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Research Article

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Optimizing the postharvest storage conditions for high quality fresh sage

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Abstract: The use of fresh sage is increasingly popular due to its unique aroma and sensory characteristics. However, sage is a perishable fresh produce with a short shelf life, with limited knowledge of its storage conditions. This work investigated the effects of various temperatures (2, 6, and 20 °C) and relative humidity (RH) levels (atmospheric-65 % and high-95 %) on the quality characteristics of fresh sage during postharvest storage. The results indicated lower weight loss and respiration rate at lower temperatures and high RH. In addition, a higher phytochemical content (phenols, flavonoids, and ascorbic acid) and antioxidant activity were observed in sage stored at 2 and 6 °C (at a high RH level). Sage stored at 6 °C and 65 % RH, also presented higher phenolics and antioxidants. Storage at 20 °C resulted in higher microbial load compared to lower temperatures. Higher sage essential oil yield was found at plants stored at 6 °C, while camphor was also found at higher levels at this temperature. Thus, from the results, it could be suggested that postharvest storage of fresh sage at 6 °C along with high RH could contribute to the preservation of a fresh, aromatic fresh produce of high nutritional value.

Keywords: fresh herbs; postharvest quality; relative humidity; *Salvia fruticosa*; temperature

1 Introduction

Salvia is the most species rich genus in Lamiaceae, encompassing approximately 1,000 species distributed all over the world and has more than 150 species in cultivation for ornamental, culinary, and/or medicinal purposes [1]. Sage (*Salvia fruticosa* Mill.; synonym *Salvia triloba* L.), often referred to as Greek sage or three-lobed sage, is a native plant species of the eastern Mediterranean region [2]. This plant has been recognized for several therapeutic benefits, such as antioxidant [3, 4], antibacterial [5], anti-proliferative [6], and anti-inflammatory activity, among others [7]. Furthermore, it has been used as a natural remedy in many Mediterranean countries to treat a wide range of ailments regarding the respiratory tract (i.e. cough, common cold, and flu), gastrointestinal tract (i.e., indigestion, constipation, and diarrhea), diabetes, and hypotension, among others [2, 8]. This herb is utilized in its fresh and dry form, while its plant preparations (i.e. tea, essential oil, hydrosol, and extract) are known for their health benefits as well [8–10]. The major essential oil (EO) compounds found in *S. fruticosa* are camphor, eucalyptol, camphene, *α*-pinene, and limonene [11] which contribute to various EO activities, including antimicrobial, antioxidant [12, 13], anti-inflammatory [3], anti-proliferative [6] and anticancer properties [14, 15].

As with other fresh herbs, sage is marketed in pre-packaged trays/containers and/or small bundles (with or without modified atmosphere packaging). While fresh herbs have a high nutritional value, these products are very perishable since they degrade quickly in storage (few days to a few weeks). Regarding the postharvest preservation of these fresh produces, scarce information is available. About 30–40 % of the fresh products in the food industry is lost between harvest and consumption for various reasons, such as pre- and postharvest mishandling, poor transportation conditions, and technological gaps, among others [16].

It is well known that fresh herbs are an important source of phytonutrients as well as a flavoring agents in culinary applications. Due to their great perishability, leafy greens (including herbs) decay rapidly after harvest. When these fresh products are kept under conditions with high temperatures and low humidity, they speed metabolic processes, lose moisture and tend to deteriorate sooner [17]. A well-documented portfolio of knowledge and technologies exists for fruits and vegetables, but this is not the case for herbs and aromatic plants, where there is limited knowledge

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and research primarily focus on basil (*Ocimum basilicum* L.) [18–20]. The behavior of main leafy vegetables during storage varies depending on the applied conditions. Environmental factors such as temperature and relative humidity (RH) influence the rate of the product's decay [21]. Room temperature, for example, 20–25 °C, speeds up the decay, resulting in the degradation of phytonutrients accompanied by color changes (i.e., yellowing, browning, and spotting), leaf wilting, and loss of flavor (odor and taste), among others. High temperatures during storage encourage moisture loss, which results in shriveling and wilting while fostering an environment advantageous to microbial growth (both spoilage and pathogenic) [22–24]. In addition, aroma and flavor are attributes that need to be preserved given their influence on the overall consumer's perception and satisfaction; therefore important to meet the market demands.

Fresh produce, including sage, can be purchased at street markets or local markets without any previous preservation methods, exposed to atmospheric temperature. Similarly, sage can be in our home kitchen for couple of days and subjected to atmospheric temperature, often referred room temperature (20–24 °C). The most commonly used method for extending the shelf life of fresh produce is cold storage (use of low temperatures along with high RH), which lowers the respiration rate of the produce and prevents moisture loss through transpiration [25, 26]. Under market cold storage conditions for fresh produce, the temperatures tend to be around 2–4 °C (not higher than 6 °C); however, they can usually reach up to 6–7 °C (if there is no strict monitoring, therefore consequences must be considered), especially in commercial market refrigerators that openings are available for consumers to pick up the fresh produce [27]. In addition, even slight variations in the RH during storage can have a significant impact on how quickly fresh vegetables lose water after harvesting when the temperature is constant. The storage environment's air moisture content should be similar (as feasible) to the vegetables' moisture content in order to minimize the product's water loss [28]. However, several medicinal aromatic plants, including sage, are grown in xerothermic conditions, which may enhance their increased biocidal properties [2, 13, 15], with decreased RH levels, and their response to high RH is less studied. Therefore, it is critical to determine the ideal storage conditions that will prevent major changes to the nutritional value, antioxidant capacity, and sensory characteristics of such products, before any further postharvest preservation techniques are examined. The purpose of the present work was to examine i) the impact of three temperature levels (2, 6 and 20 °C) under high RH as common postharvest management practices, based on the different possible temperatures that sage can be exposed after harvest and ii) the impacts of two RH levels (65 and 95 %), based on natural xerothermic environment in which sage develops or high RH stored conditions at the optimum temperature. Fresh sage was studied for the product's quality characteristics as well as essential oil yield and composition, proposing the optimum postharvest storage conditions for this herb.

2 Materials and methods

2.1 Plant material and bundle preparation

Sage (*S. fruticosa*) fresh plant material was collected (manually with a sharp knife) during early morning in October and December 2023 for the temperature and the RH experiments, respectively. Sage plants were grown on a commercial organic farm (Limassol, Cyprus 34°44'16.53"N; 32°44'40.86"E and 427 m above sea level). Following harvesting, the plant material was transported to the laboratory of Cyprus University of Technology where small bundles were prepared after cleaning and sorting the plant tissue (approximately 90–95 g per bundle). Prior to starting the experiment, the plant material was washed with 0.05 % sodium hypochlorite (NaOCl) to ensure any dust removal and possible natural microbial load, rinsed three times with sterile water and air-dried at room temperature for 30 min.

2.2 Effect of storage temperature

Eight bundles were used for each applied treatment with a total of 80 bundles for the storage temperature study. Every two bundles were placed and enclosed in a polypropylene (PP) plastic container (5 L), with four containers used as replicates per treatment. A moisturized filter paper was placed in each container achieving high RH levels (approximately 95 %) during storage. Samples were stored at refrigerator (2 ± 0.2 and 6 ± 0.2 °C) and room (20 ± 0.5 °C) temperatures until sampling days (day 0, 5, 10, and 15).

2.3 Effect of storage RH

Eight bundles were used for each applied treatment, with a total of 56 bundles for the storage RH study. Every two bundles were placed and enclosed in a PP plastic container (5 L), with four containers used as replicates per treatment. The high RH levels of approximately 95 % were achieved as described in Section 2.2. For the atmospheric RH levels of approximately 65 %, containers were enclosed without any filter paper. Samples were stored at refrigerator temperature (6 ± 0.2 °C;

the optimum temperature selected based on the results from Section 2.2) until sampling days (day 0, 5, 10, and 15).

2.4 Measurements

2.4.1 Weight loss and respiration rate

The weight of each sage bundle was recorded every sampling day (day 0, 5, 10, and 15) and the results were calculated as the percentage (%) of total weight loss. The respiration rate was estimated by sucking the air (40 s) from the container and measuring the CO_2 produced by each bundle after 1 h enclosure (at room temperature) in a container using a Dual gas analyzer (International Control Analyser Ltd, UK). The volume and the fresh weight of each bundle were reordered and the results of the CO_2 produced were expressed as mL CO_2/kg/h [29].

2.4.2 Leaf pigments, color, and visual quality

The procedure for the determination of leaf pigment content (chlorophylls and carotenoids) was carried out as previously described [30] using methanol (Merck, Darmstadt, Germany) as the solvent incubated in the dark, in a heat bath at 65 °C for 30 min. The absorbance of the extract was measured at 470, 653 and 666 nm and results were calculated for the chlorophyll a (Chl a), chlorophyll b (Chl b), total chlorophylls (Total Chl), and total carotenoids (Total Car), with values expressed as mg of chlorophylls or carotenoids per g of fresh weight.

The color of sage's leaves was assessed with the use of a portable digital colorimeter (Chroma meter CR400 Konica Minolta, Tokyo, Japan) by measuring the following CIELAB uniform color space variables: L* (brightness/lightness: 0: black/100: white), a* greenness/redness (−a*: greenness and +a*: redness) and b* (−b*: blueness and +b*: yellowness). These values were employed to determine the following color parameters: hue (h), chroma value (C) and color index (CI) [31, 32].

