



Evaluation of thermal treatments for pest control in stored Corinthian currants

Maria K. Sakka¹ · Velisaria-Eleni Gerogianni² · Marina Gourgouta¹ · George Boskou² · Vaios T. Karathanos^{2,3} · Antonia Chiou² · Christos G. Athanassiou¹

Received: 3 June 2025 / Revised: 31 December 2025 / Accepted: 19 January 2026 / Published online: 14 March 2026
© The Author(s) 2026

Abstract

The present study investigated the application of elevated and low temperatures as an alternative strategy for managing insect pests in stored Corinthian currants (*Vitis vinifera* L., var. Apyrena). The efficacy of both high- and low-temperature exposure was evaluated against two key storage pests, *Plodia interpunctella* (Lepidoptera: Pyralidae) and *Oryzaephilus surinamensis* (Coleoptera: Silvanidae), under commercial storage conditions; each of the heat (30, 35, 38 °C) and cold treatment (− 10, − 5, 5 °C) was applied for three time periods (1, 6, and 12 h). Disinfestation trials were followed by sensory evaluation and phenolic compound profiling to assess their potential impact on product quality. Results demonstrated that exposure to extreme temperatures, particularly at − 10 °C, was effective in suppressing pest emergence, whereas − 5 °C and 5 °C produced partial but significant reductions depending on species and time. At 38 °C, it also reduced progeny emergence, particularly for *O. surinamensis*, although complete control was not achieved under the tested durations. Sensory evaluation by a trained panel showed no negative effects of any temperature treatment on appearance, texture, aroma, taste, or overall acceptability. Total phenolic content displayed small increases at 38 °C, while total flavonoids remained unchanged. UHPLC–ESI–MS analysis indicated that major phenolic compounds were retained across treatments with only limited variation. Importantly, these treatments did not significantly affect dried fruit sensory attributes or major phenolic constituents. Our findings support the use of temperature-based methods for controlling stored-product insects in Corinthian currants while preserving its organoleptic properties.

Keywords Corinthian currant · *Plodia interpunctella* · *Oryzaephilus surinamensis* · Disinfestation · Phenolic compounds

Key message

- Both high- and low-temperature treatments were effective in reducing the emergence of *Oryzaephilus surinamensis* and *Plodia interpunctella*
- Higher temperatures increased phenolic content in dried fruit, but had little effect on flavonoids
- Sensory evaluation indicated that extreme temperature treatments did not adversely influence the organoleptic properties of Corinthian currants

Communicated by Antonio Biondi.

✉ Maria K. Sakka
msakka@uth.gr

¹ Laboratory of Entomology and Agricultural Zoology, Department of Agriculture, Crop Production and Rural Environment, University of Thessaly, Phytokou Str., 38446 Volos, Greece

² Laboratory of Chemistry-Biochemistry-Physical Chemistry of Foods, Department of Nutrition and Dietetics, Harokopio University, 70 El. Venizelou Ave., 176 76 Kallithea, Greece

³ Agricultural Cooperatives' Union of Aeghion, Corinthou 201, 25100 Aeghion, Greece

Introduction

Corinthian Currant, a Mediterranean dried fruit derived from the black grape (*Vitis vinifera* L.) of Apyrena variety, is predominantly cultivated in Southern Greece; it is a

sugar-rich product, containing mainly glucose and fructose (Nikolidaki et al. 2017). Previous studies of our team have demonstrated that Corinthian currants contain bioactive microconstituents, such as flavonoids and phenolic acids; among flavonoids, the flavonols quercetin and kaempferol predominate, mainly found as glycosylated derivatives, while the stilbenoids ϵ -viniferin and resveratrol are present as well. Two hydroxycinnamates of tartaric acid, that are, caftaric acid and coutaric acid, are also found in large quantities in Corinthian currants (Chiou et al. 2007, 2014; Gergianni et al. 2024; Panagopoulou et al. 2019a, b). Corinthian currant has been shown to exhibit various beneficial health effects upon consumption, which are largely attributed to the abundance of bioactive microconstituents of this product. Studies in rodents have associated Corinthian currant consumption with neuroprotective properties (Mountaki et al. 2021; Tsarouchi et al. 2022) and anti-diabetic actions (Kompoura et al. 2023). In humans, Corinthian currant consumption has been associated with increased levels of serum oxidation resistance (Kanellos et al. 2013).

Dried fruits offer advantages over fresh ones in terms of transportation efficiency and, most notably, their extended shelf life; however, a significant concern during dried fruit storage, also applied in Corinthian currant, is pest infestation. Extreme temperatures during storage have been long regarded as a viable alternative to conventional insecticides (Athanassiou and Arthur 2018). The term “cold treatment” is mostly referred to as the application of low temperatures on the commodity, while, in turn, “heat treatment” is usually applied in storage and processing facilities (Athanassiou and Arthur 2018). Nevertheless, there are cases where heat treatment has been found to be successful when applied directly on the commodity. For instance, Khamis et al. (2011) reported that flameless catalytic infrared heat could control the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae). In an earlier study with stored sultanas, Athanassiou et al. (2016) found that the application of infrared heat on the commodity for some seconds was effective for the control of the tobacco moth, *Ephestia elutella* (Hübner) (Lepidoptera: Pyralidae), the confused flour beetle, *Tribolium castaneum* Jacquelin du Val (Coleoptera: Tenebrionidae), and the saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae). More recently, Sakka et al. (2024) reported that $-10\text{ }^{\circ}\text{C}$ was effective for the complete control of all life stages of the Mediterranean flour moth, *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae), after exposure for 6 h. Nevertheless, there is still inadequate information on the effect of extreme temperatures on key properties of some durable agricultural commodities; this is particularly important in the case of dried fruits, given that any deviation from the standard organoleptic and physicochemical properties of dried fruits may be devastating for their commercial value.

While there are several studies available for the control of stored-product insects through the application of extreme temperatures, most of these works focus on either heat or cold treatment, which means that the data sets that are provided each time correspond to different insect populations and experimental conditions, and thus, often these data are not directly comparable. Moreover, the data available are mostly focused on laboratory experiments, while there are disproportionally few data on the efficacy of extreme temperatures in “real-world” storage and processing conditions. In this regard, the aim of this work was to test, in parallel, low or high temperatures in stored Corinthian currants, for the control of the Indian meal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae), and *O. surinamensis*, in commercial facilities. In addition to *P. interpunctella*, *O. surinamensis* is one of the most common and economically important coleopteran pests associated with dried fruits, including Corinthian currants. This species is regularly reported in storage and packing units in Southern Greece due to its high mobility, rapid reproduction, and ability to infest products even through very small openings or packaging defects. Its capacity to survive and develop across a wide temperature range further increases its persistence in commercial facilities. At the same time, we have also tested the impact of these temperatures directly on the quality of Corinthian currants by evaluating sensory attributes (e.g., texture, aroma, and appearance), total phenolic and total flavonoid content, and the profile of individual phenolic compounds.

Materials and methods

Materials

Corinthian currants (crop 2023) were provided by the Agricultural Cooperatives' Union of Aeghion, Greece. They are produced from a distinct black grape variety, *Vitis vinifera* L. var. Apyrena, which is traditionally cultivated in the Aeghion (Vostizza) region of the Peloponnese in Southern Greece.

Insects

All species were maintained in controlled laboratory conditions at the Laboratory of Entomology and Agricultural Zoology. Environmental chambers (Elvem, Spata, Greece) were set to $25 \pm 1\text{ }^{\circ}\text{C}$, $65 \pm 1\%$ relative humidity (r.h.), and continuous darkness. *Oryzaephilus surinamensis* was reared on oat flakes, while *P. interpunctella* was maintained on an artificial diet consisting of wheat bran (90 g), dry yeast (10 g), a honey/water mixture (18 g), glycerol (46 g), sunflower oil (3 g), and water (15 mL). For the collection of *P.*

interpunctella eggs, a specialized nested container method was used to separate adults from their eggs efficiently. The oviposition setup consisted of two stacked 2.8-L plastic transparent containers (BORA Retail GmbH), with the bottom of the upper container replaced by mesh (approximately 400 µm). This design allowed the 100 adults to remain in the upper container, while the eggs passed through the mesh into the lower container for easy collection. To collect *O. surinamensis* eggs, 100 adults of mixed sex and age were placed in a 500-mL glass jar containing a small amount (20 g) of pre-sieved flour using a 212-µm sieve (Woven Wire Sieve, Endecotts Ltd) to facilitate mating and egg laying for two days. After this period, the adults were removed, and the flour was re-sieved using the same sieve to separate the eggs. The eggs were then carefully collected using a fine single-hair paintbrush (Lineo, No. 1, Mesko-Pinsel GmbH).

Bioassay I: evaluation of high temperatures

A series of field tests were conducted to assess the efficacy of high temperatures in controlling insect populations within a production facility in Southern Greece. The experiments utilized a temperature-controlled heating chamber (Mechan Engineering, model R-DRY-5, Michanagrotiki S.A. Panormos Lavriou, Greece). Plastic cylindrical vials (7.5 cm in diameter, 8.8 cm in height) served as the experimental units. One day prior to heat exposure, 10 eggs of each insect species were placed into each vial, along with 20 g of Corinthian currants, and separate series of vials for each of the two insect species tested. These vials were embedded within 1.2-kg commercial cardboard boxes filled with currants. For each experiment, additional vials were placed outside the treated area to serve as controls.

