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Effect of Fungal Disease Damage on Acetaldehyde and Volatile Acidity in Wines Produced from Rkatsiteli, Chinuri and Khikhvi Grapes

Marina Khositashvili[1*], Medea Ormotsadze[1], Lia Kotorashvili[1], and Gaga Buishvili[2]

Abstract. *Fungal diseases of grapevine can substantially alter grape composition and, consequently, the quality parameters of the resulting wines. This study evaluated the effect of fungal disease damage on acetaldehyde concentration and volatile acidity in wines produced from three Georgian white grape cultivars: Rkatsiteli, Chinuri and Khikhvi. Healthy grapes and grapes showing fungal disease symptoms were processed by microvinification according to the classical European white-wine method. Alcoholic fermentation proceeded with indigenous yeasts and fermentation intensity was monitored gravimetrically. Acetaldehyde was determined by static headspace gas chromatography–mass spectrometry (HS–GC–MS), whereas volatile acidity was measured using official OIV methods. Volatile acidity increased in every wine produced from diseased grapes, although the magnitude of the effect depended on cultivar and juice fraction. The most pronounced increase occurred in Rkatsiteli wine, from 0.67 to 3.33 g/L, while acetaldehyde decreased slightly from 60 to 56 mg/L. In Chinuri and Khikhvi wines, acetaldehyde remained within 12–15 mg/L, whereas volatile acidity in diseased variants reached 1.37–1.54 g/L. The results indicate that increased volatile acidity is the clearest technological expression of fungal damage in the investigated wines. Because grapes affected by downy mildew and powdery mildew were not processed as separate experimental groups, the independent effects of the two diseases could not be distinguished and should be evaluated in a subsequent experiment.*

Keywords: *fungal grapevine diseases, Plasmopara viticola, Erysiphe necator, acetaldehyde, volatile acidity, Rkatsiteli, Chinuri, Khikhvi, wine quality*

[1]Georgian Scientific Research Institute of Food Industry, Doctor of Technical Sciences, Tbilisi, Georgia
[2]Lakob Gogebashvili Telavi State University, Doctor of Technical Sciences, Telavi, Georgia
[*]Corresponding author. E-mail: iashiukahsvili@gmail.com
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Üzümün göbələk xəstəlikləri ilə zədələnməsinin Rkatsiteli, Çinuri və Xixvi üzümlərindən istehsal olunan şərablarda asetaldehid və uçucu turşuluğa təsiri

Marina Xositaşvili[1*], Medea Ormotsadze[1], Lia Kotoraşvili[1], Gaga Buişvili[2]

Xülasə. *Üzüm tənəyinin göbələk xəstəlikləri üzümün tərkibini və nəticə etibarilə ondan alınan şərabların keyfiyyət göstəricilərini əhəmiyyətli dərəcədə dəyişə bilər. Bu tədqiqatda göbələk xəstəlikləri ilə zədələnmənin üç gürcü ağ üzüm sortundan – Rkatsiteli, Çinuri və Xixvidən istehsal olunan şərablarda asetaldehidin konsentrasiyasına və uçucu turşuluğa təsiri qiymətləndirilmişdir. Sağlam üzümlər və göbələk xəstəliklərinin əlamətləri müşahidə olunan üzümlər klassik Avropa ağ şərab istehsalı üsuluna uyğun olaraq mikrovinifikasiya edilmişdir. Spirt qıcqırması yerli mayaların iştirakı ilə aparılmış və qıcqırmanın intensivliyi qravimetrik üsulla izlənilmişdir. Asetaldehid statik baş boşluğu qaz xromatoqrafiyası–kütlə spektrometriyası (HS–GC–MS) üsulu ilə, uçucu turşuluq isə Beynəlxalq Üzüm və Şərab Təşkilatının (OIV) rəsmi üsullarından istifadə edilməklə müəyyən edilmişdir. Xəstəliklə zədələnmiş üzümlərdən istehsal olunan bütün şərablarda uçucu turşuluq artmışdır, lakin bu təsirin dərəcəsi üzüm sortundan və şirə fraksiyasından asılı olmuşdur. Ən nəzərəçarpacaq artım Rkatsiteli şərabında müşahidə edilmiş və uçucu turşuluq 0,67 q/L-dən 3,33 q/L-ə yüksəlmiş, asetaldehidin miqdarı isə 60 mq/L-dən 56 mq/L-ə qədər cüzi azalmışdır. Çinuri və Xixvi şərablarında asetaldehidin miqdarı 12–15 mq/L intervalında qalmış, xəstəliklə zədələnmiş üzümlərdən hazırlanan variantlarda uçucu turşuluq isə 1,37–1,54 q/L-ə çatmışdır. Nəticələr göstərir ki, uçucu turşuluğun artması tədqiq edilən şərablarda göbələk xəstəlikləri ilə zədələnmənin ən aydın texnoloji göstəricisidir. Mildyu və oidium xəstəliklərindən zədələnmiş üzümlər ayrı-ayrı eksperimental qruplar şəklində emal edilmədiyindən, bu iki xəstəliyin müstəqil təsirlərini fərqləndirmək mümkün olmamışdır və həmin təsirlər sonrakı tədqiqatlarda ayrıca qiymətləndirilməlidir.*