Macroscopic (i.e. visual quality) evaluation was conducted by a non-trained panel group (at least eight people; age range: 21–32 years; equal gender balance; previously introduced to the storage conditions of sage) using a 10-level scale (1-point interval) (1: not marketable-spoilage, 3: not marketable-brown leaves, 5: slightly marketable, 7: marketable: yellow/brown spots in leaves, 10: marketable).

2.4.3 Total phenolics, antioxidant activity, total flavonoids, and ascorbic acid

Total phenolics, total flavonoids, and antioxidants were extracted as previously described by Chrysargyris et al. [33]. In brief, fresh sage samples (1 g) pooled from two individual bundles of each treatment, were milled with 10 mL methanol 50 % (v/v) and homogenized using a mixer (ULTRA-TURRAX T 25, IKA-Werke, Germany) for 60 s. Following incubation in a sonication bath for 30 min, and in a shaker (200 rpm) for 1 h, samples were finally centrifuged 15 min, at 4 °C and 5,000 rpm. The supernatant was then collected and placed in 15 mL falcon tubes.

The phenolic content was determined using the Folin-Ciocalteu method and measuring the reaction's absorbance at 755 nm, while the results were expressed as mg of gallic acid equivalents per g of fresh weight (mg GAE/g Fw) [34]. The antioxidant capacity of fresh sage was estimated by using three different methods: i) the 2,2-diphenyl-1-picrylhydrazyl (DPPH), ii) the ferric reducing antioxidant power (FRAP), and iii) the 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) assays. The DPPH and FRAP assays were performed as previously described [33], while the ABTS assay was performed according to Wojdyło et al. [35]. Results were expressed as mg of trolox per g of fresh weight (mg trolox/g Fw). Total flavonoids were determined using the aluminum chloride colorimetric method [36] as modified in Chrysargyris et al. [37], by measuring the absorbance at 510 nm (Multiskan GO, Thermo Fischer Scientific Oy, Finland). Results expressed as mg of rutin per g of fresh weight (mg rutin/g Fw). The ascorbic acid content was measured for four fresh samples (1 g) replicates, by titration with 2,6-dichlorophenol-indophenol [38], with results calculated and expressed as mg of ascorbic acid per 100 g of fresh weight (mg AA/100 g Fw).

2.4.4 Microbial load

The microbial load such as total viable count-TVC (the total number of microorganisms i.e. bacteria, yeast and/or molds that are present in a sample) and yeasts and molds numbers were estimated as part of sage bundles microbial load. Appropriate media were used for each case, as Plate count agar (PCA, Merck, Darmstadt, Germany) for TVC and Dichloran-rose bengal chloramphenicol agar (DRBC agar, Merck, Darmstadt, Germany) for yeasts and molds, as previously described [34]. The results were expressed as log of colony forming units (cfu) per g of fresh weight (log cfu/g Fw).

2.4.5 Essential oil yield and profile

After each sampling, the plant material was dried (at 42 °C) in an air-ventilated oven (SANYO convection oven, MOV-212F, SANYO Electric Co., Ltd., Osaka, Japan). The dried tissue was then subjected to essential oil extraction for 3 h using the hydrodistillation method (Clevenger apparatus), with three replicates per treatment and day. The essential oil yield was determined as μL of EO per 100 g of dried tissue (v/w on dry weight basis and expressed as EO % yield). After the extraction, the EOs were collected and stored in amber glass tubes, at −20 °C until analysis. Analytical gas chromatography was carried out with a Shimadzu GC2010 gas chromatograph interfaced Shimadzu GC/MS QP2010 plus mass spectrometer, using conditions as described by Chrysargyris and Tzortzakis [39].

The identification of the EO compounds was carried out by comparison of their retention indices relative to n-alkanes (C8–C20), with those found in the literature or with the authentic compounds, available in our laboratory. Additional identification was provided by matching the compounds' recorded mass spectra with those of the NIST08 mass spectra library (GC-MS data system) and other published spectra [40]. The quantitative determination was carried out based on peak area integration. Each compound was expressed as a percentage of the total peak area. Components that are present with a percentage of more than 0.05 % are presented in the results tables.

2.5 Statistical analysis

A Completely Randomized Design (CRD) was employed for the experimental setup of the current study (four biological replications per treatment, except for essential oil analysis where three biological replications were used). Statistical analysis was performed using IBM SPSS version 25.0. The data were analyzed with one-way and two-way Analysis of variance (ANOVA) with two first order interactions (Temperature × Days, Humidity × Days), while Duncan's multiple range test was used to compare the treatment means at the significance level of $P = 0.05$. A principal component analysis (PCA) was carried out to detect the contribution of each variable to the total diversity and classify the studied samples based on essential oil composition. The analysis was implemented with the statistical software MetaboAnalyst 6.0.

3 Results

3.1 Effects of storage temperature

3.1.1 Weight loss and respiration rate

Figure 1 presents the effects of storage temperature on weight loss and respiration rate of fresh sage. During storage at 20 °C, increased fruit weight loss (Figure 1A) and respiration rates (Figure 1B) were observed compared storage at lower temperatures throughout the storage period. Interestingly, the respiration rates of bundles stored at 20 °C, decreased on day 15 compared to days 5 and 10, and being at similar levels with the values obtained at 6 °C and on day 15 (Figure 1B).

3.1.2 Leaf pigments, color, and visual quality

Higher chlorophyll content was found in sage stored at 2 and 20 °C compared to 6 °C after 10 days but after 15 days differences insignificant (Figure 2A–C). Carotenoid content was found higher during storage at 20 °C compared to lower temperatures on the 5th day of storage, while no significant differences were found on the other days. A darker colored product was observed during the storage of fresh sage at 20 °C compared to lower temperatures. This was evident from the higher hue angle and color index values, as well as the decreased chroma values observed on the 10th and 15th days of storage (Figure 2E–G). Moreover, a less marketable product was reported during storage of fresh sage at 20 °C (Figures 2H and 3).

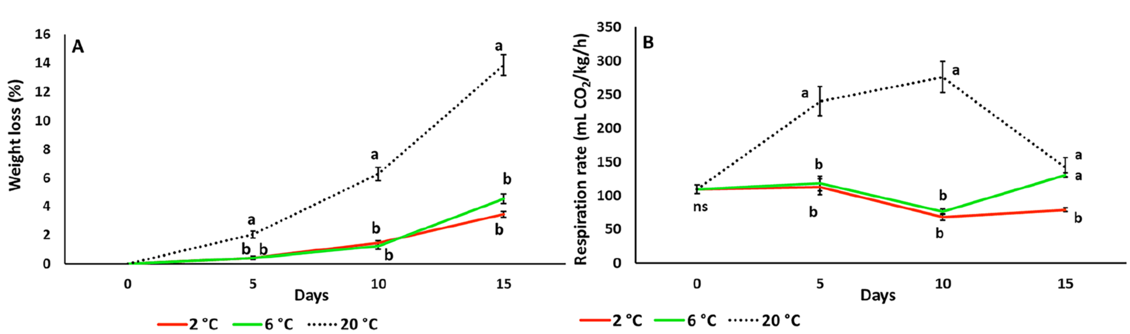

Figure 1: Effect of storage temperature on (A) weight loss and (B) respiration rate of fresh sage stored at various temperatures (2, 6, and 20 °C) for 15 days. The values presented are the mean (±standard error) ($n = 4$). Different letters indicate statistical differences ($P < 0.05$) among the treatments of the same day. ns: indicates no significance.

