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The current study aimed to explore low-cost, non-toxic, and efficient natural potato tuber suppressants. The sprout suppression properties of rosemary essential oil and coriander seed extract were assessed, and the quality of potato tubers was evaluated during storage for 12 weeks at 20 and 30°C. The sprouting rate and weight loss as well as contents of soluble sugar, starch, malondialdehyde (MDA) and hydrogen peroxide ($H_2O_2$) were determined. Additionally, the ferric-reducing antioxidant power (FRAP) and DPPH radical scavenging activity of the tubers was evaluated. The activities of catalase (CAT), peroxidase (POD), polyphenol oxidase (PPO), ascorbate peroxidase (APX), ascorbate oxidase (ASO), and their corresponding substrates of ascorbic acid (AsA), total phenolics (TPC), and total flavonoids (TFC) were also measured to determine if they depleted over the storage period. Both rosemary essential oil and coriander seed extract hindered sprouting up to 8 weeks post-treatment for tubers stored at 20°C. This was demonstrated by lower values of sprouting and weight loss at the end of the storage period. Specifically, when rosemary essential oil was used, and the tubers were stored at 20°C, there was an increase in starch content, a decrease in sugar content, an enhancement in the levels of DPPH, FRAP, AsA, TPC, and TFC, while the levels of CAT, POD, PPO, APX, ASO, MDA, and $H_2O_2$ were decreased. The results highlight the potency of rosemary essential oil treatment in delaying sprouting and preserving the fresh appearance, starch content, and antioxidants of stored potato tubers, which are crucial indicators of their quality.

**Keywords:** Potato, Temperature, Sprouting, Antioxidants, Rosemary, Coriander

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## INTRODUCTION

Potato tuber (*Solanum tuberosum* L.) is the fourth most important crop after maize, wheat, and rice worldwide for human consumption (FAO, 2019). The demand for potato production has increased as it has proven to meet the four fundamental criteria for food security: availability, quality, accessibility, and stability. Its starch content, high-quality protein, essential vitamins, particularly vitamin C, minerals, and very low-fat content contribute to maintaining a balanced diet and improving human health (Burgos et al., 2020). Improved potato storage and processing techniquees can enable farmers to produce and market potato products with added value, resulting in a highly profitable cash crop that can sustain livelihoods and promote economic growth. Egypt ranks among the top 20 global potato producers and is the second-largest potato producer and exporter in Africa (Rabia, 2016). However, the issue of potato sprouting during storage poses a significant economic challenge, resulting in substantial economic losses (El-Sherbiny et al., 2017). Globally, approximately 25% of the overall global production may be lost due to sprouting during storage, especially when potatoes are stored in hot and humid climates, frequently observed in developing countries like Egypt.

It is imperative to regulate sprouting during storage to avoid deterioration in tuber quality and solanine formation, making potatoes green and inedible (Zhang et al., 2018). Even without greening, sprouting is undesirable for potato tubers (Stark et al., 2020) as it causes weight loss, softening, and shrinkage. Consequently, it leads to changes in the nutritional and texture levels of tubers used for fresh consumption and processing (Paul et al., 2016b). In addition, sprouting leads to cellular damage and promotes the breakdown of starch. This results in senescent sweetening and browning of potatoes after frying for potato cultivars, particularly those intended for processing (Wiberley-Bradford & Bethke, 2017). Therefore, starch serves as a crucial metric for assessing the processing quality of potatoes and their derivatives. It is also important to consider the sugar content of potato tubers, as they play a significant role in the Maillard reaction and the formation of acrylamide during processing (Kumar, 2011). Furthermore, oxidative stress is induced by metabolic changes during potato postharvest storage, involving ROS production and loss of cell membrane integrity. These modifications impact the tubers' antioxidant capacity and antioxidant contents, including total phenolics and vitamin C (Rezaee et al., 2011). Therefore, it is crucial to restrict the growth of sprouts to preserve the nutritional and processing qualities of potato tubers during storage, especially if they are intended for fresh consumption and processing.