The vials were exposed to temperatures of 25 (control), 30, 35, or 38 °C for durations of 1, 6, or 12 h (Sakka et al. 2024). HOBO data loggers (Onset Computers, USA) were used to monitor the temperature during each treatment. Treatment time was measured when the target temperature was reached. After the application of heat treatment, the vials were transferred to incubators maintained at 25 °C and 65% relative humidity, where progeny emergence was assessed 65 days post-treatment. The experiments were conducted in three replicates, with three sub-replicates each, separately for each combination of temperature and time exposure tested.

Bioassay II: evaluation of low temperatures

A similar series of experiments was carried out as a small-scale study in a Corinthian currant storage facility to evaluate the impact of low temperatures on insect control. These trials utilized a temperature-controlled freezer (Platinum 340, Angelantoni Test Technologies Srl, Massa Martana,

Italy). The experimental setup remained as above, with cylindrical vials containing 10 eggs of each insect species and 20 g of currants. The vials were embedded within 1.2-kg cardboard boxes filled with currants, with control vials placed outside the treated area. The vials were exposed to temperatures of 25 °C (control), 5 °C, − 5 °C, or − 10 °C for 1, 6, or 12 h, while progeny emergence was evaluated as above (Sakka et al. 2024). The experiments were conducted in three replicates, with three sub-replicates each, separately for each combination of temperature and exposure tested.

Corinthian currant sensory analysis

Sensory characteristics were evaluated, before and after extreme temperature exposure treatments, by 18 trained panelists. All analyses were conducted immediately after the treatments. Appearance, texture (hardness, crystalline texture), taste, aroma, odor, and general acceptance of the product were assessed. Sensory attributes were assessed by hedonic sensory tests and rating tests, on which the sensory panel had been trained. Samples were assessed by using a nine-point hedonic scale, including point 1 (dislike extremely), 5 (neither like nor dislike), and 9 (like extremely) (Addo-Preko et al. 2023). The intensity of sensory attributes was evaluated by a 1–9 rating scale, where 1 was defined as “very slightly/not at all detectable” and 9 as “extremely detectable.”

Corinthian currant bioactive microconstituent analysis

Reagents and chemicals

All reagents were of analytical grade. Standards employed had HPLC purity. Apigenin, caftaric acid, (+)-catechin, chrysin, chlorogenic acid, daidzein, (–)-epicatechin, (–)-epigallocatechin, ferulic acid, formononetin, genistein, homovanillic acid, kaempferol, luteolin, (±)-naringenin, neochlorogenic acid, procyanidin B2, *trans*-resveratrol, tyrosol, 3-hydroxytyrosol, vanillin, sinapic acid, syringic acid, *p*-coumaric acid, and *trans*-cinnamic acid were purchased from Supelco (Bellefonte, PA, USA). Kaempferol-3-*O*-glucoside (astragalin), caffeic acid, epicatechin gallate, (+)-*ε*-viniferin, gallic acid, protocatechuic acid, *o*-coumaric acid, *p*-hydroxybenzoic acid, *trans*-coumaric acid, myricetin, vanillic acid, and aluminum chloride were purchased from Sigma-Aldrich, Inc. (St. Louis, MO, USA). (–)-Epigallocatechin gallate, procyanidin B1, quercetin-3-*O*-glucoside (isoquercetin), 3-*O*-methylquercetin (isorhamnetin), quercetin-3-*O*-glucuronide (miquelianin), quercetin, and quercetin-3-*O*-rutinoside (rutin) were purchased from Extrasynthese (Genay, France). Piceid was purchased from Fluorochem (Hadfield, UK). Folin–Ciocalteu reagent, sodium

carbonate, and sodium nitrite were purchased from Merck (Darmstadt, Germany), and the isotopically labeled internal standard (IS), quercetin d-3, was purchased from Cayman Chemical (Ann Arbor, MI, USA). Optima™ LC/MS grade formic acid 99.0% + used as an ultra-pure additive in the mobile phase along with LC/MS grade solvents (acetonitrile, methanol, and water) was purchased from Thermo Fisher Scientific (Pittsburgh, PA, USA).

Extraction of phenolic acids and flavonoids

The extraction of phenolic acids and flavonoids was carried out according to Chiou et al. (2007) and Gerogianni et al. (2024). Briefly, homogenized dried fruit (1.5 g) was mixed with HPLC grade methanol (5 mL), placed in a sonicator bath (Elmasonic S 60, Elma Schmidbauer GmbH, Singen, Germany), and left under periodical stirring overnight, in the dark, at room temperature. The mixture was then centrifuged (3000 rpm, 10 min); the supernatant was collected, and the remaining solid residue was extracted three additional times with HPLC grade methanol (5 mL). All extracts were combined and then evaporated under reduced pressure (Labconco, Kansas, USA). The residue was reconstituted in methanol (final volume 2 mL) and stored at -40°C until further analyses. Aliquots of these solutions were filtered through 0.22- μm PTFE syringe filters and diluted in water/methanol (1:1, v/v) containing IS working solution for the identification of individual free phenolic compounds by UHPLC–ESI–MS analysis as previously described in Gerogianni et al. (2024). All analyses were at least triplicated and conducted immediately after the treatments.

Spectrophotometric analyses

Total phenolic content was estimated using the Folin–Ciocalteu assay (Arnous et al. 2002). Gallic acid was used as a reference standard; absorbance was read at 750 nm and results were expressed as gallic acid equivalents (GAE) per 100 g Corinthian currant. Total flavonoid content was assessed by the aluminum chloride colorimetric method (Carloni et al. 2023); absorbance was read at 430 nm and results were expressed as mg rutin equivalents (RE) per 100 g Corinthian currant. All spectrophotometric data were acquired using an ELISA Reader (Power Wave X52, Biotek).

Identification and quantification of flavonoids and phenolic acids using UHPLC–ESI–MS

Samples were analyzed using a Dionex UltiMate™ 3000 Rapid Separation UHPLC+, consisting of a binary pump equipped with a degasser, an autosampler, and a column compartment. The UHPLC system was coupled to an Exactive Plus™ Orbitrap mass spectrometer (Thermo Fisher

Scientific, Bremen, Germany) equipped with a Heated Electrospray Ionization probe (HESI-II; Thermo Fisher Scientific, USA). Thermo XCalibur 4.0 software was used for the instrument setup and control of the system; Exactive Plus Tune software (Version 2.8 SP1, Thermo Fisher Scientific, Bremen, Germany) was used for the control of the mass spectrometer. Quantitative data processing was carried out using TraceFinder™ software (Version 4.1, Thermo Fisher Scientific, San Jose, CA). Chromatographic and mass spectrometric analyses—operating under negative mode—were performed as described by Gerogianni et al. (2024). The mobile phase consisted of 0.1% formic acid in acetonitrile (v/v) and 0.1% aqueous formic acid (v/v); a gradient elution on a Hypersil Gold™ C18 (100 $\times$ 2.1 mm, 1.9 μm) column (Thermo Fisher Scientific, Bremen, Germany) was applied. Injection volume was 5 μL and total run time was 18 min. External standard quantification was applied using reference curves of 44 phenolic compound standards. Chromatographic and mass spectral data of the phenolic standards used, as well as their limits of detection (LODs) and limits of quantification (LOQs), are given as supplementary material (Tables 1S and 2S, respectively).

Statistical analysis

Results are presented as the mean $\pm$ standard deviation.

For the evaluation of insects under heat and cold treatments, a two-way analysis of variance (ANOVA) was performed to assess the effects of temperature (four levels: 25 $^{\circ}\text{C}$ (control), 30 $^{\circ}\text{C}$, 35 $^{\circ}\text{C}$, or 38 $^{\circ}\text{C}$ for heat treatments; 25 $^{\circ}\text{C}$ (control), 0 $^{\circ}\text{C}$, -5°C , or -10°C for cold treatments) and exposure duration (three levels: 1 h, 6 h, or 12 h) on progeny emergence. Interaction effects between temperature and exposure duration were also evaluated. Prior to analysis, data were tested for normality using the Shapiro–Wilk test and for homogeneity of variances using Levene's test (Levene 1960; Shapiro and Wilk 1965). Significant differences among means were further examined using Tukey's HSD test, with significance set at $\alpha=0.05$. All analyses were conducted using JMP 11 software (SAS Institute Inc., Cary, NC, USA, 2013), and all figures were created using SigmaPlot software (Version 11, Systat Software Inc., San Jose, CA, USA).

Corinthian currant sensory and bioactive microconstituent content data handling were performed using Microsoft Excel. For the statistical analyses, IBM SPSS Statistics for Windows, Version 29 (IBM Corp., Armonk, N.Y., USA), was used; a two-way analysis of variance (ANOVA) was conducted to compare the detected levels of total phenolic content, total flavonoid content, and individual phenolic acid and flavonoid content in Corinthian currants subjected to different treatments. This was followed by one-way ANOVA as necessary, considering the factors of variation, which

included temperature and time of exposure of Corinthian currants (independent variables). The same procedure was followed for the sensory analysis. In all cases, Tukey's multiple range tests were performed post hoc to evaluate differences among groups. A P value of less than 0.05 was considered significant, consistent with the conventional threshold originally proposed by Fisher (1925) and widely adopted in scientific research.