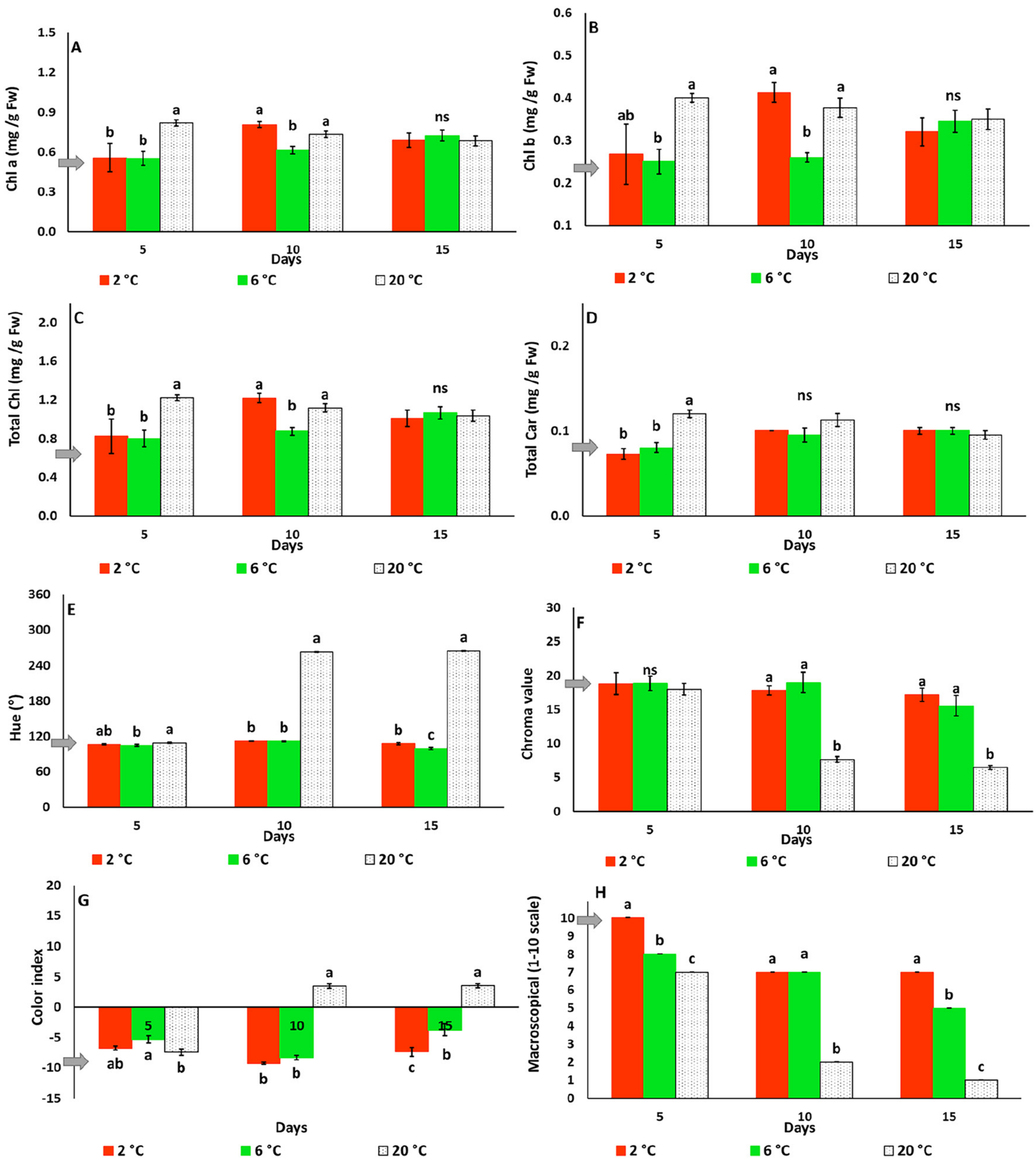

Figure 2: Effect of storage temperature on leaf pigments with (A) chlorophyll a-Chl a, (B) chlorophyll b-Chl b, (C) total chlorophyll-Total Chl, and (D) total carotenoids-Total Car; on color (E) hue, (F) chroma value, and (G) color index; and visual quality (H) macroscopical evaluation of fresh sage stored at various temperatures (2, 6, and 20 °C) and 95 % relative humidity for 15 days. The values presented are the mean (±standard error) (n = 4). Different letters indicate statistical differences ($P < 0.05$) among the treatments of the same day. Grey arrow indicates the values on day 0. ns: indicates no significance.

3.1.3 Total phenolics, antioxidant activity, total flavonoids, and ascorbic acid

The total phenolic content of fresh sage stored at 2 and 6 °C was higher than that of sage kept at 20 °C on the 10th and 15th days of storage (Figure 4A). The antioxidant activity of sage was lower at 20 °C compared to 2 and 6 °C on the 10th and 15th day of storage (Figure 4B–D). Similarly, the total flavonoids content of sage was increased on the 10th and 15th days of storage at lower temperatures of 2 and 6 °C compared to the 20 °C (Figure 4E). The ascorbic acid content was lower in sage stored at 20 °C on the 5th and 15th days of storage compared to the lower temperatures (Figure 4F).

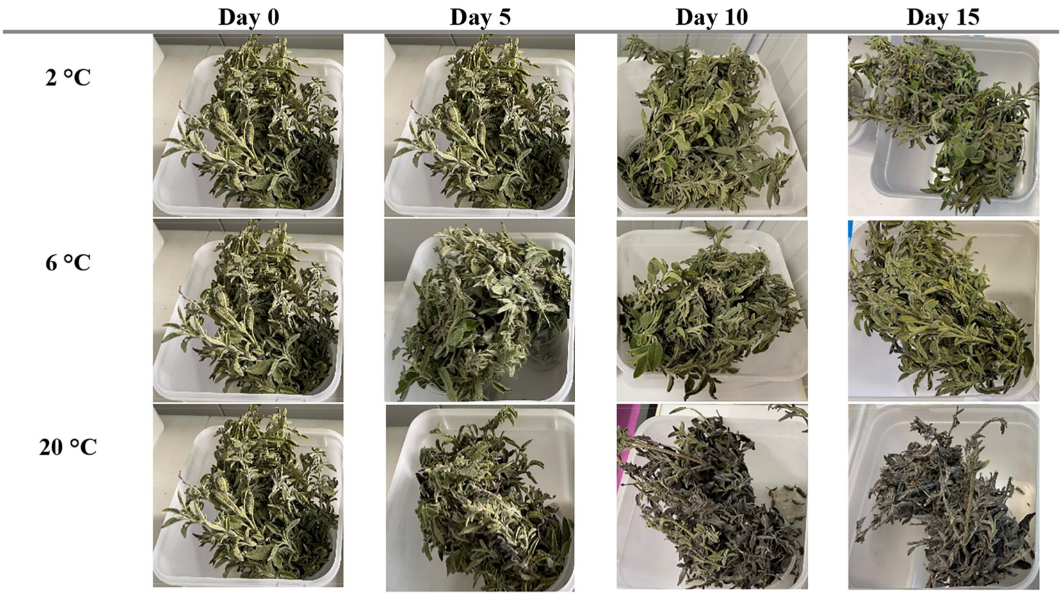

Figure 3: Effect of storage temperature on fresh sage stored up to 15 days at various temperatures (2, 6, and 20 °C) and 95 % relative humidity.

3.1.4 Microbial load

Figure 5 presents the effects of storage temperature on the microbial load of fresh sage. Storage at 6 °C resulted in lower TVC numbers compared to other investigated temperatures on the 5th and 10th days. However, on the last day (i.e. 15th day), higher TVC was observed at 6 and 20 °C compared to 2 °C (Figure 5A). Lower yeasts and molds numbers were observed on the 5th and 10th days during storage at 20 °C, whereas higher temperatures (6 and 20 °C) showed higher yeasts and molds populations at the end of storage (Figure 5B).

3.1.5 Essential oil yield and composition

The effect of different storage temperatures on the yield and quality of the EO of sage plants is presented in Table 1. Twenty-five (25) components have been identified (>0.05 %), with the major compounds being camphor (45.70 %) and eucalyptol (31.38 %) (from the analysis on day 0), while components as camphene (6.20 %), *α*-pinene (2.57 %), limonene (2.92 %), borneol (2.08 %), viridiflorol (1.93 %), and 1-octen-3-ol (1.43 %) follow. The main group of components was in oxygenated monoterpenes (averaged at 81.41 %), followed by monoterpenes (averaged at 12.36 %), oxygenated sesquiterpenes (averaged at 3.02 %), and finally by sesquiterpenes (averaged at 0.08 %). The EO yield was 0.89 %, and was affected by the different storage temperatures only after 15 days of storage, increasing to 1.15 % at 6 °C, compared to 20 °C. In general, the effect of different storage temperatures on the EO profile of sage plants was not that prominent, as almost all of the major components (camphor, eucalyptol, camphene, *α*-pinene, and limonene) remained unaffected on all sampling days (5, 10, and 15). The effect worth mentioning is observed after 15 days of storage, where camphor appeared in increased amounts at 2 °C and 6 °C, reaching up to 45.56 % and 45.65 %, respectively, compared to the 41.80 % measured at 20 °C.

3.2 Effects of storage relative humidity

3.2.1 Weight loss and respiration rate

As shown in Figure 6, increased weight loss up to 52.3 % was found in fresh sage stored under atmospheric RH compared to high RH at the end of storage (day 15) (Figure 6A). Similarly, storage of fresh sage under atmospheric RH resulted in increased respiration rate after 5 and 15 days of storage at 6 °C (Figure 6B).

3.2.2 Leaf pigments, color, and visual quality

Chlorophylls and total carotenoids were not affected by the RH levels throughout storage of fresh sage (up to 15 days at 6 °C) (Figure S1A–S1D). Similarly, no significant differences in sage's color parameters (i.e. hue, chroma value, and color index) were observed (Figure S1E–S1G). A less marketable product was reported on the last day of storage (day 15) with atmospheric RH compared to high RH (Figure 7, S1H).