Açar sözlər: *üzüm tənəyinin göbələk xəstəlikləri, Plasmopara viticola, Erysiphe necator, asetaldehid, uçucu turşuluq, Rkatsiteli, Çinuri, Xixvi, şərab keyfiyyəti*

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[1]Gürcüstan Qida Sənayesi Elmi-Tədqiqat İnstitutu, texnika elmləri doktoru, Tbilisi, Gürcüstan
[2]İakob Qoqebaşvili adına Telavi Dövlət Universiteti, texnika elmləri doktoru, Telavi, Gürcüstan
[*]Məsul müəllif. E-poçt: iashiukahsvili@gmail.com
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Introduction

Fungal diseases are among the principal challenges in modern viticulture because they reduce yield, impair the technological quality of grapes and modify the chemical and sensory properties of wine. Downy mildew, caused by Plasmopara viticola, and powdery mildew, caused by Erysiphe necator, are among the most widespread and economically important grapevine diseases. Other bunch-rot pathogens, particularly Botrytis cinerea, can also reduce yield and compromise grape and wine quality (Latorre et al., 2015; Steel et al., 2013). Infection of leaves and clusters reduces photosynthetic activity, disrupts normal berry development and alters grape metabolism, with consequences for the composition and quality of the resulting wine (Gessler et al., 2011; Rienth et al., 2021).

Changes in temperature, rainfall distribution and humidity can modify fungal disease pressure in vineyards. The direction and extent of this effect vary by region and pathogen, but mildews are expected to remain a major phytosanitary threat because their development is strongly influenced by temperature and moisture. Consequently, winemakers may increasingly face the need to process partially affected grapes, with potential effects on fermentation, chemical composition and sensory quality (Rienth et al., 2021).

Damage to berry tissues disrupts cellular integrity, promotes the activity of oxidative enzymes and creates favourable conditions for undesirable microorganisms. These changes may affect alcoholic fermentation and the qualitative and quantitative profile of fermentation-derived compounds. Wines made from grapes affected by P. viticola have been reported to show altered concentrations of aldehydes, ketones, lactones and other volatile compounds, producing atypical green, herbaceous, dried-fruit and cooked-fruit notes (Pons et al., 2018). Comparable fungal deterioration can alter wine aroma and introduce additional quality and safety risks (Steel et al., 2013; Welke, 2019).

Acetaldehyde is an important intermediate of alcoholic fermentation. Yeasts produce it through the decarboxylation of pyruvate, after which it is normally reduced to ethanol. It can also form through ethanol oxidation. Its concentration is therefore influenced by yeast metabolism, oxygen availability, fermentation conditions and the microbiological status of the wine. At elevated levels, acetaldehyde may contribute bruised-apple, nutty or oxidised sensory notes and can serve as an indicator of oxidative change (Ribéreau-Gayon et al., 2021).

Acetaldehyde is also an intermediate in the oxidation of ethanol to acetic acid. Acetic acid bacteria, including Acetobacter and Gluconobacter species, oxidise ethanol first to acetaldehyde and subsequently to acetic acid. Intensification of this pathway increases volatile acidity, a key technological and quality parameter in wine. Excessive volatile acidity adversely affects sensory quality, microbiological stability and commercial value (Ribéreau-Gayon et al., 2021). Because grape-surface microorganisms contribute to fermentation ecology, disease-related shifts in the berry microbiota may also influence spoilage pathways and wine composition (Barata et al., 2012; Liu et al., 2019).

