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Resveratrol Treatment Controls Microbial Flora, Prolongs Shelf Life, and Preserves Nutritional Quality of Fruit

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Resveratrol is known as a grapevine secondary metabolite with fungicide activity. Its exogenous application on harvested grapes resulted in the reduction of microbial flora growth, and consequently, prolonged shelf life, without affecting the nutritional quality of the fruit. Resveratrol treatment also resulted in being effective on fruit that normally does not accumulate such metabolites as, for example, tomatoes, apples, avocado pears, and peppers. As a result, all treated fruits maintained their post-harvest quality and health longer than the untreated ones. This study demonstrates the potential use of resveratrol as a natural pesticide to reduce post-harvest fungi development on a broad spectrum of fruit types.

KEYWORDS: Fruit spoilage; fruit shelf life; fungi; microbial flora; antioxidant; dietary antioxidant element; nutritional content; water content

INTRODUCTION

As is well-known, one of the main problems of modern agriculture is the post-harvest fruit losses due to pathogen's attack and natural senescence during storage. Well-established solutions to improve this situation as, for example, storage under controlled conditions and the use of synthetic pesticides are not free of problems due to human health risks and environmental effects caused by chemical pesticides. A new strategy to solve these problems consists of developing methods to improve the natural plant resistance by using, upon their identification, the plant defense molecules; in other words, to apply methods based on the own natural processes of pest suppression to control spoilage.

Resveratrol (3,5,4′-trihydroxystilbene) has been described as one of the most important molecules for resistance to fungal diseases in grapevines, as a response to the biotic and abiotic stresses. Resveratrol has been shown to have a rather broad antifungal activity, and it can be fungitoxic against the phytopathogenic fungus *Botrytis cinerea*, which is a major cause of post-harvest rot of perishable plant products in a huge variety of crops (*1*, *2*). Thus, this unspecific antifungal character and the selective accumulation of resveratrol in grape skin (*3*) makes it a good candidate as a natural pesticide against pathogen attack by improving the natural resistance of grapes to fungal infection. Furthermore, due to its antioxidant properties (*1*, *2*, *4*), resveratrol can also have positive effects on fruit conservation during storage. As a plant microcomponent, resveratrol can be present in human diet or beverages (i.e., red wine). The use of resveratrol as a natural antibiotic to reduce microbial contamination in fruit maybe very advantageous, as it could also be used during the post-harvest, up to the delivery to the consumers, without expecting risks to human health but potentially with benefits as added value to the treated food. Since the discovery of its cancer chemopreventive activity, a huge number of publications flourished to evaluate its role as a bioactive natural molecule with potential applications in phytotherapy, pharmacology, or in the nutriprotection (nutraceutic food) area (*5*−*7*). We have previously developed a direct and fast analytical laser-based technique optimized for nonvolatile compounds in fruits (*8*−*10*) and evaluated the effect of resveratrol as a natural pesticide by its exogenous application to grapes (*11*, *12*). Here, we characterized in detail the effects of resveratrol in the control of microbial flora on harvested grape fruits. In addition, we evaluated the nutritional quality of the fruit and the fruit water content in relation to the effect of resveratrol application. Finally, we have extended our observation from grapes to other fruits,

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demonstrating the potential of the use of resveratrol treatment to prolong the shelf life of different fruit types.

MATERIALS AND METHODS

Exogenous Application of Resveratrol in Fruits. The essential procedure for the treatment of the fruits with resveratrol (Sigma) is as follows (*11*, *12*): fruit was dipped in a resveratrol solution (1.6×10^{-4} M of resveratrol in water; to increase the resveratrol solubility in water, a mixture of 90% bidistilled water and 10% tap water was used) for 5 s; a second group was immersed in water for the same time period, as a control. Because of the slight solubility of resveratrol in water and to ensure an homogeneous application, the solution was stirred during the treatment. After this short treatment, the fruits were stored at the desired temperature (24 or 4 °C). For the grapes (Aledo variety), to avoid effects of different maturity stage between bunches, each bunch was cut in two similar moieties and incorporated to one of the groups. Thus, each experiment contained three half-bunches per group (treated and nontreated). All experiments were repeated up to 5 times to ensure reproducibility of the results. Several concentrations were tested to obtain optimal results with the minimum concentration possible of the compound. Results showed in this study refer to a concentration of 1.6×10^{-4} M resveratrol in water. We have also performed the same procedure on other fruit types: [apple (Golden), tomato (Rambo), avocado pear (Hass), and pepper (Lamuyo and California)]. In these cases, six pieces per experiment were used (three treated and three nontreated). The fruits used in all experiments were directly purchased from the market, and no additional cleaning was performed.