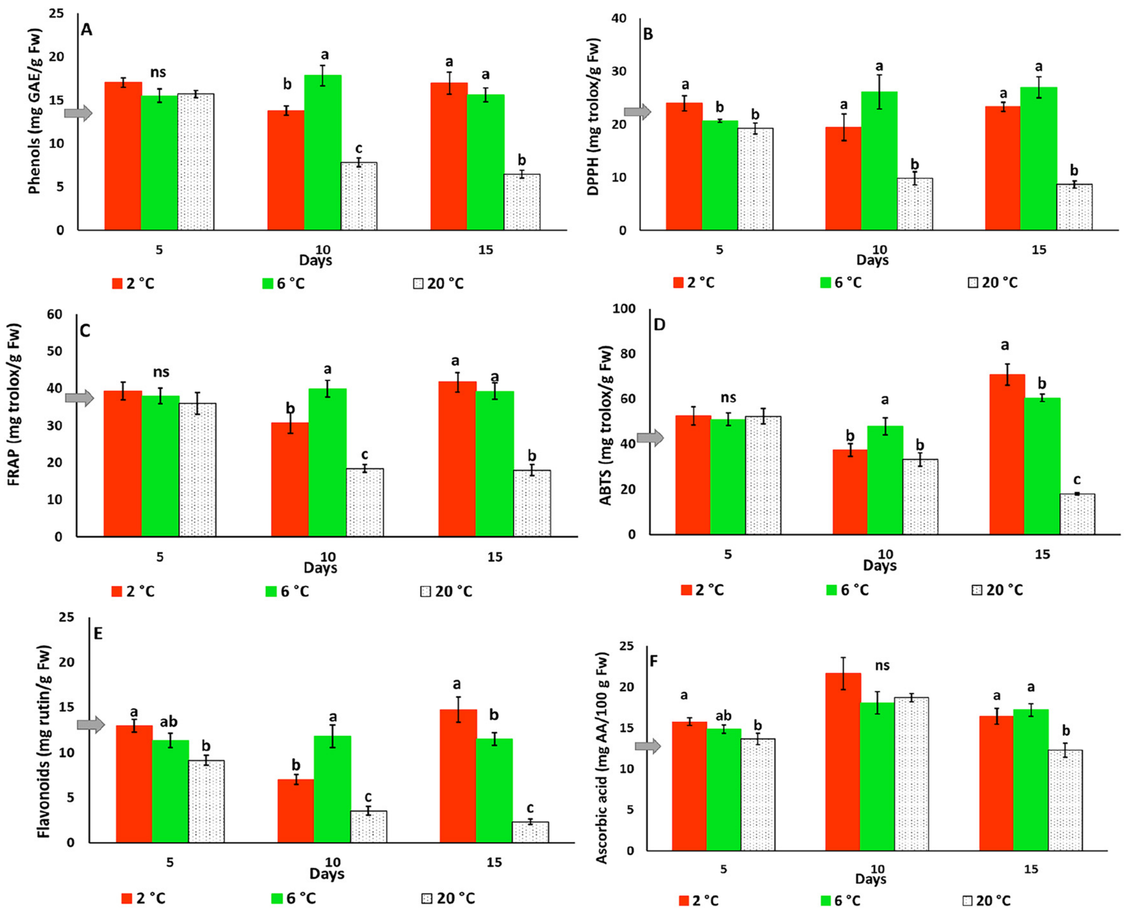

Figure 4: Effect of storage temperature on (A) total phenols, antioxidant activity (B) DPPH, (C) FRAP, (D) ABTS, (E) total flavonoids, and (F) ascorbic acid of fresh sage stored at various temperatures (2, 6, and 20 °C) and 95 % relative humidity for 15 days. The values presented are the mean (±standard error) (n = 4). Different letters indicate statistical differences (P < 0.05) among the treatments of the same day. Grey arrow indicates the values on day 0. ns: indicates no significance.

3.2.3 Total phenolics, antioxidant activity, total flavonoids, and ascorbic acid

Figure S2 presents the effects of storage RH levels on phenols, antioxidant activity, flavonoids and ascorbic acid content of fresh sage. Increased phenolic content and antioxidant activity (DPPH, ABTS) were found with storage under atmospheric RH compared to high RH on the 10th day of storage of fresh sage at 6 °C (Figure S2A, S2B, S2D). The flavonoids content of fresh sage was not affected by the RH level, whereas sage's ascorbic acid content increased at the end of storage (day 15) under atmospheric RH compared to high RH (Figure S2E, S2F).

3.2.4 Microbial load

As illustrated in Figure S3, TVC along with yeasts and molds numbers were found higher during storage in atmospheric RH compared to high RH on the 5th day of storage at 6 °C (Figure S3A, S3B). On the other hand, decreased microbial numbers were observed after 10 days of storage under atmospheric RH compared to high RH. Minor or no changes in microbial load were observed during 15 days of storage.

3.2.5 Essential oil yield and composition

The effect of storage humidity levels on the yield and quality of the EO of sage plants is presented in Table 2. Thirty-three (33) components have been identified (>0.05 %), with the major compounds being camphor (43.03 %), eucalyptol (24.17 %), camphene (6.41 %), isobornyl acetate (4.48 %), limonene (4.43 %), viridiflorol (3.23 %), α-pinene (2.73 %), β-myrcene (1.72 %), 1-octen-3-ol (1.62 %), terpinolene (1.61 %), β-caryophyllene (1.28 %) and borneol (1.19 %) from the analysis of plants on day 0, before the application of the postharvest humidity treatments. The main group of components was oxygenated monoterpenes (averaged at 75.30 %), followed by monoterpenes (averaged at 16.54 %),

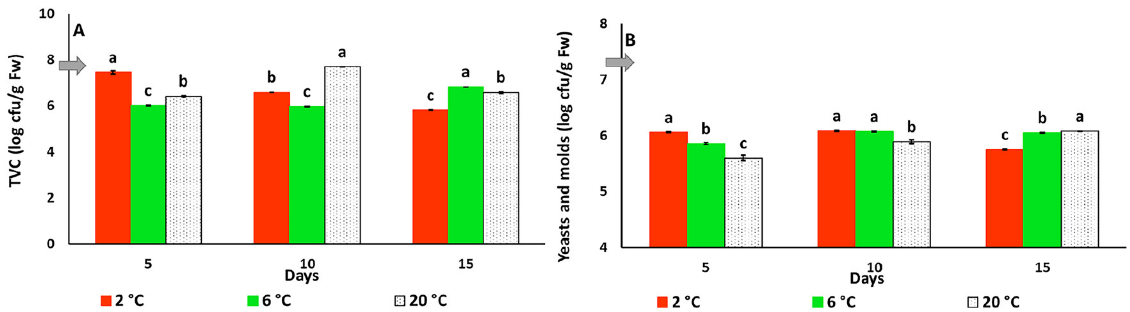

Figure 5: Effect of storage temperature on the microbial load (A: total viable count-TVC and B: yeast and molds) of fresh sage stored at various temperatures (2, 6, and 20 °C) and 95 % relative humidity for 15 days. The values presented are the mean (±standard error) (n = 4). Different letters indicate statistical differences (P < 0.05) among the treatments of the same day. Grey arrow indicates the values on day 0.

oxygenated sesquiterpenes (averaged at 1.62 %), and finally by sesquiterpenes (averaged at 1.20 %).

The EO yield was 1.79 %, and it was affected by the different humidity applications during storage; considering the measurements on days 5 and 10, the yield of the plants stored with high humidity was measured almost 30 % higher than those stored without additional humidity (atmospheric RH). Regarding the major compounds, the effect of humidity on camphor was recorded only after 15 days of storage, where it appeared significantly lower, when high humidity was applied, while the opposite was measured for components such as eucalyptol and isobornyl acetate, on the same day. The amount of camphor in the EO during days 5 and 10 was unaffected by humidity levels, while in both storage periods, eucalyptol appeared significantly lower when high humidity was applied. Other compounds with low participation (<1.00 %) in the EOs were variably affected by humidity levels during storage (*p*-cymene, linalool, borneol, etc.) Figure 7.

3.3 Two-way ANOVA and PCA of the effects of temperature, humidity and days of storage

Two-way Anova analysis revealed that temperature as well as the temperature × days interaction significantly affected all the tested parameters at $P < 0.05$, $P < 0.01$, and $P < 0.001$ except for ascorbic acid. The Days of storage significantly affected all tested parameters at $P < 0.001$ (Table S1).

Humidity affected respiration rate, DPPH, and FRAP at $P < 0.05$, weight loss, and ABTS at $P < 0.01$, macroscopical and yeast/molds at $P < 0.001$. The days of storage affected color index, chlorophylls, FRAP and flavonoids at $P < 0.05$; phenols, ABTS and ascorbic acid at $P < 0.01$; weight loss, respiration rate, macroscopical, carotenoids, DPPH, TVC and yeast/molds at $P < 0.001$. The interaction of humidity × days of storage affected macroscopical, TVC and yeast/molds at $P < 0.001$ (Table S1).

Principal component analysis (PCA) was performed to identify groups and indicate similarities and differences in multivariate data. The analysis of our data for temperature effects during the storage period showed that the first eight principal components (PCs) were associated with eigenvalues higher than 1, explaining 98.2 % of the cumulative variance, with PC1 accounting for 62.2 %, PC2 for 13.8 %, PC3 for 8.2 %, PC4 for 6.2 %, PC5 for 3.1 %, PC6 for 2.1 %, PC7 for 1.4 % and PC8 for 1.2 %. The loading plot of PC1 and PC2 correlated variables as follows: the upper left quadrant included α-terpineol, terpinolene, cymen-8-ol p, β-myrcene, α-humulene, limonene; the upper right quadrant included linalool, cis-sabinene hydrate, terpinene-4-ol; the lower left quadrant included α-terpinyl acetate, viridiflorol, caryophyllene oxide, borneol, isobornyl acetate; the lower right quadrant included tricyclene (Figure 8A).

