwig faeces on the quality of finished wines could, however, not be identified by Huth (2011). However, this discrepancy might be explained by Huth's (2011) usage of a lower dose of faeces, by the vinification of a more aromatic grape variety (e.g., 'Riesling') and by the use of a less discriminatory sensory analysis technique (e.g., overall rating of aroma and taste). While at harvest up to 1.6 g earwig faeces were isolated from one kilogram of grapes in Germany (Huth, 2011), a maxima of 0.03 g earwig faeces/kg grapes were found in Western Switzerland (unpublished data). Thus, the applied dose of 0.6 g faeces/kg grapes matches well the situation in vineyards heavily infested with earwigs, but exceeds quantities found in moderately infested vineyards. It will therefore be interesting to test at which dose consumers are no longer able to perceive the unpleasant aroma and taste of faeces in wines, and how often this threshold is actually exceeded in practice.

The two-out-of-five tests demonstrated that both 'Chasselas' and 'Pinot Noir' wines contaminated with only 5 earwigs/kg grapes cannot be distinguished from the uncontaminated control wines. 'Pinot Noir' grapes had to be contaminated with at least 10 individuals/kg grapes until the finished wines smelled and tasted significantly different than the control wine. The perception threshold therefore seems to be between 5 to 10 earwigs/kg grapes. This value is in accordance with the findings of Schruft *et al.* (1995), but falls about 10 times below the perception threshold calculated by Huth (2011). Taking into account that the average weight of a grape cluster is 300 g for 'Chasselas' and 180 g for 'Pinot noir', one can estimate that the "adult earwig taint" becomes noticeable at levels of 1.5 to 3 earwigs per 'Chasselas' cluster and 0.9 to 1.8 earwigs per 'Pinot

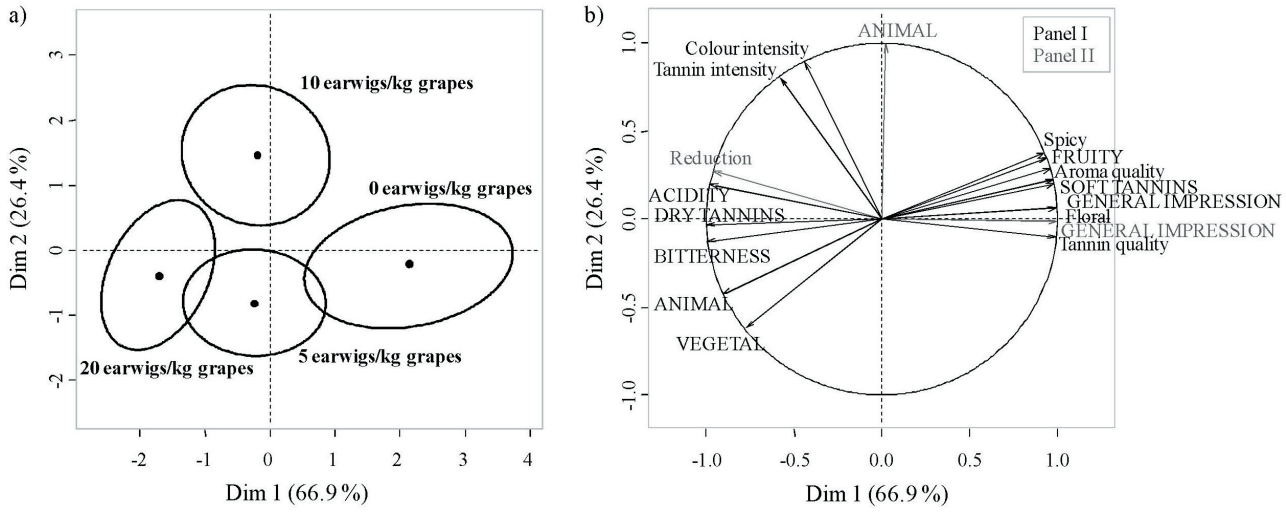

Fig. 4: MFA plots of the 'Pinot Noir' wines processed with the four different levels of living *F. auricularia* adults. **a**) First two factors product map inclusive their 95 % confidence interval, **b**) first two factors circle of correlation. In capital letters: sensory descriptors that were assessed by both panels.

Noir' cluster. Compared to the taint caused by the multicoloured Asian ladybeetle *Harmonia axyridis*, the perception threshold of earwigs is about 5 to 10 times higher (Linder *et al.* 2009). The threshold value of 5 to 10 earwigs/kg grapes is probably rarely attained in the moderately infested vineyards of Switzerland (unpublished data), but in regions heavily infested with earwigs, such as vineyards in Southern Germany, the value might be exceeded on a regular basis (Schruft *et al.* 1995, Huth, 2011). If the threshold is exceeded at harvest, finished wines risk to smell more reduced, more vegetal, more animal, less fruity, less floral and less spicy as well as they might taste more bitter.

In conclusion, the results show that there is a risk of wine contamination by *F. auricularia*, but the perception threshold is quite high. Therefore, it is too early to reclassify the status of earwigs from a beneficial insect to a viticultural pest. Its actual status is probably somewhere in between the two. Population densities can vary strongly over time and space depending on local soil type, microenvironment, meteorological conditions and physical characteristics of the grape variety (Huth *et al.* 2009 a). At present, the development of countrywide chemical control strategies against earwigs does not seem to be necessary. Winegrowers should rather monitor the evolution of European earwig population in their vineyards in order to anticipate future problems. Large populations can be reduced for example by cultural methods such as mechanical disturbance of the natural vegetation in the machine track (Huth *et al.* 2010 b). Moreover, earwigs can be blown out of grape clusters by conventional air-blast sprayers shortly before harvest (Michael Breuer, pers. comm.). And finally, harvesters can shake infested grape clusters and winegrowers can sort heavily contaminated grapes on a sorting table in order to reduce the number of processed earwigs and faeces.

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