Different methods have been used for sprouting management in various parts of the world, but they all have certain limitations. Cold-temperature storage is the most efficient and commonly employed technique for maintaining the quality of processed potatoes during extended periods of storage (Magdalena & Dariusz, 2018). Nevertheless, cold-temperature storage may not be adequate for processing due to cold-induced sweetening, which results in dark fry, affecting the quality of the potato product (Hou et al., 2017). An alternative method to prevent sprouting is the use of chemical sprout suppressants (Paul et al., 2016b). Chlorpropham or CIPC (Nurit et al., 1989), 1,4-dimethyl naphthalene (Campbell et al., 2012), maleic hydrazine (De Blauwer et al., 2012), and 3-decen-2-one are among the most frequently utilized methods (Visse-Mansiaux et al., 2021). However, some of these products have demonstrated toxic environmental and consumer health properties (CIPC). Consequently, various governments, including the European Commission in 2019, have banned these products (European Commission, 2019). Physical approaches such as microwave, gamma, and ultraviolet irradiations are another novel method of sprout suppression, but they are expensive (Boivin et al., 2020). Therefore, the application of natural products to control sprouting and prolong the storage life of perishables has recently garnered significant interest due to their cost-effectiveness and environmentally friendly nature.

Efforts have been made to investigate the efficacy of certain compounds, such as essential oils, as potent anti-suppressants for potatoes. Due to their organic source and biodegradability, these compounds are both safe for human consumption and environmentally friendly (Santos et al., 2019). The bioactivities of these oils in restricting potato tuber sprouting are primarily attributed to the enrichment of monoterpene compounds (Gómez-Castillo et al., 2013; Finger et al., 2018). However, there are significant barriers to the widespread use of these products in potato storage due to their impact on sprouting, which varies with storage temperature, cultivar, and treatment technique. Therefore, the aim of the present study was to evaluate the sprout-suppressive capability of some monoterpene-containing essential oil products as coriander (*Coriandrum sativum* L.) seeds and rosemary (*Rosmarinus officinalis* L.) for potato tubers (cultivar Barcelona). The study focused on the impact of these oils on morphophysiological parameters and antioxidant capacity, which are significant parameters for the validity of potato tubers during storage.

## MATERIALS AND METHODS

### Experimental design

The experiment was conducted using a completely randomized design at the Department of Botany, Faculty of Science, Ain Shams University, Egypt. The potato tubers of cultivar Barcelona were obtained from the Agriculture Research Center, Giza, Egypt. Tubers of comparable size and shape were carefully washed and then air-dried before treatments. Pulverized coriander seeds (200 g) were mixed with 1 L of ethanol (95%) in flasks. The flasks were kept in an ultrasonic cleaner (Kunshan-500B) for one minute to boost solubility and then kept in laboratory conditions for 20 hours. After filtration, ethanol was evaporated using a rotary evaporator. The obtained extract was adjusted with distilled water to approximately 5% and kept in glass bottles at 5°C until usage. An emulsion (10%) of rosemary extract was prepared by diluting crude rosemary oil in distilled water with 0.05% ethanol as an emulsifier. The freshly harvested tubers were grouped into three groups: the first was sprayed with coriander extract, the second with rosemary extract, and the third was utilized as a control. Each group of untreated and treated potatoes was divided into two subsets, then packed in small paper boxes and stored in two controlled incubators at 20°C and 30°C, respectively. Three replicates of samples were collected at 0, 2, 4, 6, 8, 10, and 12 weeks of storage for analysis.

### Determination of sprouting and weight loss

The tuber sprouting was evaluated following the methodology outlined by Murigi (2016). Tubers were considered sprouted once they exhibited a visible sprout measuring at least 3 mm in length. The sprouting was calculated as a percentage based on the number of sprouted tubers relative to the total number per sample. The sprout length (SPL) was measured in centimeters (cm) per sample at different intervals. The weight loss percentage (WT loss) during postharvest storage was determined according to Mattiuz et al. (2009) by weighing the initial weight of the tubers at a 6-week interval during the storage period and calculated according to the following equation:

$$\text{WT loss (\%)} = ((Wi - Ws)/Wi) \times 100$$

Where Wi = initial weight, Ws = weight at examined time.