The analysis of our data for humidity effects during storage period showed that the first six principal components (PCs) were associated with eigenvalues higher than 1, explaining 97.7 % of the cumulative variance, with PC1 accounting for 47.4 %, PC2 for 22.0 %, PC3 for 16.7 %, PC4 for 6.0 %, PC5 for 3.5 %, and PC6 for 2.1 %. The loading plot of PC1 and PC2 correlated variables as follows: the upper left quadrant included linalool, cis-sabinene hydrate, eucalyptol; the upper right quadrant included terpinene-4-ol, isobornyl acetate, α-terpineol, p-cymene, cymen-8-ol p, terpinolene, α-terpinyl acetate, limonene, borneol; the lower left quadrant included α-thujene, tricyclene, α-pinene, 1-octen-3-ol, α-terpinene; the lower right quadrant included camphene, camphor, caryophyllene, α-humulene, γ-terpinene, n decane, viridiflorol (Figure 8B).

4 Discussion

Fresh culinary herbs are preferred by consumers due to their unique flavor and aroma, as well as the health benefits

Table 1: Effect of storage temperature on the essential oil yield and composition (%) of *Salvia fruticosa* plants stored at various temperatures (2, 6, and 20 °C) and 95 % relative humidity for 15 days.

Compound	RI	Day 0	Day 5			Day 10			Day 15		
			2 °C	6 °C	20 °C	2 °C	6 °C	20 °C	2 °C	6 °C	20 °C
tricyclene	922	0.09 ± 0.00	0.08 ± 0.00	0.08 ± 0.00	0.08 ± 0.00	0.08 ± 0.01	0.09 ± 0.01	0.07 ± 0.01	0.08 ± 0.01	0.09 ± 0.00	0.10 ± 0.01
α-thujene	926	0.04 ± 0.00	0.05 ± 0.00ab	0.05 ± 0.00a	0.04 ± 0.00b	0.04 ± 0.00b	0.05 ± 0.00a	0.06 ± 0.00a	0.04 ± 0.00	0.04 ± 0.00	0.05 ± 0.01
α-pinene	933	**2.57 ± 0.27**	**2.46 ± 0.04**	**2.39 ± 0.06**	**2.48 ± 0.02**	**2.34 ± 0.11**	**2.50 ± 0.22**	**2.40 ± 0.11**	**2.14 ± 0.03**	**2.34 ± 0.17**	**2.76 ± 0.27**
camphene	948	**6.20 ± 0.66**	**5.64 ± 0.14**	**5.72 ± 0.34**	**5.75 ± 0.16**	**5.45 ± 0.47**	**6.13 ± 0.75**	**5.61 ± 0.38**	**5.49 ± 0.06**	**5.61 ± 0.35**	**6.38 ± 0.23**
1-octen-3-ol	976	**1.43 ± 0.13**	**1.48 ± 0.05**	**1.42 ± 0.09**	**1.42 ± 0.09**	**1.49 ± 0.11**	**1.52 ± 0.14**	**1.59 ± 0.09**	**1.39 ± 0.04**	**1.43 ± 0.11**	**1.80 ± 0.14**
β-myrcene	989	0.86 ± 0.17	0.76 ± 0.06	0.78 ± 0.07	0.81 ± 0.03	0.77 ± 0.10	0.80 ± 0.07	0.91 ± 0.03	0.61 ± 0.11	0.68 ± 0.09	0.89 ± 0.10
α-terpinene	1,017	0.03 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.01 ± 0.01	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.03 ± 0.01
p-cymene	1,024	0.66 ± 0.05	0.61 ± 0.06	0.60 ± 0.04	0.56 ± 0.03	0.62 ± 0.05	0.58 ± 0.01	0.57 ± 0.01	0.56 ± 0.08	0.61 ± 0.07	0.86 ± 0.10
limonene	1,028	**2.92 ± 0.58**	**2.67 ± 0.32**	**2.61 ± 0.24**	**2.82 ± 0.04**	**2.53 ± 0.29**	**2.74 ± 0.21**	**2.82 ± 0.10**	**2.05 ± 0.39**	**2.18 ± 0.28**	**2.74 ± 0.23**
eucalyptol	1,031	**31.38 ± 3.46**	**32.30 ± 2.79**	**31.48 ± 2.58**	**32.46 ± 1.81**	**32.04 ± 2.33**	**29.57 ± 2.09**	**31.33 ± 2.62**	**34.80 ± 3.97**	**33.65 ± 2.51**	**33.17 ± 1.55**
γ-terpinene	1,036	0.03 ± 0.00	0.03 ± 0.00	0.02 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00
cis-sabinene hydrate	1,058	0.01 ± 0.01	0.02 ± 0.02	0.03 ± 0.01	0.03 ± 0.01	0.03 ± 0.00b	0.04 ± 0.00ab	0.07 ± 0.01a	0.02 ± 0.02	0.05 ± 0.01	0.05 ± 0.01
terpinolene	1,067	0.25 ± 0.06	0.19 ± 0.02	0.19 ± 0.02	0.20 ± 0.01	0.16 ± 0.03b	0.20 ± 0.01ab	0.29 ± 0.01a	0.13 ± 0.04	0.16 ± 0.01	0.24 ± 0.04
linalool	1,100	0.15 ± 0.03	0.16 ± 0.02	0.14 ± 0.02	0.16 ± 0.03	0.13 ± 0.00	0.14 ± 0.02	0.18 ± 0.03	0.12 ± 0.01	0.15 ± 0.03	0.16 ± 0.03
α-thujone	1,106	0.09 ± 0.00	0.07 ± 0.01	0.08 ± 0.02	0.11 ± 0.01	0.31 ± 0.13	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
camphor	1,145	**45.70 ± 0.21**	**45.99 ± 0.40**	**46.30 ± 0.10**	**46.10 ± 0.13**	**46.38 ± 0.11**	**46.69 ± 0.44**	**46.43 ± 0.62**	**45.56 ± 0.85a**	**45.65 ± 0.01a**	**41.80 ± 0.75b**
borneol	1,166	**2.08 ± 0.19**	**1.91 ± 0.32**	**1.80 ± 0.19**	**1.38 ± 0.24**	**1.82 ± 0.17**	**1.77 ± 0.13**	**1.40 ± 0.13**	**1.65 ± 0.28**	**1.85 ± 0.24**	**1.93 ± 0.08**
terpinene-4-ol	1,178	0.84 ± 0.08	0.86 ± 0.05	0.82 ± 0.06	0.77 ± 0.07	0.73 ± 0.01	0.75 ± 0.09	0.84 ± 0.10	0.79 ± 0.06	0.83 ± 0.03	0.83 ± 0.11
cymen-8-ol p	1,186	0.38 ± 0.03	0.40 ± 0.02ab	0.42 ± 0.01a	0.34 ± 0.01b	0.34 ± 0.03	0.39 ± 0.02	0.38 ± 0.02	0.29 ± 0.07	0.32 ± 0.02	0.26 ± 0.04
α-terpineol	1,191	0.24 ± 0.01	0.22 ± 0.01ab	0.20 ± 0.01b	0.24 ± 0.01a	0.19 ± 0.02	0.18 ± 0.02	0.22 ± 0.02	0.17 ± 0.04	0.19 ± 0.01	0.23 ± 0.03
isobornyl acetate	1,287	0.81 ± 0.10	0.65 ± 0.11a	0.59 ± 0.05ab	0.29 ± 0.05b	0.47 ± 0.06ab	0.60 ± 0.01a	0.35 ± 0.03b	0.47 ± 0.10	0.52 ± 0.09	0.46 ± 0.06
α-terpinyl acetate	1,349	0.30 ± 0.08	0.29 ± 0.08	0.26 ± 0.05	0.24 ± 0.06	0.22 ± 0.05	0.24 ± 0.01	0.22 ± 0.04	0.16 ± 0.07	0.19 ± 0.05	0.31 ± 0.05
α-humulene	1,462	0.06 ± 0.06	0.06 ± 0.04	0.08 ± 0.05	0.09 ± 0.05	0.08 ± 0.04	0.11 ± 0.06	0.13 ± 0.06	0.02 ± 0.02	0.04 ± 0.04	0.15 ± 0.04
caryophyllene oxide	1,587	0.39 ± 0.17	0.37 ± 0.20	0.45 ± 0.18	0.40 ± 0.19	0.42 ± 0.12	0.56 ± 0.13	0.47 ± 0.15	0.33 ± 0.19	0.42 ± 0.16	0.62 ± 0.13
viridiflorol	1,594	**1.93 ± 0.72**	**2.12 ± 1.00**	**2.83 ± 1.07**	**2.58 ± 0.92**	**2.66 ± 0.52**	**3.56 ± 0.80**	**2.87 ± 0.90**	**1.91 ± 0.93**	**2.18 ± 0.69**	**2.40 ± 0.34**
Total identified		99.43 ± 0.10	99.41 ± 0.11	99.35 ± 0.14	99.41 ± 0.16	99.35 ± 0.15	99.26 ± 0.12	99.30 ± 0.15	98.85 ± 0.65	99.22 ± 0.21	98.32 ± 0.29
Monoterpenes		13.40 ± 1.72	12.33 ± 0.51	12.29 ± 0.74	12.61 ± 0.28	11.90 ± 1.03	12.99 ± 1.27	12.57 ± 0.61	11.05 ± 0.63	11.65 ± 0.96	13.89 ± 0.96
Oxygenated monoterpenes		81.12 ± 3.08	82.10 ± 2.10	81.43 ± 2.37	81.78 ± 1.80	82.11 ± 2.10	79.68 ± 2.53	81.10 ± 2.03	83.52 ± 2.62	82.80 ± 2.30	78.68 ± 2.01
Sesquiterpenes		0.06 ± 0.06	0.06 ± 0.04	0.08 ± 0.05	0.09 ± 0.05	0.08 ± 0.04	0.11 ± 0.06	0.13 ± 0.06	0.02 ± 0.02	0.04 ± 0.04	0.15 ± 0.04
Oxygenated sesquiterpenes		2.32 ± 0.89	2.49 ± 1.20	3.28 ± 1.25	2.98 ± 1.11	3.08 ± 0.64	4.13 ± 0.93	3.33 ± 1.05	2.24 ± 1.12	2.60 ± 0.85	3.02 ± 0.47
Others		2.54 ± 0.31	2.42 ± 0.24	2.27 ± 0.19	1.95 ± 0.19	2.18 ± 0.23	2.36 ± 0.15	2.16 ± 0.15	2.02 ± 0.20	2.14 ± 0.24	2.58 ± 0.25
Yield		0.89 ± 0.12	1.33 ± 0.07	1.24 ± 0.01	1.31 ± 0.08	1.61 ± 0.14	1.34 ± 0.00	1.30 ± 0.19	1.01 ± 0.04ab	1.15 ± 0.09a	0.88 ± 0.01b

The values presented are the mean (±standard error) (n = 3). Different letters indicate statistical differences ($P < 0.05$) among the treatments of the same day. The compound content greater than 1 % and the essential oil yield are highlighted in bold.