Although numerous studies have addressed the effects of grapevine diseases on vine physiology, berry metabolism and wine aroma, less information is available on the formation of acetaldehyde and volatile acidity in wines produced from diseased grapes, particularly for Georgian cultivars. Studies of grape biofilm and must demonstrate that vineyard disease-management conditions can modify microbial diversity carried into fermentation (Escribano-Viana et al., 2018). This subject is of practical and scientific importance for Georgia, one of the oldest centres of grape and wine culture. The aim of this study was to evaluate the effect of fungal disease damage on acetaldehyde and volatile acidity in wines produced from the Georgian white grape cultivars Rkatsiteli, Chinuri and Khikhvi, and to compare the observed changes according to cultivar and juice fraction.

Materials and Methods

Grapes and experimental design

The study examined the Georgian white grape cultivars Rkatsiteli, Chinuri and Khikhvi and the wines produced from them. Healthy Chinuri and Khikhvi grapes and grapes displaying fungal disease symptoms were collected at the Jighaura Experimental Base of the Scientific-Research Center of Agriculture, Georgia. Healthy and diseased Rkatsiteli grapes were collected from the experimental vineyard of Iakob Gogebashvili Telavi State University. The diseased grapes were processed as a single experimental category; therefore, this study evaluates the overall effect of fungal damage and does not distinguish the independent effects of downy mildew and powdery mildew.

Grapes were harvested at technological maturity. Before processing, soluble solids, titratable acidity and pH were determined. Soluble solids were measured by refractometry. Titratable acidity was determined by titration with 0.1 N sodium hydroxide and expressed as tartaric acid equivalents (g/L), while pH was measured using a calibrated pH meter. Microvinification was carried out under semi-industrial conditions in the teaching and research winery of Iakob Gogebashvili Telavi State University. All samples were processed according to the classical European white-wine method. For Chinuri and Khikhvi, each grape sample was separated into free-run and pressed juice fractions. Free-run juice was obtained without direct pressing, whereas pressed juice was collected after pressing. This design was used to assess whether the greater extraction of components from damaged berry skins and pulp influenced acetaldehyde and volatile acidity. Rkatsiteli samples were not separated into these fractions.

Fermentation and routine wine analyses

Alcoholic fermentation proceeded with indigenous yeasts, without the addition of commercial starter cultures, at 16–18 °C. Fermentation was monitored daily by the gravimetric method based on carbon dioxide loss. Fermentation lasted approximately 12 days in musts from healthy grapes and 15 days in musts from diseased grapes, possibly reflecting differences in must composition and indigenous microbiota. After completion of alcoholic fermentation, the wines were racked from the lees and subjected to physicochemical analysis. Alcohol content, pH, titratable acidity and volatile acidity were determined according to the official analytical methods recommended by the International Organisation of Vine and Wine (OIV, 2024). Volatile acidity is reported as g/L.

Determination of acetaldehyde

Acetaldehyde was determined at Wine Laboratory (Winelab, Georgia) by a validated headspace gas chromatography–mass spectrometry method. Analyses were performed using an Agilent Technologies 7890B gas chromatograph equipped with a 5977B mass selective detector, a Headspace PAL RSI 120 autosampler and an Agilent DB-624UI capillary column (30 m × 0.32 mm × 1.8 μm).

Helium of 99.99% purity was used as the carrier gas at a constant flow rate of 1.25 mL/min. Static headspace sampling enabled the determination of volatile compounds without prior distillation. A 10 mL aliquot of wine was placed in a 20 mL headspace vial and incubated at 40 °C for 20 min, after which the gas phase was automatically injected into the chromatographic system. Chromatographic separation was performed using a temperature programme, and mass-spectrometric detection was conducted in selected-ion monitoring mode. Acetaldehyde was identified by its retention time (1.35 min) and the monitored ion (m/z 32). Quantification used an external calibration curve prepared from certified standard solutions. The working range was 10–1000 mg/L and calibration linearity was $R^2 = 0.9974$.