Microbiological Analysis. A related work (*13*) on the development influence of *B. cinerea* on infected grapes described the microbial flora that flourish on the fruit surface, demonstrating that the deterioration of the grapes is not only due to the development of *B. cinerea* but also to other organisms present on the fruit, mainly yeast and imperfect fungi such as *Penicillium*, *Aspergillus*, and *Alternaria* spp. In this study, we referred more generally to mold (such as the phytopathogenic fungi mentioned previously) and yeast to indicate the microbial species analyzed. In vitro determination of mold and yeast growth on grapes was carried out by the surface extension method. The samples (grapes treated and nontreated with resveratrol) were weighed and diluted in a sterile saline solution of tryptone salt 0.1%, and then sucessives decimal dilutions were prepared to enable proper colony quantification. The 0.1 mL aliquots of each dilution were incubated on a Petri dish at 24 °C for two to four days using a Saboraud medium contanining 10 mg/L cloramphenicol to avoid bacterial growth. Identification of the microbial flora was performed by a small fraction of the colony being stained with lactophenol blue and the morphology with an optical microscope being analyzed. Counting of yeast and mold was carried out separately, and the results are expressed as colony forming units per gram of sample.

Bromatological Analysis. Several analyses were carried out on grapes to determine the biochemical parameters that characterize the nutritional quality of the fruit. The following parameters were analyzed with standard procedures commonly used in food quality studies: proteins, determined by Kjeldahl method (*14*); free carbohydrates, determined by the anthrone method (*15*); sugars, determined by HPLC (*16*); water content, determined by weight losses during sample dehydration at 100 °C up to constant weight (*17*); and ashes, determined by weight differences before and after calcination (*14*).

RESULTS

Exogenous application of resveratrol reduced post-harvest decay in most of the fruit types tested, such as tomatoes (**Figure 1A**,**B**), grapes, apples, avocado pears (Supporting Information), and green and red peppers (not shown). The treatment, however, was far less effective in strawberries, probably due to the higher ripening rate of this fruit.

Grapes treated with resveratrol and stored at 4 °C in parallel with control (nontreated) grape bunches showed a clear decrease in both mold (**Figure 1C**) and yeast growth. After 10 days of storage, the amount of mold on nontreated fruits increased 10^3-fold (from 10 cfu/g to 4.6×10^4), whereas resveratrol treatment reduced microbial growth to only a 10-fold increase (from 10 cfu/g to 3.2×10^2). Yeast proliferation (not shown) was slower when compared to that of the mold and increased on nontreated fruit by 10-fold (from 2.5×10^2 cfu/g to 2.3×10^3 cfu/g), yet resveratrol treatment seemed to arrest the remaining yeast proliferation around the basal levels within 10 days of storage (from 2.5×10^2 cfu/g to 1.9×10^2 cfu/g). Storage at 24 °C reduced the effects of the treatment on fungal growth that decreased only 10-fold with respect to nontreated fruits (10^4 cfu/g in treated fruit vs 10^5 cfu/g in nontreated fruit, **Figure 1D**). This effect might be related to a faster thriving of mold that resulted in a different dose/effect ratio of resveratrol. Nevertheless, storage at 24 °C did not affect the resveratrol treatment with respect to yeast proliferation that remained approximately at basal levels within the period of storage also at this temperature (not shown).

The grape berries are mainly composed of water (approx 80%), sugars (15%), fibers (1.5%), and other components (*18*). Evaluation of resveratrol-treated grapes, stored at 4 °C during the experiment, indicated that nutritional contents were mostly unaltered in resveratrol treated as compared to nontreated fruit. Differences between distinct samples were not relevant regarding the main nutritional components such as carbohydrates, minerals, and proteins that remained at comparable levels in treated and nontreated fruits (**Table 1**). A similar result was obtained with respect to the content in soluble sugars, namely, glucose, fructose, and sucrose (Supporting Information). Furthermore, the percentage of the total sugars and carbohydrates was not affected by the treatment. Similar analyses were also perfomed with grapes stored at 24 °C with no substantial differences in the main nutritional components between treated and nontreated grapes (data not shown).