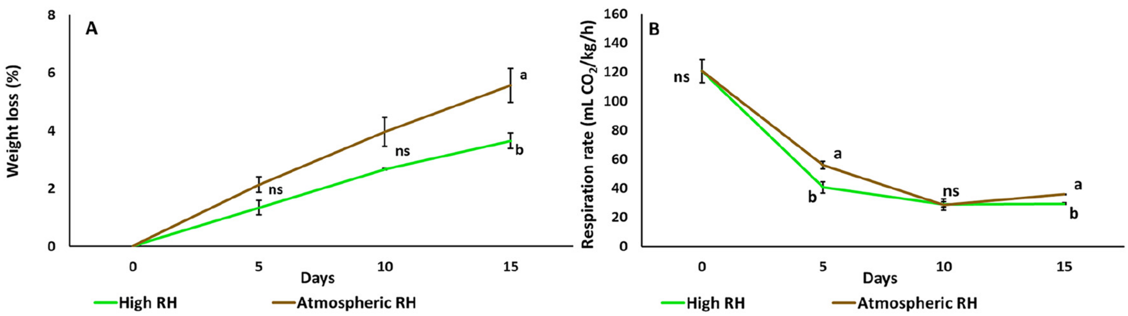

Figure 6: Effect of storage relative humidity (RH) level on (A) weight loss and (B) respiration rate of fresh sage stored at 6 °C for 15 days. The values presented are the mean (±standard error) (n = 4). Different letters indicate statistical differences ($P < 0.05$) among the treatments of the same day. ns: indicates no significance.

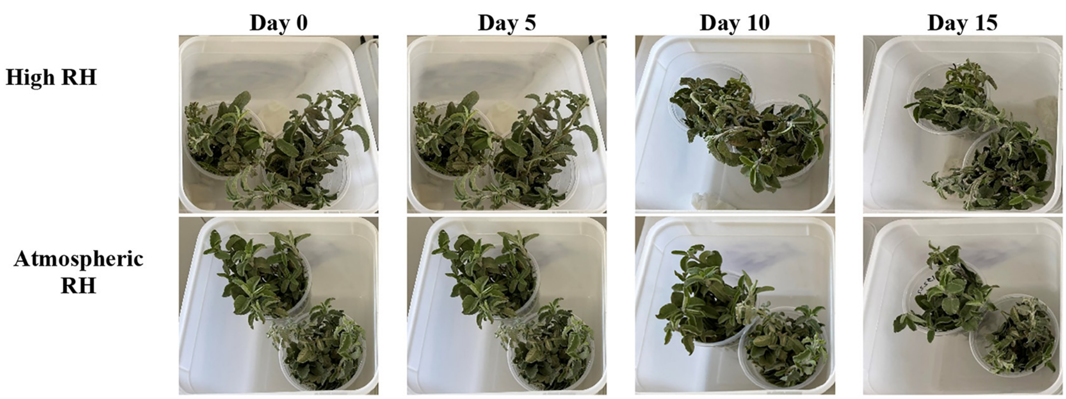

Figure 7: Effect of storage relative humidity (RH) level on fresh sage stored at 6 °C for 15 days.

they provide [8, 41]. Similar to other leafy greens, fresh herbs are considered very perishable produce that should be kept at low temperatures to slow down their metabolic processes and avoid undesirable alterations that could lead to a rapid decline in the product's quality [42]. Through postharvest chemical and physical treatments, the food industry can preserve these fresh products.

During storage, reduced temperature and high RH reduce the respiratory and enzymatic activity and contribute to slowing down any pathogenic activity. Thus, it creates a storage environment that is appropriate for preserving perishable fresh produce like herbs. In addition, this scenario reduces the rate of water loss and respiration rate, which slows and/or inhibits the growth of spoilage bacteria while minimizing at the same time the fresh produce's metabolic activity [25, 26]. Greater metabolic activity and a shorter shelf life are indicated by a higher respiration rate. Short shelf life and poor food quality are correlated with excessive water loss. The weight loss of fresh produce results from water loss, which is linked to an acceleration of respiration and transpiration of stored produce, leading to their deterioration. Transpiration causes the majority of vegetables to lose around 3–10 % of their weight (in some cases perhaps even more) [43]. Notably, poor quality in leafy greens (exhibited by shriveled and wilted leaves) is associated with significant weight loss (greater than 3 %) [44]. In leafy greens and culinary herbs, higher respiration is related to enhanced metabolic processes and faster senescence, which appears as leaf wilting and yellowing [45]. In the current study, higher weight loss was observed at 20 °C (high RH) and during storage under atmospheric RH (at 6 °C) (up to 14 % and 6 %, respectively) compared to lower temperatures and higher RH. Thus, lower storage temperatures accompanied by high RH reduce the water loss and respiration rate of fresh sage, mirroring higher quality and prolonged storage conditions. This was also evident in a previous study with rosemary stored at 4 °C and relatively high RH (85–90 %) after various postharvest treatments [34]. In this case, rosemary was able to absorb environmental moisture, increasing its weight (i.e., lower weight loss). This was related mainly to the xerothermic environment where rosemary is usually grown. The above was the initiative to include higher and lower RH in the present study, for a similar xerothermic plant as sage and its responses to postharvest handling. One aspect that contributes to

Table 2: Effect of storage relative humidity (RH) level on the essential oil yield and composition (%) of *Salvia fruticosa* plants stored at 6 °C for 15 days.