**Extraction and estimation of total soluble sugar, sucrose, and starch contents**

The extraction of soluble sugars was carried out according to Prud'homme et al. (1992). A known weight of fresh tissue was mixed and boiled with 10 ml of 80% (v/v) ethanol, then cooled and filtered. The filtrate was oven-dried at 60°C. The remaining was dissolved in a known volume of water and used for soluble sugar determination. The residue was oven-dried for a minimum of 48 hours at 80 °C, and its dry weight was accurately determined, then kept for starch determination. The total soluble sugar and sucrose contents were estimated according to those described by Blakeney & Mutton (1980) and Hubbard & Pharr (1992), respectively, and calculated as µg/g fresh weight. The starch content was determined by the method of Thayermanavan & Sadasivam (1984) and calculated as µg/g dry weight.

**Estimation of malondialdehyde (MDA)**

Heath & Packer's (1968) approach was used to determine the lipid peroxidation product, MDA. A known fresh weight, which had been homogenized in water, was combined with an equal volume of a 0.5% solution of thiobarbituric acid containing 20% trichloroacetic acid. The mixture was heated to 95 ℃ for 30 min, then immediately chilled in an ice bath before centrifuging at 3000×g for 5 minutes. The supernatant's absorbance was measured at 532 and 600 nm (Spectronic 601, Milton Roy Company). The results were expressed in nmol / g fresh weight.

**Estimation of hydrogen peroxide ($H_2O_2$)**

The hydrogen peroxide ($H_2O_2$) content was measured using the methodology developed by Velikova et al. (2000). A known fresh weight was homogenized with 0.1% trichloroacetic acid in an ice bath. Subsequently, 1 ml of 1 M KI and 0.5 ml of 10 mM potassium phosphate buffer (pH 7.0) were added to 0.5 ml of the supernatant. At 390 nm, the absorbance was measured (Spectronic 601 from Milton Roy Company), and the $H_2O_2$ content was expressed as mM/g fresh weight.

**Estimation of ascorbic acid (AsA)**

Ascorbic acid (AsA) was measured using the Mukherjee & Choudhuri (1983) method. Ten g of fresh tissue was extracted using 10 ml of 6% trichloroacetic acid. A solution of 1 ml of extract and 2 ml of 2% dinitrophenyl hydrazine was added to an acidic medium, followed by one drop of 10% thiourea (in 70% ethanol). The solution was heated to its boiling point for a duration of 15 minutes using a water bath. Subsequently, at a temperature of 0°C in an ice bath, 5 ml of 80% (v/v) $H_2SO_4$ were added. Spectronic 601 Milton Roy Company was used to test the absorbance at 530 nm. The resultant quantity of AsA was expressed as mg AsA/g fresh weight.

**Estimation of total phenolic content (TPC)**

Makkar et al. (1993) protocol was used for total phenolic content determination. Subsequently, 0.5 g of dry weight was extracted with 80% cold methanol (v/v). Approximately 1 ml of the extract was mixed with 0.5 ml of Folin-Ciocalteau reagent and stood for 3 min. A volume of 1 ml of saturated sodium carbonate solution (20% $NaCO_3$) was added to the mixture and then allowed to stand for 1 hour. The absorbance was read at 725 nm (Spectronic 601, Milton Roy Company). The concentration of total phenols was calculated from the standard curve of gallic acid and expressed as mg/g dry weight.

**Estimation of total flavonoid content (TFC)**

Flavonoids in the methanolic extract were quantified using the aluminum chloride colorimetric method (Chang et al., 2002). A 0.5 g of dry weight was extracted with 80% cold methanol. About 0.5 ml of methanolic extract was diluted in distilled water (1.5 ml) and mixed with 10% aluminum chloride (0.5 ml), 1 M potassium acetate (0.1 ml), and distilled water (2.8 ml). The mixture was then incubated at room temperature for a duration of 30 min. The absorbance of the resulting reaction mixture was measured at 415 nm (Spectronic 601, Milton Roy Company). The quantification of total flavonoids was done based on a standard curve of quercetin prepared in 80% methanol. The results were expressed in mg quercetin equivalent/g dry weight.