Important differences were found with respect to the water content of the samples, which is one of the main parameters affecting the firmness and shelf life of fruits. Results (**Figure 1E**,**F**) indicated that grapes treated with resveratrol maintained a higher water content when stored both at 4 and at 24 °C. It is evident from the graph in **Figure 1E** (storage at 4 °C) that humidity is better maintained in the treated grapes: after 16 days of storage, the water content is 5.4% higher in the samples treated with resveratrol than in the nontreated ones. A similar trend is observed for the samples stored at 24 °C (**Figure 1F**); in this case, the analysis was conducted only up to 8 days because the deterioration of the samples did not enable a longer period of analysis.

DISCUSSION

As indicated earlier, tens of thousands of secondary plant metabolites have been identified insofar, and there is a growing evidence that most of these compounds are involved in the defense mechanisms of the plants, thus representing a large reservoir of natural pesticides to be used for pest control (*19*−*21*). This study describes a possible application of the anti-microbial natural molecule resveratrol to control post-harvest mold development. Resveratrol seemed to be a good candidate as natural pesticide due to its rather unspecific antifungal character (*22*−*25*); in addition, due to its antioxidant properties, *trans*-resveratrol can also have positive effects on fruit conservation during storage. To demonstrate the capabilities of resveratrol as a natural pesticide, this study has been extended to other fruits than grapes that do not accumulate self-produced resveratrol. In addition, the nutritional quality of the fruit after