Compound	RI	Day 0	Day 5		Day 10		Day 15	
			High RH	Atmospheric RH	High RH	Atmospheric RH	High RH	Atmospheric RH
tricyclene	922	0.05 ± 0.00	0.05 ± 0.01	0.06 ± 0.00	0.06 ± 0.00b	0.08 ± 0.00a	0.06 ± 0.00	0.06 ± 0.00
α-thujene	926	0.05 ± 0.00	0.08 ± 0.01	0.06 ± 0.00	0.06 ± 0.00	0.07 ± 0.00	0.04 ± 0.00	0.05 ± 0.00
α-pinene	933	**2.73 ± 0.03**	**2.75 ± 0.19**	**3.00 ± 0.03**	**2.96 ± 0.04**	**3.23 ± 0.10**	**2.87 ± 0.03b**	**3.07 ± 0.02a**
camphene	948	**6.41 ± 0.04**	**6.56 ± 0.73**	**6.86 ± 0.06**	**6.53 ± 0.07**	**7.08 ± 0.20**	**6.53 ± 0.09**	**6.81 ± 0.01**
1-octen-3-ol	976	**1.62 ± 0.00**	**1.44 ± 0.07**	**1.30 ± 0.03**	**1.61 ± 0.01b**	**1.87 ± 0.05a**	**1.55 ± 0.01b**	**1.69 ± 0.02a**
β-myrcene	989	**1.72 ± 0.01**	**1.58 ± 0.10**	**1.59 ± 0.01**	**1.55 ± 0.02**	**1.55 ± 0.03**	**1.62 ± 0.00a**	**1.55 ± 0.00b**
n-decane	1,000	0.08 ± 0.01	0.10 ± 0.00a	0.09 ± 0.00b	0.09 ± 0.01	0.09 ± 0.00	0.09 ± 0.00	0.10 ± 0.00
α-phellandrene	1,004	0.10 ± 0.00	0.09 ± 0.01	0.08 ± 0.00	0.08 ± 0.00a	0.07 ± 0.00b	0.08 ± 0.00	0.08 ± 0.00
α-terpinene	1,017	0.07 ± 0.00	0.12 ± 0.00a	0.09 ± 0.00b	0.08 ± 0.00b	0.10 ± 0.00a	0.08 ± 0.00	0.08 ± 0.00
p-cymene	1,024	0.14 ± 0.00	0.32 ± 0.01a	0.23 ± 0.00b	0.14 ± 0.00b	0.17 ± 0.00a	0.20 ± 0.00a	0.17 ± 0.00b
limonene	1,028	**4.43 ± 0.03**	**4.44 ± 0.38**	**4.32 ± 0.01**	**3.97 ± 0.14**	**3.94 ± 0.11**	**4.66 ± 0.02**	**4.68 ± 0.06**
eucalyptol	1,031	**24.17 ± 0.12**	**22.72 ± 1.77b**	**28.05 ± 0.12a**	**27.38 ± 0.12b**	**29.77 ± 0.21a**	**24.73 ± 0.08a**	**23.15 ± 0.11b**
γ-terpinene	1,036	0.14 ± 0.00	0.22 ± 0.02	0.14 ± 0.01	0.15 ± 0.00	0.16 ± 0.01	0.14 ± 0.00b	0.16 ± 0.00a
cis-Sabinene hydrate	1,058	0.24 ± 0.00	0.14 ± 0.06	0.21 ± 0.00	0.23 ± 0.00a	0.18 ± 0.00b	0.16 ± 0.00a	0.14 ± 0.00b
terpinolene	1,067	**1.61 ± 0.01**	**1.35 ± 0.12**	**1.18 ± 0.01**	**1.24 ± 0.01a**	**1.04 ± 0.02b**	**1.36 ± 0.01**	**1.37 ± 0.01**
linalool	1,100	0.35 ± 0.00	0.29 ± 0.07	0.42 ± 0.01	0.35 ± 0.01a	0.31 ± 0.00b	0.39 ± 0.01a	0.28 ± 0.00b
α-thujone	1,106	0.17 ± 0.00	0.39 ± 0.17	0.32 ± 0.00	0.09 ± 0.00b	0.13 ± 0.00a	0.09 ± 0.00a	0.00 ± 0.00b
octen-3-yl acetate 1	1,111	0.15 ± 0.00	0.14 ± 0.02a	0.04 ± 0.00b	0.09 ± 0.00	0.09 ± 0.00	0.34 ± 0.01a	0.13 ± 0.00b
β-thujone	1,116	0.00 ± 0.00	0.26 ± 0.09	0.20 ± 0.01	0.05 ± 0.00a	0.04 ± 0.00b	0.05 ± 0.00a	0.00 ± 0.00b
trans-sabinol	1,142	0.00 ± 0.00	0.97 ± 0.30	0.42 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
camphor	1,145	**43.03 ± 0.17**	**45.48 ± 0.49**	**44.24 ± 0.08**	**45.02 ± 0.49**	**44.11 ± 0.64**	**45.70 ± 0.05b**	**46.86 ± 0.00a**
borneol	1,166	**1.19 ± 0.02**	**1.05 ± 0.06a**	**0.77 ± 0.03b**	**0.93 ± 0.01a**	**0.77 ± 0.01b**	**1.18 ± 0.06**	**1.18 ± 0.01**
terpinene-4-ol	1,178	0.51 ± 0.00	0.63 ± 0.12	0.51 ± 0.00	0.49 ± 0.01	0.45 ± 0.01	0.71 ± 0.00a	0.47 ± 0.01b
cymen-8-ol p	1,186	0.23 ± 0.00	0.23 ± 0.00a	0.14 ± 0.00b	0.16 ± 0.00a	0.12 ± 0.00b	0.34 ± 0.00a	0.23 ± 0.00b
α-terpineol	1,191	0.17 ± 0.00	0.21 ± 0.02	0.16 ± 0.00	0.17 ± 0.00a	0.13 ± 0.00b	0.25 ± 0.01a	0.17 ± 0.00b
n-dodecane	1,200	0.09 ± 0.01	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.11 ± 0.00
trans-thujanol acetate	1,267	0.04 ± 0.00	0.00 ± 0.00	0.02 ± 0.02	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.01	0.06 ± 0.00
isobornyl acetate	1,287	**4.48 ± 0.08**	**3.22 ± 0.26**	**3.02 ± 0.05**	**2.93 ± 0.04a**	**1.68 ± 0.04b**	**3.17 ± 0.06a**	**2.37 ± 0.00b**
α-terpinyl acetate	1,349	0.34 ± 0.00	0.40 ± 0.04a	0.21 ± 0.01b	0.24 ± 0.00	0.21 ± 0.01	0.47 ± 0.01a	0.38 ± 0.00b
β-caryophyllene	1,425	**1.28 ± 0.01**	**0.71 ± 0.10**	**0.85 ± 0.02**	**0.95 ± 0.00**	**0.88 ± 0.03**	**0.50 ± 0.50**	**1.33 ± 0.02**
α-humulene	1,462	0.74 ± 0.00	0.33 ± 0.09	0.22 ± 0.00	0.39 ± 0.01	0.38 ± 0.01	0.31 ± 0.00b	0.39 ± 0.01a
caryophyllene oxide	1,587	0.14 ± 0.01	0.16 ± 0.07	0.00 ± 0.00	0.07 ± 0.00a	0.00 ± 0.00b	0.21 ± 0.01	0.22 ± 0.00
viridiflorol	1,594	**3.23 ± 0.09**	**2.36 ± 0.92**	**0.54 ± 0.01**	**1.55 ± 0.02a**	**0.91 ± 0.04b**	**1.49 ± 0.01**	**2.21 ± 0.02**
Total identidfied		99.74 ± 0.02	98.89 ± 0.02	99.45 ± 0.02	99.77 ± 0.01	99.73 ± 0.02	99.26 ± 0.48	99.54 ± 0.02
Monoterpenes		16.18 ± 0.05	16.44 ± 1.36	16.74 ± 0.12	15.91 ± 0.28	16.71 ± 0.47	16.53 ± 0.13	16.96 ± 0.08
Oxygenated monoterpenes		71.60 ± 0.08	73.72 ± 2.88	76.45 ± 0.13	75.98 ± 0.38	76.95 ± 0.40	74.89 ± 0.20a	73.83 ± 0.13b
Sesquiterpenes		2.02 ± 0.02	1.04 ± 0.19	1.07 ± 0.02	1.34 ± 0.01	1.26 ± 0.04	0.81 ± 0.50	1.72 ± 0.03
Oxygenated sesquiterpenes		3.37 ± 0.09	2.53 ± 0.99	0.54 ± 0.01	1.62 ± 0.02a	0.91 ± 0.04b	1.70 ± 0.00b	2.43 ± 0.02a
Others		6.56 ± 0.09	5.16 ± 0.36	4.65 ± 0.01	4.92 ± 0.06a	3.89 ± 0.00b	5.33 ± 0.08a	4.60 ± 0.03b
Yield		1.79 ± 0.04	1.56 ± 0.00a	1.22 ± 0.03b	1.60 ± 0.00a	1.22 ± 0.00b	1.89 ± 0.03	2.02 ± 0.04

The values presented are the mean (±standard error) (n = 3). Different letters indicate statistical differences ($P < 0.05$) among the treatments of the same day. The compound content greater than 1 % and the essential oil yield are highlighted in bold.

significant water loss through transpiration is the high ratio of surface to volume along with the numerous stomata on the surface of leafy vegetables [46]. Compared to other herbs like spearmint, mint, and basil, sage has smaller leaves meaning smaller leaf surface area, and this could partially explain the lower water loss observed in this study compared to other studies investigating spearmint and/or mint [43, 46]. To prevent excessive water loss and minimize quality losses, it is advised to maintain the RH of the storage room at the same levels as the vegetable's moisture content [28].