**DPPH radical scavenging assay**

The extract's DPPH radical scavenging activity was assessed according to the method described by Hatano et al. (1988). Subsequently, 1 ml of methanolic extracted samples was added to 0.5 mL of methanolic DPPH (2,2-diphenyl-1-picrylhydrazyl) solution. The mixture was incubated in the dark for 30 min and then measured at 517 nm (Spectronic 601, Milton Roy Company). The results were calculated using the following equation:

$$\text{DPPH radical scavenging (\%)} = (A_{DPPH} - A_{sample}) / A_{DPPH} \times 100$$

Where $A_{DPPH}$ is the absorption of the DPPH control solution against the blank of solvent, and $A_{sample}$ is the

absorption of the extract against the blank of sample solution.

**Ferric reducing antioxidant power (FRAP) assay**

FRAP was carried out according to the method described by Oyaizu (1986). A known fresh weight was extracted with methanol/chloroform (2:1). 0.5 ml of extract was mixed with 1.25 ml of 0.2M sodium phosphate buffer (pH 6.6) and 1.25 ml of 1% potassium ferricyanide. The reaction mixtures were incubated in a water bath at 50°C for 20 min, followed by 1.25 ml of 10% trichloroacetic acid, then centrifuged for 10 min at room temperature. Approximately 1.25 ml of supernatant was mixed with 1.25 ml of deionized water and 0.25 ml of 0.1% $FeCl_3$. The absorbance was measured at 700 nm (Spectronic 601, Milton Roy Company). Ascorbic acid was used as a standard curve, and the results were expressed as mg/g fresh weight.

**Extraction and assaying activity of certain antioxidant enzymes**

First, 10 g of fresh tissue was ground in liquid nitrogen and extracted by extraction media: 100 mM potassium phosphate buffer (pH 7.8), 0.1 mM EDTA, 1% PVP, and 0.1% Triton X 100. The homogenates were centrifuged at $20000_{\times g}$ for 20 min. Then, the supernatant was adjusted to a known volume to assay the activity of certain enzymes. Catalase activity (CAT; EC 1.11.1.6) was assayed according to the method of Aebi (1984) and expressed in units ($Ug^{-1}$ FW). One unit of enzyme activity was defined as the amount of enzyme that reduced 50% of $H_2O_2$ in 1 min at 25ºC (Kong et al., 1999). Polyphenol oxidase (PPO; EC 1.10.3.1) and peroxidase activities (POD; EC 1.11.1.7) were assayed following the method described by Kar & Mishra (1976), and the enzyme activity was expressed in units ($Ug^{-1}$ FW). Ascorbate peroxidase (APX; EC 1.11.1.11) and ascorbate oxidase (ASO; EC 1.10.33.3) activities were measured using the methods of Koricheva et al. (1997) and Diallinas et al. (1997), respectively, and expressed as mM/g fresh weight/min.

**Statistical analysis**

A one-way analysis of variance (ANOVA) was performed using the software package SPSS v20.0 (SPSS Inc., Chicago, USA). The statistical significance of the means was assessed using Duncan's test with a significance level of $P \leq 0.05$. Furthermore, Pearson's correlation was conducted at significance levels of 1% and 5% to examine the relationship between various parameters.

## RESULTS

**Sprouting, sprout length (SPL), and weight (WT) loss**

Figure 1 depicts the relation between storage time and sprouting, specifically for untreated tubers stored at 30°C. These tubers showed the most significant increase in sprouting throughout the entire storage period. The treatment of tubers with either rosemary or coriander inhibited sprouting until the end of the seventh week of the storage period compared with the untreated control (Figure 2a). Sprouting began on the eighth week for tubers treated with rosemary at a temperature of 20°C. These tubers had the lowest amount of sprouting throughout the storage period (36.0%), followed by tubers treated with coriander (41.1%), compared to untreated tubers at the same temperature (Figure 2a). As storage time increases, the sprout length increases, particularly for untreated tubers stored at 30°C. These tubers displayed the highest sprout length values until the end of the storage time (Figure 2b). In contrast, rosemary-treated tubers stored at 20°C recorded the lowest sprout length, followed by coriander-treated ones, compared with untreated tubers at the same temperature (Figure 2b). A storage period of 6 weeks resulted in a reduction in the weight of the untreated stored tubers, particularly at 30°C (Figure 2c). However, treatments with either rosemary or coriander significantly reduced weight loss compared with untreated ones. At the end of the storage period, the lowest weight loss was detected in rosemary-treated tubers stored at 20°C (Figure 2c).