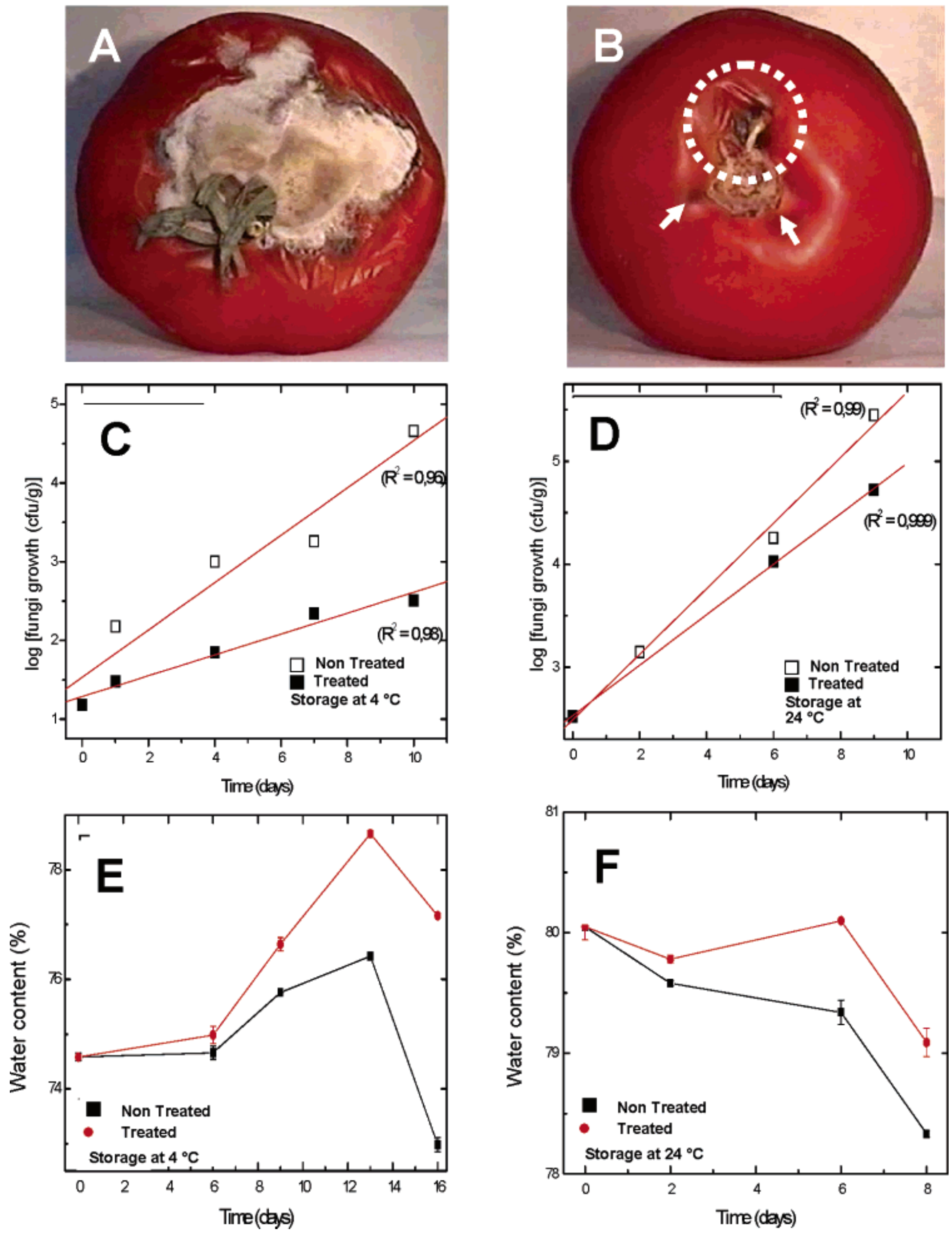

Figure 1. Resveratrol treatment inhibits mold development on grapes and other fruit types. Tomato: spoilage comparison of nontreated and *trans*-resveratrol treated tomato fruits stored at 24 °C for 30 days after treatment is shown. **(A)** Nontreated tomato fruits show clear advance of microbial flora growth on the fruit skin (recognizable as white/gray mold on the shoulder of the fruit). **(B)** Tomato fruit treated with *trans*-resveratrol. Despite early symptoms of spoilage visible as a darkening of the inner flesh (arrows) and breaking of the fruit skin (dashed circle), resveratrol treated tomato fruits undoubtedly have a longer shelf life and reduction of microbial flora growth as compared to untreated fruits (**A**). Similar behavior was observed also in other fruit types, including apple, avocado pear, and pepper (Supporting Information). **(C)** Grapes: logarithm of mold growth vs time for nontreated and *trans*-resveratrol treated grapes stored at 4 °C during the experiment. Results indicate a clear reduction of mold growth in resveratrol-treated (○) versus untreated (■) fruits over time. R^2: linear regression coefficient. **(D)** Grapes: logarithm of mold growth vs time for nontreated and *trans*-resveratrol treated grapes (stored at 24 °C during the experiment). R^2: linear regression coefficient. **(E)** Grapes: time evolution of the water content in nontreated and *trans*-resveratrol treated grapes. Grapes were stored at 4 °C. Water content decrease is clearly slower in resveratrol treated fruits than in nontreated. The early raising in water content observed in both samples up to the 13th day can be attributed to the high humidity in the freezer that, in principle, would affect both samples in the same manner. **(F)** Grapes: time evolution of the water content in nontreated and trans-resveratrol treated grapes. Grapes stored at 24 °C. The descrease in water content at 24 °C is more dramatic than at 4 °C (**E**). As in **panel E**, water content decrease is clearly slower in resveratrol treated fruits than in nontreated.

treatment with resveratrol has been assessed to assay the full impact of this compound.

Results indicated that treatment improved fruit shelf life, not only contracting microbial flora growth but also reducing water losses, without affecting nutritional content. The maintenance of water content (and therefore fruit firmness) after resveratrol treatment is very important to evaluate the quality of very juicy fruits such as grapes and may be explained by two distinct modes of action. One possible mechanism could be due to the action of resveratrol as a natural pesticide, thus avoiding mechanical damage to the skin by microbial growth and penetration into the fruit; as a consequence, treated fruits would