Results and discussion

Bioassay I: evaluation of high temperatures

For both species tested, main effects and their interaction were found to be significant in most of the combinations tested (Table 1). The relatively high natural mortality observed in the controls, particularly at the egg stage, is consistent with previous reports describing substantial variability in egg viability for both *P. interpunctella* and *O. surinamensis* (Jacob et al. 1989; Athanassiou et al. 2016; Hou et al. 2018). Such variability is often attributed to the mechanical sensitivity of eggs and handling-related factors, which are inherent to egg-stage bioassays. Regarding the progeny emergence of *O. surinamensis*, this was found to range between 0.3 and 2.3 individuals per vial (Fig. 1). For this species, in most cases, progeny emergence was similar to that of the control, while the increase in the exposure

interval did not cause any considerable effect. The only exception was the trials that had been conducted at 38 °C, where the increase in the exposure interval significantly decreased progeny emergence. At this temperature, progeny emergence after 12 h of exposure was significantly lower than in the other treatments (Fig. 1). Emergence of *P. interpunctella* ranged between 1.1 and 3.0 individuals/vial, and the range of individuals counted in the treated vials was comparable with that in the control vials (Fig. 2). As observed with *O. surinamensis*, emergence was reduced at the highest temperature tested, but the exposure interval did not have a noticeable effect even at this temperature. These data indicate that the temperature range tested here is effective for the vast majority of the exposure intervals tested, which stand in accordance with the data that have been illustrated in earlier studies for the efficacy of heat treatments in different types of structures (Boina et al. 2008; Mahroof et al. 2006; Subramanyam et al. 2011; Athanassiou and Arthur 2018). In principle, the 24-h application is the baseline recommendation for structural heat treatments in food and processing facilities, given that this exposure interval can control all life stages of most stored-product insects, provided that the temperature level is at the level of 50 °C (Subramanyam et al. 2011). Our study suggests that temperature levels below this threshold can still be effective against stored-product insects, but progeny development may not be completely avoided.

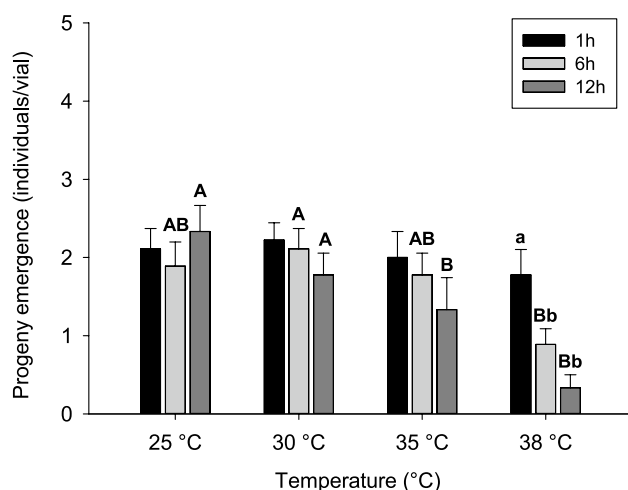


Fig. 1 Emergence of *Oryzaephilus surinamensis* individuals (number of individuals/vial $\pm$ SE), from eggs that had been exposed for 1, 6, and 12 h at 25 °C (control), 30, 35, and 38 °C, as recorded 65 days post-exposure. Different uppercase letters indicate significant differences among temperatures within each exposure interval (in all cases, error $df=32.3$; Tukey's HSD test at $p=0.05$). Different lowercase letters indicate significant differences among exposures within the same temperature (in all cases, error $df=24.2$; Tukey's HSD test at $p=0.05$). Where no letters exist, no significant differences were noted

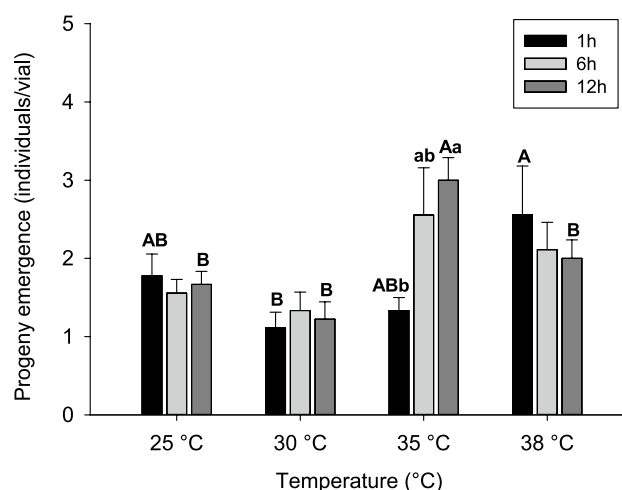


Fig. 2 Emergence of *Plodia interpunctella* individuals (number of individuals/vial $\pm$ SE), from eggs that had been exposed for 1, 6, and 12 h at 25 °C (control), 30 °C, 35 °C, and 38 °C, as recorded 65 days post-exposure. Different uppercase letters indicate significant differences among temperatures within each exposure interval (in all cases, error $df=32.3$; Tukey's HSD test at $p=0.05$). Different lowercase letters indicate significant differences among exposures within the same temperature (in all cases, error $df=24.2$; Tukey's HSD test at $p=0.05$). Where no letters exist, no significant differences were noted

Table 1 ANOVA parameters for main effects and interactions for *Oryzaephilus surinamensis* and *Plodia interpunctella* exposed to heat (30, 35, or 38 °C) and cold (5, - 5, or - 10 °C) for 1, 6, and 12 h [total degrees of freedom (df) = 96]

	df	<i>Oryzaephilus surinamensis</i>				<i>Plodia interpunctella</i>			
		Heat		Cold		Heat		Cold	
		F	P	F	P	F	P	F	P
Whole model	11	4.17	< 0.01	3.29	< 0.001	12.20	< 0.001	15.83	< 0.01
Intercept	1	423.84	< 0.01	372.09	< 0.001	369.39	< 0.001	269.89	< 0.01
Time	2	4.17	0.18	0.74	0.48	2.38	0.098	6.88	< 0.01
Temperature	3	9.29	< 0.01	6.92	< 0.001	41.53	< 0.001	47.20	< 0.01
Time*temperature	6	1.61	0.15	2.33	0.38	0.80	0.57	3.12	< 0.01

Bioassay II: evaluation of low temperatures

Most main effects and interactions were significant except ‘time’ and ‘Time*temperature’ for *O. surinamensis* (Table 1). The number of individuals recorded for *O. surinamensis* ranged between 0 and 2.1 individuals/vial (Fig. 3). Emergence of *O. surinamensis* in the control vial was similar to what was recorded at 5 °C, with the exception of the 12-h exposure, where emergence at this temperature was significantly lower than that in the control. At lower temperatures, emergence was further reduced, and no emergence was recorded at -5 °C after 12 h of exposure and in all exposures at - 10 °C (Fig. 3). In the case of *P. interpunctella*, emergence ranged between 0 and 2 individuals per vial (Fig. 4). For this species, emergence in vials that had been exposed at 0 and - 5 °C was similar to that in the control vials. In contrast, no emergence was recorded at the lowest temperature tested, regardless of the exposure interval (Fig. 4). Our data suggest that cold treatment can be used effectively to kill parental individuals for the species tested, but, if exposure is not sufficient, eggs may survive, and progeny survival is likely to occur after the termination of the treatment. This has been illustrated in previous studies where different life stages of both species had been tested for temperature levels between 0 and - 15 °C (Athanassiou et al. 2018a, b). At the same time, exposure at 0 °C may not be effective against adults of stored-product insects, even in the absence of acclimation (Wijayarathne and Fields 2010; Athanassiou and Arthur 2020). Hence, at the exposures tested here, progeny is likely to be recorded even when insects are exposed to -5 °C, suggesting that short exposures at - 10 °C are probably a safer disinfestation approach. Similar patterns of incomplete control at milder low temperatures have been reported for both species in laboratory studies, where egg survival and subsequent progeny emergence were observed following short exposures at temperatures above - 10 °C (Athanassiou et al. 2018a, b). The present study extends these findings by demonstrating that such effects are also evident under commercial storage conditions.

Sensory characteristics

Under the conditions applied, extreme temperature treatment did not significantly affect Corinthian currant sensory attributes (Fig. 5). There were no significant differences between the untreated (control) sample and the thermally treated ones. Neither exposure temperature nor exposure duration apparently affected the organoleptic characteristics of Corinthian currants under study. Regarding the intensity of attributes, no specific defects or off-flavors were detected in the treated samples compared to the control (data not shown), confirming that the treatments did not alter the sensory profile intensity beyond acceptable limits.