The validated method had a limit of detection (LOD) of 12.2 mg/L and mean accuracy of 98.4% and repeatability of 1.2%. Acetaldehyde results are expressed as mg/L. Concentrations reported for Chinuri and Khikhvi wines (12–15 mg/L) lie near the lower end of the validated working range; these values are therefore interpreted cautiously in the Discussion.

Data treatment

Analytical determinations were performed on samples obtained from microvinification carried out under controlled, replicated conditions. Comparative analysis of healthy and diseased samples, and of free-run and pressed fractions where available, was used to evaluate the overall effect of fungal damage. However, the dataset available for the present analysis comprised mean concentrations per treatment rather than individual replicate values, standard deviations could not be recalculated. Table 1 therefore reports mean concentrations together with the percentage change relative to the corresponding healthy control. In the absence of replicate-level data, no formal test of statistical

significance is presented; differences are described in terms of their magnitude and the consistency of their direction across cultivars and juice fractions.

Results

Processing grapes affected by fungal disease produced the most consistent change in volatile acidity (Table 1). Volatile acidity was higher in every wine from diseased grapes than in its corresponding healthy control. The magnitude of the change, however, depended on cultivar and on whether free-run or pressed juice was used.

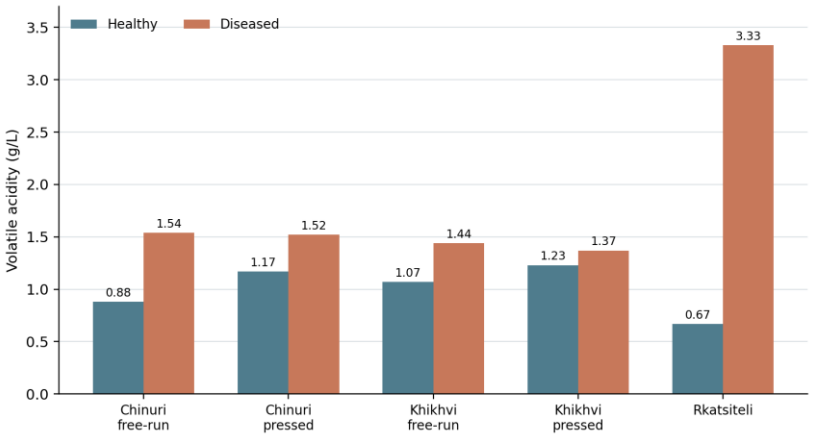

Figure 1

Volatile acidity in wines produced from healthy and diseased grapes

Figure 1 highlights the consistent increase in volatile acidity in all diseased variants and the exceptionally large response of Rkatsiteli. The visual comparison also shows that the disease-associated increase was greater in the free-run than in the pressed fraction for both Chinuri and Khikhvi.

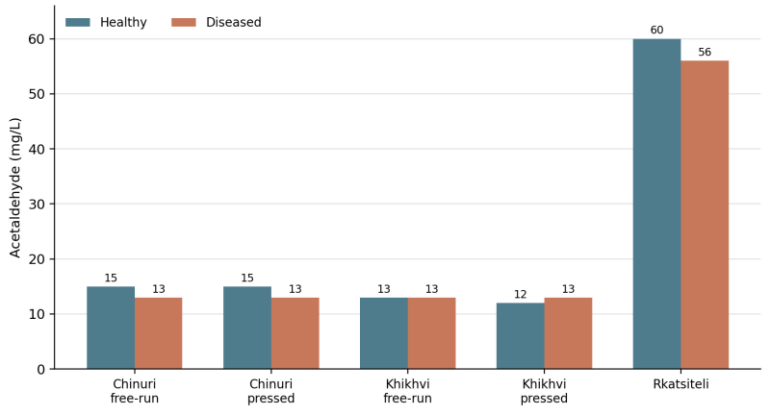

Figure 2

Acetaldehyde concentration in wines produced from healthy and diseased grapes

Figure 2 demonstrates a different response pattern for acetaldehyde. Disease did not produce a consistent increase: concentrations decreased in Chinuri and Rkatsiteli, remained unchanged in Khikhvi free-run wine and increased only slightly in the Khikhvi pressed fraction. The substantially higher baseline concentration in Rkatsiteli was primarily cultivar-related rather than disease-induced.