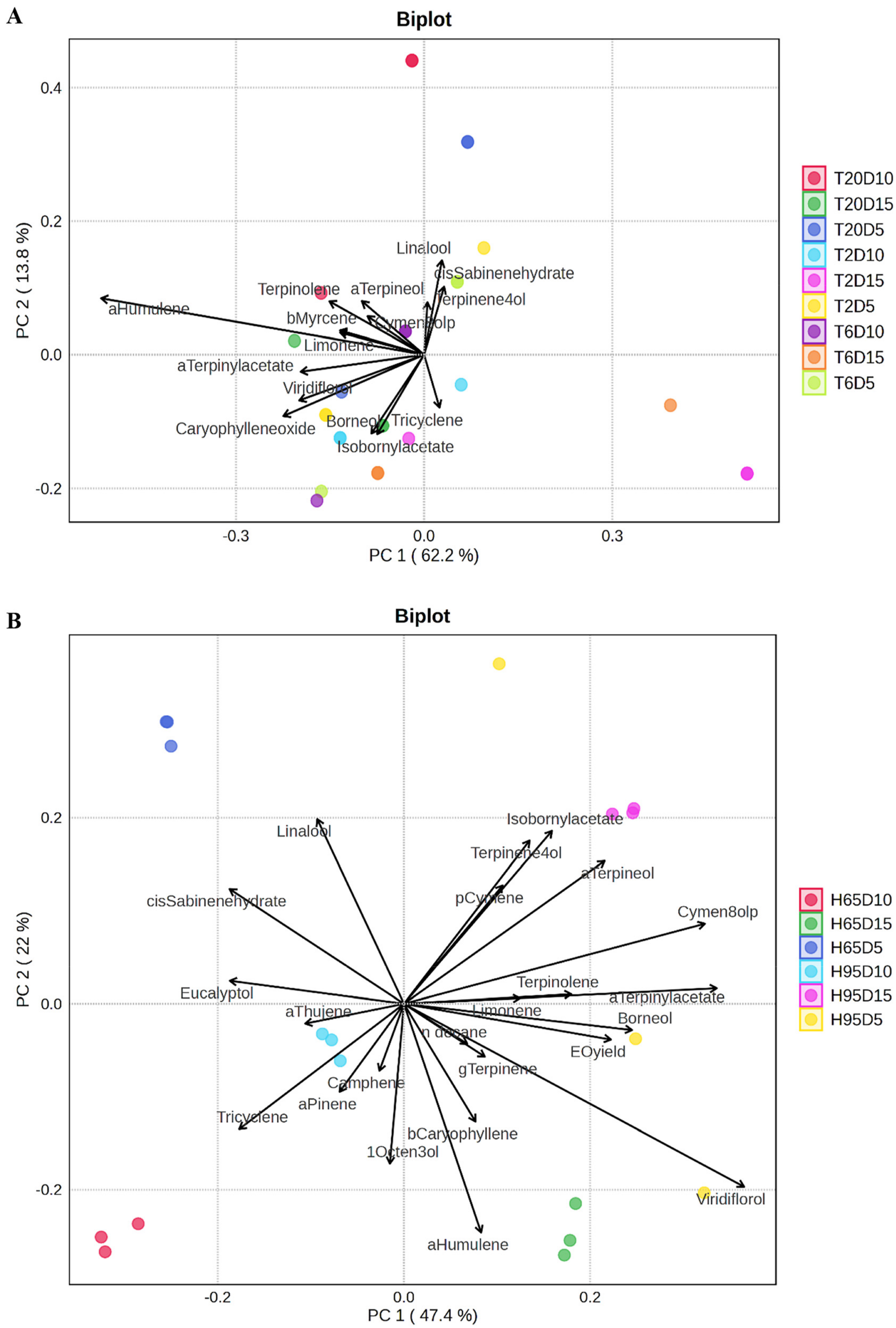

Figure 8: Loading plot of principal components 1 and 2 for (A) temperature (T: at 2, 6 and 20 °C) and (B) humidity (H: at 65 and 95 %) factors during storage period (day 5, 10, and 15 as D5, D10 and D15, respectively).

Quality is by default the set of attributes that render a product appealing to consumers [47]. Enhanced respiration, ethylene production during storage or packaging, and mechanical injury (during harvest and/or processing) can all hasten the development of decay signs (such as leaf yellowing/browning, surface scald) [48]. Furthermore, minimizing leaf degradation and preserving the quality of leafy greens depend on managing the decomposition of proteins and chlorophylls, which are typical signs of senescence [49]. Throughout the senescence process, pigments such as chlorophylls and carotenoids decompose, resulting in leaf yellowing and/or browning [43]. A less marketable (i.e. darker/brownish leaves) product was observed during storage of fresh sage at 20 °C, while storage of fresh sage under atmospheric RH also resulted in a less marketable product. Higher water loss (due to increased respiration and transpiration) has been associated with greater color abnormalities, especially at higher temperatures and lower RH, due to the coagulation of lipoproteins and the loss of chlorophyll's green color [28]. Delaying the oxidation of chlorophylls by managing the storage conditions is the primary strategy for preventing the development of browning in leafy greens [50]. Another factor related to the browning of leaves is the activity of enzymes such as phenylalanine ammonia lyase (PAL) and polyphenol oxidase (PPO) [51], with the former being involved in the synthesis of phenolic compounds as a response to various environmental stimuli, while the latter catalyzes the oxidation and polymerization of polyphenols, resulting in brown/black pigmented compounds like o-quinones [52].

Culinary herbs, especially sage, are considered as good providers of phytochemicals such as antioxidants. Multiple studies have demonstrated that a diet containing polyphenols may possess preventive and/or protective benefits against chronic diseases, including cancer, heart problems, and neurological disorders, among others [53]. According to the findings of the present study, sage stored at 2 and 6 °C presented higher phytochemical content (phenols, flavonoids, AA, and antioxidant activity), which enhanced the nutritive value of the product. In addition, increased phenolic content, AA content, and antioxidant activity were observed in the case of atmospheric RH, while total flavonoids remained unaffected. Sage naturally contains high levels of non-enzymatic (phenols, flavonoids) and enzymatic antioxidant molecules (catalase, ascorbate peroxidase etc.) that are triggered to mitigate oxidative stress [54]. Postharvest treatments that enhance these natural antioxidant systems can prolong shelf life and preserve quality. As previously stated, storage under unfavorable conditions such as high temperature and/or low RH could ignite processes such as enzymatic activity that could lead to the oxidation of polyphenols and the formation of colorless o-diphenols which then form brown colored polymers [50]. This could partially explain the lower phenolic content and antioxidant activity observed in the current study during the storage of fresh sage at 20 °C and under atmospheric RH. These observations were also reported by Sun et al. during the postharvest storage of baby mustard under low and high storage temperatures (4 and 20 °C), where low temperatures delayed the loss of polyphenols and the antioxidant capacity of the product investigated [55]. These findings along with the current research are further supported by the fact that low temperatures (0–5 °C) slow down the activity of PPO, thus controlling enzymatic browning [56, 57]. However, leaf browning could also occur due to non-enzymatic processes such as AA degradation and/or microbial activity.

The microbial load of fresh food is a major determinant of its shelf life. If a product has a moderate microbiological load while being kept at high relative humidity, its shelf life will be greatly reduced [48]. Lower TVC numbers were found at 6 °C (during the first days), while those numbers rose along with yeasts and molds at the end of storage. On the other hand, storage under atmospheric RH showed higher TVC and yeasts and molds populations on the first days, while those numbers were reduced on the last day. The increase in phytonutrients such as phenols, flavonoids, and AA can explain the decrease in microbial load of endophytes, which preserve the fresh produce. The increase in antioxidants as a part of the plant's defense mechanisms due to "eustress" could have lowered the microbial load of fresh sage due to the antimicrobial activity of these compounds [53]. In addition, the inherent antimicrobial activity of herbs such as sage and rosemary also contributes to the lower microbial load, which aids the extension of the shelf life of these fresh products [34]. It has been previously shown that fresh produce with a high microbial load is more susceptible to quality deterioration including leaf browning due to the activity of spoilage microorganisms such as *Pseudomonas* spp. compared to those with a lower microbial load [58, 59]. Thus, storage at lower temperatures like 2–5 °C alone or in combination with other means (so called "hurdle technology") contributes to the preservation of fresh produce including fresh herbs by delaying the microbial activity.

Essential oils (EOs) are a primary product of medicinal aromatic plants. While EOs are insoluble in water, they dissolve in practically all organic solvents. Among their main components are hydrocarbons, ketones, aldehydes, alcohols, ethers, esters, and oxides [60]. They include components with strong biocidal activities, including antioxidant and antibacterial qualities. The presence of secondary metabolites formed by plants is necessary for the EOs biological activity [61]. Sage stored at 6 °C and under high RH presented higher

EO yield. The main EO's components in the present study were camphor, eucalyptol, camphene, α-pinene, and limonene, being in agreement with previous studies [7, 11]. Interestingly, almost all of the EO's major components remained unaffected throughout the storage, whereas higher camphor content was found in sage stored at 2 and 6 °C. Increased camphor and eucalyptol levels are of great importance due to the well documented antifungal, antioxidant [12, 62], anti-inflammatory [3] and anticancer properties [14]. On the other hand, lower camphor levels were observed on the last day storage with high RH, while eucalyptol was found reduced at high RH on the first days. Since sage belongs to the Lamiaceae family, its EO is stored on the leaf surface, which could easily be released when exposed to high storage temperatures due to water movement (i.e. respiration/transpiration) [63]. The findings of the current research could be further explained by the lower ratio of leaf surface to volume, as sage's leaves are smaller and thicker compared to other herbs with higher leaf area such as basil, that lose water to a greater extent [46]. This means that evaporation of water along with volatile compounds is controlled at lower storage temperatures preserving the EOs quality of herbs during their postharvest storage. Having these observations in mind, one could further support the above findings of lower microbial load due to the antimicrobial activity previously shown by compounds such as camphor and eucalyptol [12].

5 Conclusions

The current work assessed the effects of various temperatures (2, 6, and 20 °C) and relative humidity (RH) levels (atmospheric and high, 65 and 95 % respectively) on the quality characteristics of fresh sage during postharvest storage in an attempt to select the optimum conditions for the postharvest storage of this herb. From the results, it was found that lower temperatures and high RH led to lower weight loss and respiration rates. An increase in phenols, flavonoids, ascorbic acid, and antioxidant activity was reported during storage at 2 and 6 °C (at a high RH level), whereas atmospheric RH and 6 °C also presented higher phenolic and ascorbic acid content, and antioxidant activity. Higher temperature (20 °C) resulted in higher microbial load (TVC, yeasts and molds) compared to lower temperatures. In addition, storage temperature also affected sage's essential oil yield as higher yield was found in plants stored at 6 °C. Sage's EO major compound was also found at higher levels at this temperature. From these observations, it could be concluded that postharvest storage of fresh sage at 6 °C and high RH could evidently contribute to the preservation of this produce. The high moisture during storage can be achieved by placing the sage in packaging material (bags or containers) with semi-transparent properties, controlling the exchange of humidity and/or air composition. Under commercial storage of 6 °C instead of 2 °C. Following the optimization of storage temperature and storage relative humidity, future studies could employ common postharvest preservation means, including but not limited to ozone, electrolyzed water, chitosan, salts and 1-Methylcyclopropene for ethylene and respiration rates slowing down as well as preservation against postharvest pathogens.

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