Table 2 Phenolic compounds (mg/100 g) identified and quantified in Corinthian currants (*Vitis vinifera* L., var. Apyrena), before and after exposure to extreme temperatures (− 10, − 5, 5, 30, 35, or 38 °C) for 1 h

Temperature (°C)	− 10	− 5	5	Untreated	30	35	38
Compound	Phenolic aldehyde						
Vanillin	0.10±0.01	0.10±0.01	0.10±0.01	0.10±0.01	0.09±0.01	0.09±0.01	0.10±0.01
	Benzoic acids						
<i>p</i> -Hydroxybenzoic acid	0.33±0.03	0.29±0.08	0.31±0.05	0.36±0.06	0.30±0.04	0.27±0.05	0.26±0.03
Gallic acid	0.16±0.01	0.12±0.03	0.14±0.03	0.15±0.03	0.10±0.00	0.11±0.02	0.14±0.03
Protocatechuic acid	0.19±0.01	0.18±0.04	0.19±0.03	0.20±0.03	0.15±0.00	0.19±0.03	0.17±0.02
Syringic acid	0.23±0.01	0.28±0.14	0.22±0.04	0.21±0.04	0.19±0.02	0.16±0.06	0.15±0.03
Vanillic acid	1.19±0.07 ^{ABC}	1.26±0.27 ^{BC}	1.39±0.13 ^C	1.18±0.18 ^{ABC}	1.05±0.12 ^{ABC}	0.91±0.09 ^A	0.96±0.04 ^{AB}
Homovanillic acid	0.13±0.00	0.13±0.00	0.13±0.00	0.13±0.00	0.12±0.00	0.13±0.00	0.13±0.00
	Cinnamic acids						
Caffeic acid	0.15±0.04 ^B	0.12±0.02 ^{AB}	0.08±0.01 ^A	0.09±0.03 ^{AB}	0.07±0.00 ^A	0.11±0.01 ^{AB}	0.13±0.02 ^{AB}
<i>trans</i> -Cinnamic acid	0.10±0.00	0.10±0.00	0.10±0.00	0.10±0.00	0.09±0.00	0.10±0.00	0.10±0.00
Caftaric acid	11.56±0.74 ^D	10.60±2.04 ^{BCD}	10.76±0.25 ^{CD}	8.51±0.87 ^{AB}	7.59±0.55 ^A	9.28±0.55 ^{ABC}	10.06±0.93 ^{BCD}
<i>trans</i> -Coutaric acid	2.55±0.24 ^C	2.38±0.43 ^{BC}	2.36±0.11 ^{BC}	1.86±0.32 ^{AB}	1.59±0.12 ^A	1.97±0.18 ^{ABC}	2.11±0.30 ^{ABC}
<i>p</i> -Coumaric acid	0.01±0.00	0.03±0.01	0.04±0.00	0.02±0.01	0.01±0.01	0.01±0.00	0.03±0.01
Ferulic acid	0.02±0.00 ^A	0.07±0.03 ^{AB}	0.08±0.00 ^B	0.04±0.03 ^{AB}	0.03±0.03 ^{AB}	0.01±0.00 ^A	0.06±0.03 ^{AB}
	Flavan-3-ols						
Catechin	0.08±0.04 ^{AB}	0.07±0.03 ^{AB}	0.05±0.01 ^{AB}	0.05±0.02 ^{AB}	0.02±0.00 ^A	0.06±0.02 ^{AB}	0.13±0.10 ^B
	Proanthocyanidins						
Procyanidin B1	0.16±0.05	0.16±0.06	0.13±0.05	0.10±0.07	0.13±0.01	0.11±0.03	0.15±0.05
Procyanidin B2	0.03±0.04	0.02±0.01	0.01±0.00	0.02±0.02	0.01±0.00	0.01±0.00	0.03±0.03
	Flavonols						
Isorhamnetin	0.16±0.01 ^C	0.14±0.02 ^{ABC}	0.14±0.01 ^{BC}	0.13±0.01 ^{ABC}	0.11±0.00 ^A	0.12±0.01 ^{AB}	0.13±0.01 ^{AB}
Kaempferol	0.07±0.00	0.05±0.01	0.07±0.02	0.05±0.01	0.04±0.01	0.03±0.00	0.05±0.01
Myricetin	0.06±0.01	0.05±0.00	0.05±0.00	0.05±0.00	0.04±0.00	0.05±0.00	0.05±0.00
Quercetin	0.16±0.02 ^{AB}	0.12±0.01 ^{AB}	0.18±0.04 ^B	0.14±0.05 ^{AB}	0.11±0.03 ^{AB}	0.08±0.01 ^A	0.15±0.05 ^{AB}
	Flavonol derivatives						
Astragalin	0.57±0.10	0.72±0.18	0.95±0.48	0.71±0.23	0.55±0.25	0.43±0.14	0.56±0.22
Isoquercetin	0.53±0.08	0.56±0.10	0.74±0.21	0.57±0.18	0.48±0.15	0.47±0.04	0.52±0.16
Miquelianin	0.85±0.12	0.83±0.18	0.86±0.24	0.78±0.26	0.63±0.12	0.88±0.32	1.00±0.27
Rutin	0.04±0.00	0.04±0.00	0.05±0.01	0.04±0.02	0.03±0.01	0.03±0.00	0.04±0.01
	Stilbenoids						
<i>trans</i> -Resveratrol	0.03±0.02 ^{AB}	0.05±0.02 ^{AB}	0.00±0.00 ^A	0.03±0.04 ^{AB}	0.01±0.00 ^A	0.03±0.00 ^{AB}	0.07±0.02 ^B
<i>Z</i> -ε-Viniferin	0.15±0.08	0.25±0.15	0.17±0.03	0.15±0.08	0.10±0.01	0.18±0.06	0.24±0.12
Piceid	0.04±0.04	0.04±0.01	0.05±0.00	0.01±0.01	0.01±0.00	0.04±0.01	0.07±0.05

Values presented are the means±standard deviation of three samples analyzed in triplicate. Values in the same row not sharing upper case superscript letters indicate statistically significant differences at confidence level 95% (Tukey's HSD test at $P=0.05$). Where no letters exist, no significant differences were noted.

The overall acceptance of the product had a rating score of 7, which was evaluated as “like.” Among the characteristics studied, the crystalline texture of the samples treated at − 10 °C for 1 and 12 h was rated lower than that of the untreated samples. The aroma was well preserved even after exposure at 38 °C for 12 h, while the hardness and chewiness of the product remained desirable for all samples. Two-way ANOVA indicated no significant differences between sensory attributes of samples based

on temperature of exposure and its duration. No correlation was observed between treatments and the appearance, color, hardness, chewiness, odor, taste, and aroma of Corinthian currants. These results are consistent with the findings of Athanassiou et al. (2017), who reported that nitrogen-based controlled atmosphere fumigation at 38–43 °C for 3 days does not affect the sensory attributes of Corinthian currants.

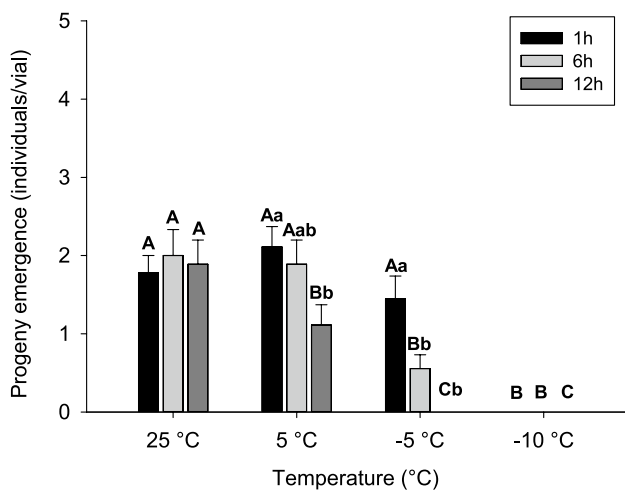


Fig. 3 Progeny emergence from *Oryzaephilus surinamensis* eggs exposed to 1, 6, and 12 h at 25 °C (control), 5 °C, -5 °C, and -10 °C, assessed 65 days post-exposure. Different uppercase letters indicate significant differences among temperatures within each exposure interval (in all cases, error $df=32.3$; Tukey's HSD test at $p=0.05$). Different lowercase letters indicate significant differences among exposures within the same temperature (in all cases, error $df=24.2$; Tukey's HSD test at $p=0.05$). Where no letters exist, no significant differences were noted

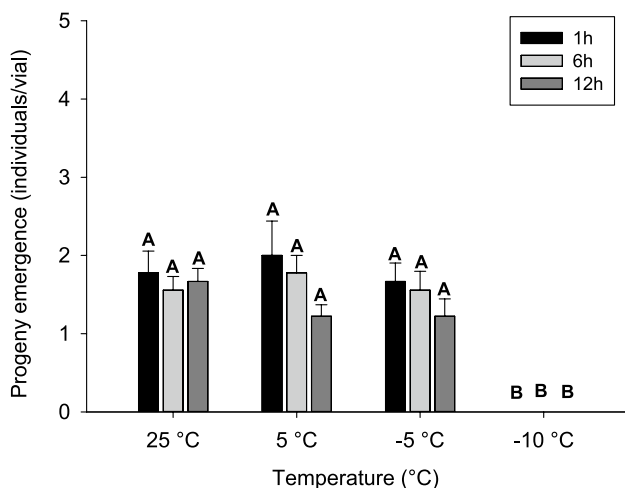


Fig. 4 Progeny emergence from *Plodia interpunctella* eggs exposed to 1, 6, and 12 h at 25 °C (control), 5 °C, -5 °C, and -10 °C, assessed 65 days post-exposure. Different uppercase letters indicate significant differences among temperatures within each exposure interval (in all cases, error $df=32.3$; Tukey's HSD test at $p=0.05$). Different lowercase letters indicate significant differences among exposures within the same temperature (in all cases, error $df=24.2$; Tukey's HSD test at $p=0.05$). Where no letters exist, no significant differences were noted