Table 1. Main Nutritional Parameters of Stored Grapes[a]

		time after treatment (days)	nontreated	treated
proteins (%)	fresh	0 (control)	0.75 ± 0.01	
		3	0.66 ± 0.02	0.63 ± 0.02
		6	0.90 ± 0.01	0.68 ± 0.01
		9	0.73 ± 0.01	0.71 ± 0.02
		13	0.84 ± 0.041	0.71 ± 0.01
		16	0.80 ± 0.01	0.81 ± 0.04
	lioph.	0 (control)	2.94 ± 0.04	
		3	2.97 ± 0.08	2.74 ± 0.09
		6	3.55 ± 0.05	2.68± 0.05
		9	3.02 ± 0.04	3.05 ± 0.08
		13	3.57 ± 0.17	3.31 ± 0.05
		16	2.97 ± 0.55	3.54 ± 0.18
free carbohydrates (%)	fresh	0 (control)	22.95 ± 0.77	
		3	15.54 ± 1.81	16.62 ± 0.49
		6	19.90 ±1.92	17.41 ± 0.62
		9	19.64 ± 0.26	18.66 ± 1.55
		13	17.62 ± 0.12	15.40 ± 0.53
		16	20.65 ± 0.65	16.71 ± 0.45
	lioph.	0 (control)	90.30 ± 3.02	
		3	69.30 ± 8.09	72.57 ± 2.15
		9	78.02 ± 7.52	68.93 ± 2.45
		6	81.04 ± 1.09	79.89 ± 6.65
		13	74.74 ± 0.53	72.15 ± 2.47
		16	76.42 ± 2.07	73.18 ± 1.95
ashes (%)	fresh	0 (control)	0.72 ± 0.04	
		3	0.59 ± 0.04	0.70 ± 0.01
		9	0.90 ± 0.08	0.73 ± 0.05
		6	0.87 ± 0.13	0.83 ± 0.06
		13	0.79 ± 0.07	0.73 ± 0.02
		16	0.86 ± 0.03	0.67 ± 0.03
	lioph.	0 (control)	2.83 ± 0.15	
		3	2.64 ± 0.18	3.06 ± 0.05
		9	3.52 ± 0.32	2.88 ± 0.20
		6	3.58 ± 0.56	3.55 ± 0.26
		13	3.36 ± 0.31	3.37 ± 0.12
		16[a]	3.18 ± 0.13	2.93 ± 0.12

[a] Main nutritional parameters of nontreated and *trans*-resveratrol treated grapes stored at 4 °C during the experiment (fresh and liophilized samples). Differences between distinct samples were not relevant regarding the main nutritional components as carbohydrates, minerals, and proteins that remained at comparable levels in treated and nontreated fruits. Data are indicated as mean ± SD.

preserve the integrity of the skin to a higher degree, and consequently, the water losses would be lower as compared with the nontreated fruits. Another possible mechanism considers resveratrol as an impermeabilizer, which produces a coat that surrounds the fruit. Resveratrol, in fact, is poorly water soluble, and its vapor pressure (to date not avalaible) is supposed to be similar to that of stilbene, which is considered to be negligible and in any case much lower than that of water. Thus, we suggest that resveratrol distribution as a thin coat around the fruit reduces water vapor pressure, and consequently, preserves water content and fruit firmness. Work is now in progress to investigate the latter possibility.

The main problems of microbial contamination in food are not only due to their ability to spoil it, but the risk to human health, such as infection in humans, accumulation of mycotoxins, or induction of allergy in individuals hypersensitive to fungal antigens. Moreover, the use of synthetic pesticides in agriculture may be risky to human health; usually, pesticide use must end at a specific time before harvest but sometimes unproper treatments in fruit may result in retention of toxic chemicals in the fruit released to the market. The use of resveratrol as a natural pesticide as demonstrated in this study offers a new, simple, inexpensive, and safe modality to improve the shelf life of fruits preserving their natural post-harvest quality. Indeed, resveratrol is generally considered as a plant natural compound with a huge potential as added nutrional value in food, but yet the mechanism of action of resveratrol in plant-pathogen interactions (*26*) and in cancer prevention (*27*−*29*) are not completely understood. Therefore, further investigations of the resveratrol effect in human diet are highly desirable.

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Supporting Information Available: Figure of different fruit types upon resveratrol treatment; table data for graph in panels C and D; table data of soluble sugars in nontreated and *trans*-resveratrol treated grapes stored at 4 °C during the experiment (glucose, sucrose, fructose). This material is available free of charge via the Internet at http://pubs.acs.org.

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