Table 1
Acetaldehyde and volatile acidity in wines produced from healthy and diseased grapes

Cultivar	Juice fraction	Grape condition	Acetaldehyde (mg/L)	Volatile acidity (g/L)	Δ VA (%)
Chinuri	Free-run	Healthy	15	0.88	—
Chinuri	Free-run	Diseased	13	1.54	+75.0
Chinuri	Pressed	Healthy	15	1.17	—
Chinuri	Pressed	Diseased	13	1.52	+29.9
Khikhvi	Free-run	Healthy	13	1.07	—
Khikhvi	Free-run	Diseased	13	1.44	+34.6
Khikhvi	Pressed	Healthy	12	1.23	—
Khikhvi	Pressed	Diseased	13	1.37	+11.4
Rkatsiteli	Not separated	Healthy	60	0.67	—
Rkatsiteli	Not separated	Diseased	56	3.33	+397.0

Values are means of triplicate microvinifications. ΔVA (%) is the percentage change in volatile acidity relative to the corresponding healthy control. Acetaldehyde concentrations for Chinuri and Khikhvi (12–15 mg/L) lie near the lower end of the validated working range and should be interpreted with corresponding caution.

In Chinuri free-run wine, fungal damage increased volatile acidity from 0.88 to 1.54 g/L, corresponding to a 75.0% increase. In the pressed fraction, volatile acidity increased from 1.17 to 1.52 g/L, or by 29.9%. Acetaldehyde decreased from 15 to 13 mg/L in both diseased variants (13.3%). Thus, in Chinuri, fungal damage was clearly reflected by increased volatile acidity but did not promote acetaldehyde accumulation in the finished wine.

In Khikhvi free-run wine, volatile acidity increased from 1.07 to 1.44 g/L (34.6%), while acetaldehyde remained unchanged at 13 mg/L. In the pressed fraction, the increase in volatile acidity was smaller, from 1.23 to 1.37 g/L (11.4%), and acetaldehyde increased only slightly, from 12 to 13 mg/L. The effect of diseased grapes was therefore more pronounced in the free-run Khikhvi fraction. The greatest difference occurred in Rkatsiteli wine. Volatile acidity increased from 0.67 to 3.33 g/L, representing an approximately 4.97-fold, or 397%, increase. The direction of this result agrees with evidence that ripe-rot-affected grapes can substantially increase volatile acidity in wine (Miele & Rizzon, 2013). This value was markedly higher than those obtained for the other samples and indicates intensified undesirable microbiological and oxidative activity during the processing and fermentation of diseased grapes. Nevertheless, acetaldehyde decreased from 60 to 56 mg/L. The high volatile acidity was therefore not accompanied by the accumulation of acetaldehyde in the final wine. This pattern may reflect the intermediate metabolic role of acetaldehyde, which can undergo further oxidation to acetic acid or react with other wine constituents (Ribéreau-Gayon et al., 2021).

Discussion

The pronounced cultivar-related difference in acetaldehyde concentration is noteworthy. Chinuri and Khikhvi wines contained 12–15 mg/L, whereas Rkatsiteli wines contained 56–60 mg/L. Because all wines fermented with indigenous yeasts, these differences may reflect both cultivar composition and variation in the natural microbiota and fermentation kinetics. A controlled experiment would be needed to separate these effects. No simple direct relationship between acetaldehyde and volatile acidity was evident in the final wines. Volatile acidity increased in all diseased variants, while acetaldehyde decreased, remained unchanged or increased only slightly. A single endpoint

measurement of acetaldehyde cannot capture its complete formation and conversion dynamics during fermentation and oxidation. Future studies should therefore monitor acetaldehyde and volatile acidity at several stages of fermentation.

Conclusion

Fungal disease damage increased volatile acidity in every comparable wine produced from Rkatsiteli, Chinuri and Khikhvi grapes. The most pronounced change occurred in Rkatsiteli wine, where volatile acidity increased from 0.67 to 3.33 g/L. In Chinuri and Khikhvi, the increases were more moderate and varied according to juice fraction. Acetaldehyde did not increase consistently in response to disease, confirming that its endpoint concentration was not directly proportional to volatile acidity. From a practical perspective, volatile acidity requires particularly close control when diseased grapes are processed. These conclusions apply to the combined effect of fungal damage; a disease-separated experiment is required to determine the independent effects of downy mildew and powdery mildew.

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