Total phenolic and total flavonoid content

Total phenolic content of Corinthian currant before and after treatment at extreme temperatures is given in Fig. 6. Total phenolic content of the untreated-control-sample was 265.2 ± 44.8 mg GAE/100 g of dried fruit; this is in line with previous studies evaluating Corinthian currant total phenolic content (Chiou et al. 2007, 2014; Panagopoulou et al. 2019b), where values ranging between 210 and 274 mg GAE/100 g of dried fruit have been reported. Two-way ANOVA revealed statistically significant interactions between the effects of temperature and time of exposure on Corinthian currants subjected to various treatments (Table 3S). Furthermore, one-way ANOVA revealed that temperature significantly influenced total phenolic content. In general, samples treated at 38 °C seemed to have higher total phenolic content. Maillard reaction products, formed in plant matrices at higher temperatures, may interfere with the Folin-Ciocalteu assay (Singleton et al. 1985). On the other hand, increased temperatures may liberate low molecular weight natural antioxidants, found in bound forms (Lee et al. 2003). However, given the total phenolic content range found in this study, these differences may not be considered remarkable for the product characterization.

In the case of total flavonoids, the untreated (control) sample content was found to be 136.7 ± 22.9 mg RE/100 g of dried fruit. Unlike total phenolic content, Corinthian currant total flavonoid content was not affected by the extreme temperature treatments (Fig. 7); neither temperature nor time of exposure was found to affect total flavonoid content.

Individual phenolic compounds

Individual phenolic content was analyzed by UHPLC-ESI-MS; indicative extracted ion chromatograms (XIC) of a Corinthian currant control sample and a standard phenolic compound solution are given as supplementary material (Figs S1, S2). The Corinthian currant control sample used in the present study was found to contain 27 phenolic compounds (Tables 2, 3 and 4). Among the phytochemicals quantified, caftaric acid—a caffeic acid ester with tartaric acid—predominated (8.5 ± 0.9 mg/100 g) followed by *trans*-coutaric acid (1.86 ± 0.32 mg/100 g)—the respective ester of coumaric acid—and the flavonoid miquelianin (0.78 ± 0.26 mg/100 g), in line with previously reported data (Gerogianni et al. 2024); however, their contents were rather lower than those reported by Gerogianni et al. (2024). Several other benzoic and cinnamic acids were found together with flavonoids, such as quercetin and some

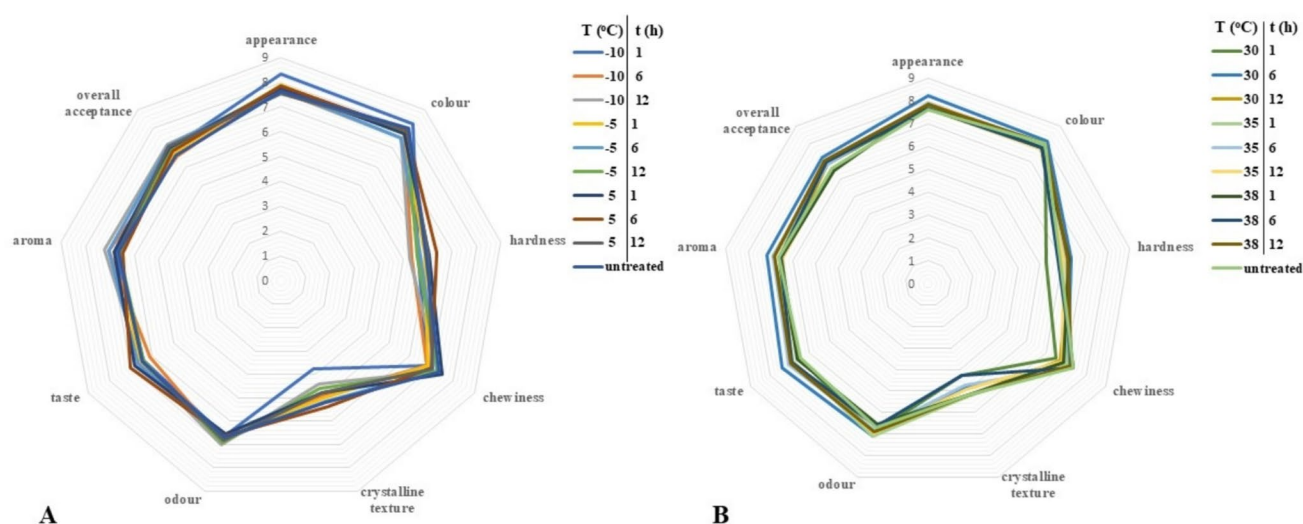


Fig. 5 Sensory attributes in terms of appearance, color, texture (hardness and crystalline texture), odour, taste, aroma, and overall acceptance of Corinthian currants, before and after exposure for 1, 6, and

12 h at: **a** low temperatures (-10 , -5 , 5 °C); **b** high temperatures (30 , 35 , and 38 °C)

quercetin derivatives, and stilbenoids such as resveratrol, ϵ -viniferin, and piceid. Among the benzoic acids, vanillic acid was the most abundant with content in line with that reported by Gerogianni et al. (2024) and Chiou et al. (2007). Gallic acid content was found to be lower than that reported by Gerogianni et al. (2024) and Chiou et al. (2007) and in line with that reported Vasilakopoulou et al. (2022), while *p*-hydroxybenzoic acid, protocatechuic acid, and syringic acid content found in the present study were in line with or higher than the ones previously reported. Among the cinnamic acids, caffeic acid and ferulic acid content was in the same order of magnitude as in the study of Gerogianni et al. (2024) but lower than that reported by Chiou et al. (2007). Corinthian currant flavonols, namely isorhamnetin, kaempferol, and myricetin, were detected at lower levels than those in the study of Gerogianni et al. (2024) and Vasilakopoulou et al. (2022). Quercetin and isoquercetin were found lower than in the study of Gerogianni et al. (2024) but aligning with those reported by Vasilakopoulou et al. (2022). The stilbenoids *trans*-resveratrol and piceid aligned in content with that reported by Gerogianni et al. (2024), while ϵ -viniferin was found lower than that reported in the same study. The same also applies for catechin. Besides the flavonoids and phenolic acids quantified, seven more compounds were found as traces in all samples studied, namely epicatechin, epigallocatechin, epigallocatechin gallate, epicatechin gallate, apigenin, luteolin, and chrysin. The variations

mentioned above are rather expected, as Corinthian currant is a natural agricultural product.

All the compounds found in the Corinthian currant control sample were also present in the extreme temperature-treated samples (Tables 2, 3, 4). Two-way ANOVA, conducted on all the Corinthian currant samples, revealed a statistically significant interaction between temperature and time of exposure for caftaric acid, *trans*-coutaric acid, *p*-coumaric acid, ferulic acid, and isorhamnetin. Benzoic acids, *trans*-cinnamic acid, kaempferol, flavonol derivatives, and stilbenoids seemed to be significantly affected only by exposure temperature, while caffeic acid and myricetin were affected by exposure time as well. Further analysis with one-way ANOVA for each parameter (temperature and/or time) showed variations in the individual phenolic content. Caffeic acid was detected at higher levels at 5 °C after 12 h of exposure. The same applied for myricetin at -10 °C for 1 h of exposure. However, no specific trend could be extracted with respect to the duration and temperature of the treatment.

Conclusion

The present study demonstrated that temperature can affect progeny emergence of *O. surinamensis* and *P. interpunctella* in Corinthian currants, with the magnitude of this effect depending on both temperature level and exposure duration. Notably, exposure at -10 °C for 6–12 h resulted

Table 3 Phenolic compounds (mg/100 g) identified and quantified in Corinthian currants (*Vitis vinifera* L., var. Apyrena), before and after exposure to extreme temperatures (− 10, − 5, 5, 30, 35, or 38 °C) for 6 h

Temperature (°C)	− 10	− 5	5	Untreated	30	35	38
Compound	Phenolic aldehyde						
Vanillin	0.10±0.01	0.10±0.01	0.10±0.01	0.10±0.01	0.09±0.01	0.09±0.01	0.10±0.01
	Benzoic acids						
<i>p</i> -Hydroxybenzoic acid	0.35±0.05	0.32±0.05	0.31±0.03	0.36±0.06	0.32±0.02	0.27±0.05	0.26±0.04
Gallic acid	0.17±0.02	0.14±0.01	0.14±0.02	0.15±0.03	0.12±0.02	0.13±0.03	0.15±0.04
Protocatechuic acid	0.23±0.02 ^B	0.20±0.01 ^{AB}	0.18±0.02 ^{AB}	0.20±0.03 ^{AB}	0.17±0.01 ^A	0.16±0.00 ^A	0.20±0.02 ^{AB}
Syringic acid	0.28±0.15	0.26±0.05	0.21±0.02	0.21±0.04	0.16±0.01	0.17±0.03	0.21±0.03
Vanillic acid	1.23±0.28	1.27±0.09	1.21±0.21	1.18±0.18	1.20±0.18	0.92±0.03	1.21±0.20
Homovanillic acid	0.13±0.00	0.13±0.00	0.13±0.00	0.13±0.00	0.13±0.00	0.13±0.00	0.13±0.00
	Cinnamic acids						
Caffeic acid	0.13±0.03 ^C	0.12±0.01 ^{BC}	0.07±0.00 ^A	0.09±0.03 ^{ABC}	0.08±0.01 ^{AB}	0.09±0.01 ^{ABC}	0.11±0.00 ^{ABC}
<i>trans</i> -Cinnamic acid	0.10±0.01	0.10±0.01	0.10±0.01	0.10±0.01	0.10±0.01	0.10±0.01	0.10±0.01
Caftaric acid	9.93±0.51	10.06±2.04	9.46±2.18	8.51±0.87	8.57±0.55	9.54±0.78	10.06±1.45
<i>trans</i> -Coutaric acid	1.91±0.26	2.36±0.40	2.23±0.70	1.86±0.32	1.80±0.20	1.97±0.15	1.88±0.17
<i>p</i> -Coumaric acid	0.01±0.00	0.01±0.00	0.03±0.01	0.02±0.01	0.00±0.00	0.03±0.01	0.01±0.01
Ferulic acid	0.01±0.00	0.01±0.00	0.06±0.03	0.04±0.03	0.01±0.00	0.06±0.03	0.03±0.03
	Flavan-3-ols						
Catechin	0.06±0.04	0.05±0.01	0.04±0.03	0.05±0.02	0.05±0.03	0.10±0.04	0.06±0.02
	Proantocyanidins						
Procyanidin B2	0.01±0.01	0.01±0.00	0.02±0.01	0.02±0.02	0.01±0.01	0.03±0.01	0.01±0.00
	Flavonols						
Isorhamnetin	0.14±0.02	0.14±0.01	0.13±0.01	0.13±0.01	0.13±0.02	0.11±0.00	0.14±0.01
Kaempferol	0.06±0.01	0.06±0.01	0.06±0.02	0.05±0.01	0.04±0.01	0.03±0.01	0.07±0.01
Myricetin	0.05±0.00 ^B	0.05±0.00 ^A	0.05±0.00 ^A	0.05±0.00 ^A	0.05±0.00 ^A	0.05±0.00 ^A	0.05±0.00 ^A
Quercetin	0.17±0.09	0.14±0.03	0.13±0.05	0.14±0.05	0.11±0.03	0.10±0.04	0.19±0.07
	Flavonol derivatives						
Astragalin	0.77±0.42 ^{AB}	0.79±0.14 ^{AB}	0.86±0.14 ^B	0.71±0.23 ^{AB}	0.33±0.14 ^A	0.44±0.15 ^{AB}	0.87±0.09 ^B
Isoquercetin	0.69±0.21 ^{AB}	0.69±0.11 ^{AB}	0.66±0.13 ^{AB}	0.57±0.18 ^{AB}	0.39±0.15 ^A	0.48±0.12 ^{AB}	0.80±0.13 ^B
Miquelianin	0.94±0.14	0.91±0.22	0.88±0.17	0.78±0.26	0.59±0.26	0.83±0.18	0.86±0.23
Rutin	0.03±0.01	0.04±0.01	0.04±0.01	0.04±0.02	0.02±0.01	0.03±0.01	0.05±0.01
	Stilbenoids						
<i>trans</i> -Resveratrol	0.03±0.01 ^{AB}	0.04±0.01 ^{AB}	0.01±0.00 ^A	0.03±0.04 ^{AB}	0.03±0.01 ^{AB}	0.05±0.01 ^{AB}	0.16±0.18 ^B
<i>Z</i> - ϵ -Viniferin	0.14±0.03	0.18±0.04	0.16±0.05	0.15±0.08	0.21±0.14	0.23±0.13	0.29±0.10
Piceid	0.02±0.00 ^{AB}	0.03±0.01 ^{AB}	0.04±0.03 ^{AB}	0.01±0.01 ^A	0.03±0.02 ^{AB}	0.05±0.01 ^{AB}	0.06±0.01 ^B

Values presented are the means ± standard deviation of three samples analyzed in triplicate. Values in the same row not sharing upper case superscript letters indicate statistically significant differences at confidence level 95% (Tukey's HSD test at $P=0.05$). Where no letters exist, no significant differences were noted.

in complete suppression of progeny emergence in both species, while higher temperatures, particularly 38 °C for 12 h, significantly reduced emergence rates of *O. surinamensis*. However, milder temperatures or shorter exposure times did not fully prevent progeny development, emphasizing the importance of optimizing temperature–time combinations to ensure effective pest control. From a sensory perspective, extreme temperature treatments did not

negatively affect the organoleptic properties of Corinthian currants. Attributes such as appearance, color, aroma, texture, and taste were rated consistently across treated and control samples. Overall acceptance remained high, supporting the use of such treatments without compromising consumer perception. Regarding the dried fruit's quality, total phenolic content showed some statistically significant increases at elevated temperatures, while total

Table 4 Phenolic compounds (mg/100 g) identified and quantified in Corinthian currants (*Vitis vinifera* L., var. Apyrena), before and after exposure to extreme temperatures (− 10, − 5, 5, 30, 35, and 38 °C) for 12 h

Temperature (°C)	− 10	− 5	5	Untreated	30	35	38
Compound	Phenolic aldehyde						
Vanillin	0.10 ± 0.01	0.10 ± 0.01	0.10 ± 0.01	0.10 ± 0.01	0.10 ± 0.01	0.09 ± 0.01	0.10 ± 0.01
	Benzoic acids						
<i>p</i> -Hydroxybenzoic acid	0.33 ± 0.07 ^{AB}	0.37 ± 0.08 ^B	0.35 ± 0.02 ^{AB}	0.36 ± 0.06 ^{AB}	0.24 ± 0.02 ^A	0.24 ± 0.03 ^A	0.29 ± 0.06 ^{AB}
Gallic acid	0.17 ± 0.03	0.17 ± 0.01	0.13 ± 0.01	0.15 ± 0.03	0.13 ± 0.09	0.10 ± 0.01	0.14 ± 0.01
Protocatechuic acid	0.20 ± 0.01 ^{AB}	0.22 ± 0.03 ^B	0.17 ± 0.01 ^{AB}	0.20 ± 0.03 ^{AB}	0.17 ± 0.04 ^{AB}	0.14 ± 0.01 ^A	0.20 ± 0.00 ^{AB}
Syringic acid	0.26 ± 0.02 ^{BC}	0.27 ± 0.02 ^C	0.22 ± 0.05 ^{ABC}	0.21 ± 0.04 ^{A^{BC}}	0.13 ± 0.05 ^A	0.17 ± 0.02 ^{AB}	0.23 ± 0.06 ^{BC}
Vanillic acid	1.21 ± 0.07 ^{AB}	1.46 ± 0.15 ^B	1.07 ± 0.10 ^A	1.18 ± 0.18 ^{AB}	1.01 ± 0.16 ^A	1.02 ± 0.06 ^A	1.16 ± 0.12 ^{AB}
Homovanillic acid	0.13 ± 0.00	0.13 ± 0.00	0.13 ± 0.00	0.13 ± 0.00	0.13 ± 0.00	0.12 ± 0.00	0.13 ± 0.00
	Cinnamic acids						
Caffeic acid	0.19 ± 0.09 ^B	0.14 ± 0.02 ^{AB}	0.13 ± 0.01 ^{AB}	0.09 ± 0.03 ^A	0.08 ± 0.04 ^A	0.09 ± 0.00 ^A	0.12 ± 0.01 ^{AB}
<i>trans</i> -Cinnamic acid	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.09 ± 0.00	0.10 ± 0.00
Caftaric acid	11.48 ± 1.36 ^C	10.91 ± 1.51 ^{BC}	8.01 ± 1.17 ^A	8.51 ± 0.87 ^{AB}	10.06 ± 1.64 ^{ABC}	9.11 ± 1.18 ^{ABC}	9.41 ± 1.01 ^{ABC}
<i>trans</i> -Coutaric acid	2.85 ± 0.64 ^B	2.21 ± 0.22 ^{AB}	1.85 ± 0.30 ^A	1.86 ± 0.32 ^A	2.22 ± 0.46 ^{AB}	1.94 ± 0.30 ^A	2.06 ± 0.40 ^{AB}
<i>p</i> -Coumaric acid	0.02 ± 0.02	0.03 ± 0.01	0.01 ± 0.00	0.02 ± 0.01	0.01 ± 0.00	0.02 ± 0.01	0.03 ± 0.01
Ferulic acid	0.01 ± 0.00	0.07 ± 0.03	0.01 ± 0.00	0.04 ± 0.03	0.01 ± 0.00	0.04 ± 0.04	0.06 ± 0.03
	Flavan-3-ols						
Catechin	0.06 ± 0.02	0.07 ± 0.02	0.04 ± 0.01	0.05 ± 0.02	0.07 ± 0.04	0.09 ± 0.03	0.10 ± 0.05
	Proantocyanidins						
Procyanidin B1	0.12 ± 0.06	0.10 ± 0.03	0.07 ± 0.04	0.10 ± 0.07	0.12 ± 0.03	0.11 ± 0.02	0.14 ± 0.07
Procyanidin B2	0.02 ± 0.00	0.02 ± 0.01	0.01 ± 0.00	0.02 ± 0.02	0.02 ± 0.01	0.02 ± 0.00	0.03 ± 0.02
	Flavonols						
Isorhamnetin	0.13 ± 0.01 ^{AB}	0.15 ± 0.02 ^{AB}	0.11 ± 0.00 ^A	0.13 ± 0.01 ^{AB}	0.14 ± 0.04 ^{AB}	0.13 ± 0.00 ^{AB}	0.16 ± 0.02 ^B
Kaempferol	0.05 ± 0.00	0.08 ± 0.02	0.04 ± 0.00	0.05 ± 0.01	0.05 ± 0.04	0.06 ± 0.02	0.08 ± 0.01
Myricetin	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00
Quercetin	0.14 ± 0.03	0.18 ± 0.06	0.11 ± 0.04	0.14 ± 0.05	0.21 ± 0.29	0.13 ± 0.04	0.25 ± 0.09
	Flavonol derivatives						
Astragalin	0.59 ± 0.09	0.83 ± 0.23	0.50 ± 0.10	0.71 ± 0.23	0.60 ± 0.46	0.67 ± 0.24	0.89 ± 0.08
Isoquercetin	0.61 ± 0.09	0.67 ± 0.13	0.42 ± 0.12	0.57 ± 0.18	0.57 ± 0.60	0.65 ± 0.11	0.85 ± 0.09
Miquelianin	1.00 ± 0.33 ^{AB}	0.87 ± 0.05 ^{AB}	0.54 ± 0.16 ^A	0.78 ± 0.26 ^{AB}	0.69 ± 0.48 ^A	0.74 ± 0.28 ^{AB}	1.44 ± 0.56 ^B
Rutin	0.04 ± 0.02 ^{AB}	0.04 ± 0.01 ^{AB}	0.02 ± 0.00 ^A	0.04 ± 0.02 ^{AB}	0.03 ± 0.03 ^A	0.04 ± 0.02 ^{AB}	0.09 ± 0.03 ^B
	Stilbenoids						
<i>trans</i> -Resveratrol	0.07 ± 0.03	0.06 ± 0.02	0.06 ± 0.02	0.03 ± 0.04	0.01 ± 0.00	0.06 ± 0.03	0.04 ± 0.02
Z- ϵ -Viniferin	0.19 ± 0.06 ^{AB}	0.26 ± 0.03 ^B	0.11 ± 0.04 ^A	0.15 ± 0.08 ^{AB}	0.12 ± 0.02 ^A	0.22 ± 0.08 ^{AB}	0.16 ± 0.03 ^{AB}
Piceid	0.05 ± 0.02 ^{AB}	0.05 ± 0.03 ^B	0.01 ± 0.00 ^A	0.01 ± 0.01 ^{AB}	0.02 ± 0.00 ^{AB}	0.05 ± 0.01 ^{AB}	0.04 ± 0.02 ^{AB}

Values presented are the means ± standard deviation of three samples analyzed in triplicate. Values in the same row not sharing upper case superscript letters indicate statistically significant differences at confidence level 95% (Tukey's HSD test at $P=0.05$). Where no letters exist, no significant differences were noted.

flavonoid content remained largely unaffected. Analysis of individual phenolics revealed some treatment-related variations, especially in compounds such as caftaric acid, ferulic acid, and isorhamnetin, though no clear temperature- or time-dependent trends were observed. All phenolic compounds identified in the control were also present in treated samples, indicating no major degradation or loss of key phytochemicals.

In conclusion, extreme temperature treatments—particularly cold treatment at − 10 °C—offer an effective and

residue-free method for pest control in stored Corinthian currants. Importantly, the present study provides evidence that these approaches can be implemented under real commercial storage conditions, bridging the gap between laboratory efficacy data and practical application. At the same time, these treatments preserve the product's sensory appeal and phenolic integrity, supporting their use as practical, non-chemical interventions in commercial storage and processing environments.

Fig. 6 Corinthian currant total phenolic content (mg GAE/100 g Corinthian currant) before and after exposure at extreme temperatures (− 10, − 5, 5, 30, 35, and 38 °C, for 1, 6, and 12 h). For each separate exposure time (1, 6, 12 h), values with the same letter do not significantly differ at $p=0.05$ among samples treated at different temperatures

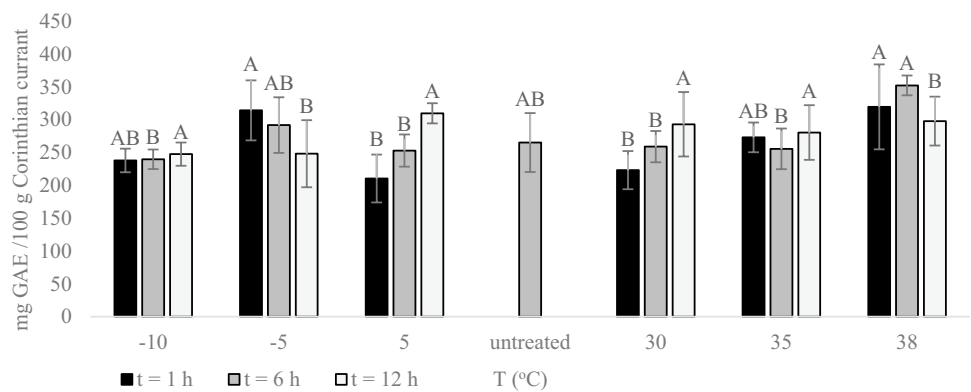
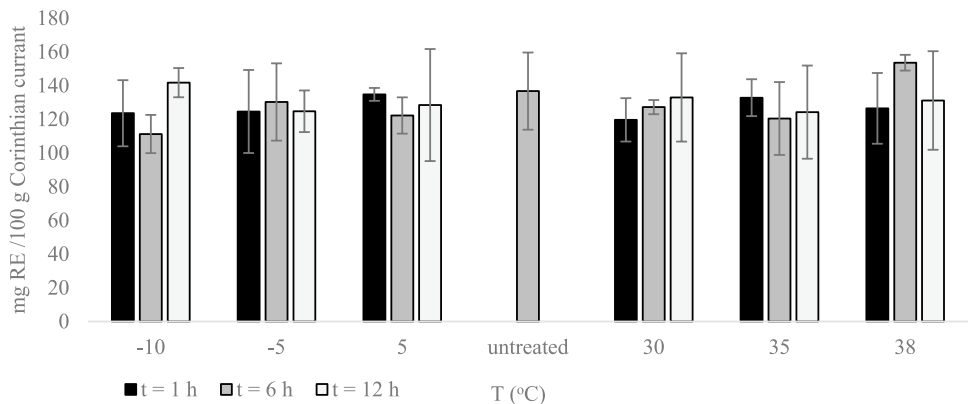


Fig. 7 Corinthian currant total flavonoid content (mg RE/100 g currants) before and after exposure at extreme temperatures (− 10, − 5, 5, 30, 35, and 38 °C, for 1, 6, and 12 h)



Author contributions

MKS, VEG, MG, CGA, AC and VTK conceived and designed research. MKS, VEG, MG, GB, VTK, AC, CGA conducted experiments. VEG, MG analysed data. MKS, AGA, AC and VTK contributed to writing the paper. All authors reviewed and approved the final manuscript.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10340-026-02018-0>.

Acknowledgements This work was funded by the General Secretariat for Research and Innovation of the Ministry of Development and Investments under the PRIMA Programme. PRIMA is an Art.185 initiative supported and co-funded under Horizon 2020, the European Union's Programme for Research and Innovation (project code: ITP21-0476806). Acronym: GreenDriedFruits.

Funding Open access funding provided by HEAL-Link Greece.

Declarations

Conflict of interest The authors declare no competing interests.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes

were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Addo-Preko E, Amissah JGN, Adjei MYB (2023) The relevance of the number of categories in the hedonic scale to the Ghanaian consumer in acceptance testing. *Front Food Sci Technol* 3:1071216. <https://doi.org/10.3389/frfst.2023.1071216>
- Arnous A, Makris DP, Kefalas P (2002) Correlation of pigment and flavanol content with antioxidant properties in selected aged regional wines from Greece. *J Food Compos Anal* 15:655–665. <https://doi.org/10.1006/jfca.2002.1070>
- Athanassiou CG, Arthur FH (2020) Cool down–warm up: Differential responses of stored product insects after gradual temperature changes. *Insects* 11:158. <https://doi.org/10.3390/insects11030158>
- Athanassiou CG, Chiou A, Rumbos CI, Karagiannis A, Nikolidaki E, Panagopoulou E, Kouvelas A, Karathanos VT (2016) Effects of electric infrared heating with light source penetration on microbial and entomological loads on dried currants and their organoleptic characteristics. *J Pest Sci* 89:931–943. <https://doi.org/10.1007/s10340-015-0727-2>

- Athanassiou CG, Chiou A, Rumbos CI, Sotiropoulos V, Sakka M, Nikolidaki EK, Panagopoulou EA, Kouvelas A, Katechaki E, Karathanos VT (2017) Effect of nitrogen in combination with elevated temperatures on insects microbes and organoleptic characteristics of stored currants. *J Pest Sci* 90:557–567. <https://doi.org/10.1007/s10340-016-0806-z>
- Athanassiou CG, Arthur FH (2018) Recent advances in stored product protection. Springer, Berlin, Germany
- Athanassiou CG, Arthur FH, Kavallieratos NG, Hartzler KL (2018a) Susceptibility of different life stages of *Tribolium confusum* Jacquelin du Val (Coleoptera: Tenebrionidae) and *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae) to cold treatment. *J Econ Entomol* 111:1481–1485. <https://doi.org/10.1093/jee/toy103>
- Athanassiou CG, Arthur FH, Hartzler KL (2018b) The efficacy of low temperatures for the control of all life stages of *Plodia interpunctella* and *Liposcelis bostrychophila*. *J Pest Sci* 91:1363–1369. <https://doi.org/10.1007/s10340-018-0982-0>
- Boina DR, Subramanyam B, Alavi S (2008) Dynamic model for predicting survival of mature larvae of *Tribolium confusum* during facility heat treatments. *J Econ Entomol* 101:989–997. <https://doi.org/10.1093/jee/101.3.989>
- Carloni P, Albacete A, Martínez-Melgarejo PA, Girolametti F, Truzzi C, Damiani E (2023) Comparative analysis of hot and cold brews from single-estate teas (*Camellia sinensis*) grown across Europe: an emerging specialty product. *Antioxidants* 12:1306. <https://doi.org/10.3390/antiox12061306>
- Chiou A, Karathanos V, Mylona A, Salta F, Preventi F, Andrikopoulos N (2007) Currants (*Vitis vinifera* L.) content of simple phenolics and antioxidant activity. *Food Chem* 102:516–522. <https://doi.org/10.1016/j.foodchem.2006.06.009>
- Chiou A, Panagopoulou EA, Gatzali F, De Marchi S, Karathanos VT (2014) Anthocyanins content and antioxidant capacity of Corinthian currants (*Vitis vinifera* L., var. Apyrena). *Food Chem* 146:157–165. <https://doi.org/10.1016/j.foodchem.2013.09.062>
- Hou J, Zhang L, Wang S (2018) Effects of low pressure treatment on the mortality of different life stages of Indianmeal moth (*Plodia interpunctella*) and the quality of dried Chinese Jujube. *Insects* 9:136. <https://doi.org/10.3390/insects9040136>
- Jacob TA, Fleming DA (1989) The difference in the developmental period and mortality of some field strains of *Oryzaephilus surinamensis* (L.) at constant temperatures (Coleoptera: Silvanidae). *J Stored Prod Res* 25:73–76. [https://doi.org/10.1016/0022-474X\(89\)90013-1](https://doi.org/10.1016/0022-474X(89)90013-1)
- Fisher RA (1925) Statistical methods for research workers. Oliver & Boyd, Edinburgh
- Gerogianni V-E, Panagopoulou EA, Vasilakopoulou PB, Karathanos VT, Chiou A (2024) Free and bound polar phenols in Corinthian currants (*Vitis vinifera* L., var. Apyrena). *J Food Compos Anal* 125:105789. <https://doi.org/10.1016/j.jfca.2023.105789>
- Kanellos PT, Kaliora AC, Gioxari A, Christopoulou GO, Kalogeropoulos N, Karathanos VT (2013) Absorption and bioavailability of antioxidant phytochemicals and increase of serum oxidation resistance in healthy subjects following supplementation with raisins. *Plant Foods Hum Nutr* 68:411–415. <https://doi.org/10.1007/s11130-013-0389-2>
- Khamis M, Subramanyam B, Dogan H, Flinn PW, Gwartz JA (2011) Effects of flameless catalytic infrared radiation on *Sitophilus oryzae* (L.) life stages. *J Stored Prod Res* 47:173–178. <https://doi.org/10.1016/j.jspr.2010.11.002>
- Kompoura V, Prapa I, Vasilakopoulou PB, Mitropoulou G, Nelios G, Balafas E, Kostomitopoulos N, Chiou A, Karathanos VT, Bezirtzoglou E, Kourkoutas Y, Yanni AE (2023) Corinthian currants supplementation restores serum polar phenolic compounds, reduces IL-1 β , and exerts beneficial effects on gut microbiota in streptozotocin-induced type-1 diabetic rat. *Metabolites* 13:415. <https://doi.org/10.3390/metabo13030415>
- Lee S-C, Kim J-H, Jeong S-M, Kim D-R, Ha J-U, Nam KC, Ahn DU (2003) Effect of far-infrared radiation on the antioxidant activity of rice hulls. *J Agric Food Chem* 51:4400–4403. <https://doi.org/10.1021/jf0300285>
- Levene H (1960) Robust tests for equality of variances. In: Olkin I, Ghurye SG, Hoefding W, Madow WG, Mann HB (eds) Contributions to probability and statistics: essays in honor of Harold Hotelling. Stanford University Press, Stanford, pp 278–292
- Mahroof R, Subramanyam B (2006) Susceptibility of *Plodia interpunctella* (Lepidoptera: Pyralidae) developmental stages to high temperatures used during structural heat treatments. *Bull Entomol Res* 97:539–545. <https://doi.org/10.1016/10.1079/BER2006454>
- Mountaki C, Dafnis I, Panagopoulou EA, Vasilakopoulou PB, Karvelas M, Chiou A, Karathanos VT, Chroni A (2021) Mechanistic insight into the capacity of natural polar phenolic compounds to abolish Alzheimer's disease-associated pathogenic effects of apoE4 forms. *Free Radic Biol Med* 171:284–301. <https://doi.org/10.1016/j.freeradbiomed.2021.05.022>
- Nikolidaki EK, Chiou A, Christea M, Gkegka AP, Karvelas M, Karathanos VT (2017) Sun-dried Corinthian currant (*Vitis vinifera* L., var. Apyrena) simple sugar profile and macronutrient characterization. *Food Chem* 221:365–372. <https://doi.org/10.1016/j.foodchem.2016.10.070>
- Panagopoulou EA, Chiou A, Karathanos VT (2019a) Water-soluble vitamin content of sun-dried Corinthian raisins (*Vitis vinifera* L., var. Apyrena). *J Sci Food Agric* 99:5327–5333. <https://doi.org/10.1002/jsfa.9771>
- Panagopoulou EA, Chiou A, Nikolidaki EK, Christea M, Karathanos VT (2019b) Corinthian raisins (*Vitis vinifera* L., var. Apyrena) antioxidant and sugar content as affected by the drying process: a 3-year study. *J Sci Food Agric* 99:915–922. <https://doi.org/10.1002/jsfa.9263>
- Sakka MK, Gourgouta M, Athanassiou CG (2024) Efficacy of extreme temperatures on all life stages of the Mediterranean flour moth, *Ephestia kuehniella* (Lepidoptera: Pyralidae). *Agronomy* 14:1307. <https://doi.org/10.3390/agronomy14061307>
- Singleton V, Trousdale E, Zaya J (1985) One reason sun-dried raisins brown so much. *Am J Enol Vitic* 36:111–113. <https://doi.org/10.5344/ajev.1985.36.2.111>
- Shapiro SS, Wilk MB (1965) An analysis of variance test for normality (complete samples). *Biometrika* 52:591–611. <https://doi.org/10.1093/biomet/52.3-4.591>
- Subramanyam B, Mahroof R, Brijwani M (2011) Heat treatment of grain-processing facilities for insect management: a historical overview and recent advances. *Stewart Postharvest Rev* 3:1. <https://doi.org/10.2212/spr.2011.3.9>
- Tsarouchi M, Fanarioti E, Karathanos VT, Dermon CR (2022) Protective effects of currants (*Vitis vinifera*) on corticolimbic serotonergic alterations and anxiety-like comorbidity in a rat model of Parkinson's disease. *Int J Mol Sci* 24:462. <https://doi.org/10.3390/ijms24010462>
- Vasilakopoulou PB, Fanarioti E, Tsarouchi M, Kokotou MG, Dermon CR, Karathanos VT, Chiou A (2022) Polar phenoldetection in rat brain: development and validation of a versatile UHPLC-MS method and application on the brain tissues of Corinthian currant (*Vitis vinifera* L., var. Apyrena) fed rats. *Food Chem* 390:133131. <https://doi.org/10.1016/j.foodchem.2022.133131>

Wijayarathne LKW, Fields PG (2010) Effect of methoprene on the heat tolerance and cold tolerance of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). J Stored Prod Res 46:166–173. <https://doi.org/10.1016/j.jspr.2010.04.001>

Her research interest focus on insect behavior, insecticide resistance, chemical and non-chemical control of stored product insects.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Maria K. Sakka Dr Maria Sakka is currently a Postdoctoral Researcher at University of Thessaly, in the Laboratory of Entomology and Agricultural Zoology. She holds a PhD from the University of Thessaly, School of Agricultural Sciences, Department of Agriculture Crop Production and Rural Environment. She has received scholarships and awards from different organizations such as the State Scholarships Foundation (IKY) and Hellenic Foundation for Research and Innovation (H.F.R.I.). She

has worked on different research projects funded by EU and Greece. She has published >40 papers in peer-reviewed journals (h-index 14).