**Total soluble sugar (TSS), sucrose, and starch contents**

According to the results, the TSS levels showed a gradual increase from the fourth week until the end of storage. This increase was particularly notable in untreated tubers stored at 20 and 30°C (Figure 3a). The untreated tubers kept at 30°C reached the highest level of TSS by the end of the storage period. However, the minimum TSS level was recorded in rosemary-treated tubers kept at 20°C at the same temperature (Figure 3a). Both untreated and treated potatoes exhibited a comparable trend in sucrose content in response to the temperatures studied during the storage period (Figure 3b). Conversely, the starch content of untreated tubers stored at temperatures of 20 and 30°C exhibited a consistent

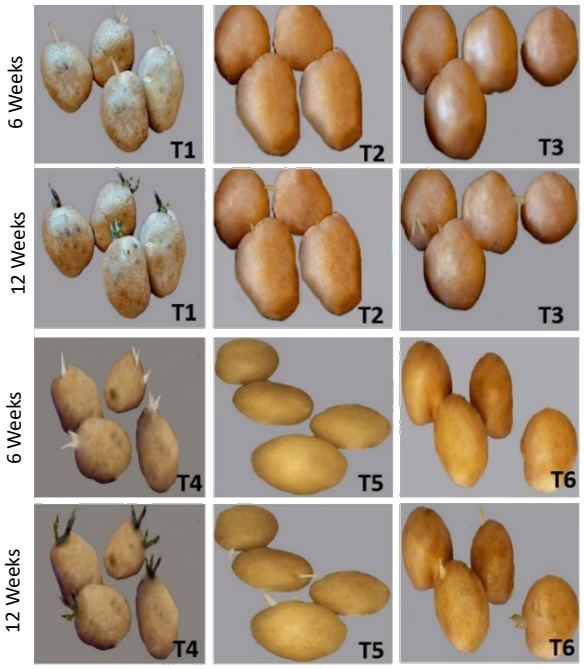


**Figure 1.** Effect of storage temperature (20°C and 30°C) and treatments with either rosemary or coriander extracts on sprouting of potato tubers at 6 and 12 weeks of postharvest storage. T1: untreated tubers at 20°C; T2: rosemary-treated tubers at 20°C; T3: coriander-treated tubers at 20°C; T4: untreated tubers at 30°C; T5: rosemary-treated tubers at 30°C; and T6: coriander-treated tubers at 30°C.

decline starting in the fourth week and persisting until the end of the storage period (Figure 3c). However, compared to the untreated tubers, the application of either coriander or rosemary considerably preserved the starch content of the treated potatoes, especially those maintained at 20°C (Figure 3c).

### Contents of malondialdehyde (MDA) and hydrogen peroxide ($H_2O_2$)

The untreated potato tubers exhibited substantial increases in MDA content from the sixth week until the end of the experimental period. During the same period, tubers treated with either rosemary or coriander showed a decrease in MDA content compared to untreated tubers (Figure 4a). By the end of the storage period, untreated tubers stored at 30°C showed the highest increase in MDA levels, followed by those stored at 20°C (21.9 nmol/g and 15 nmol/g), respectively. The tubers treated with rosemary and stored at 20°C exhibited the lowest MDA content, with a value of 7.5 nmol/g (7.5 nmol/g) (Figure 4a). During the storage period, both treated and untreated tubers showed a similar pattern in the $H_2O_2$ level in response to two temperatures under study (Figure 4b). At the end of the storage period, while untreated

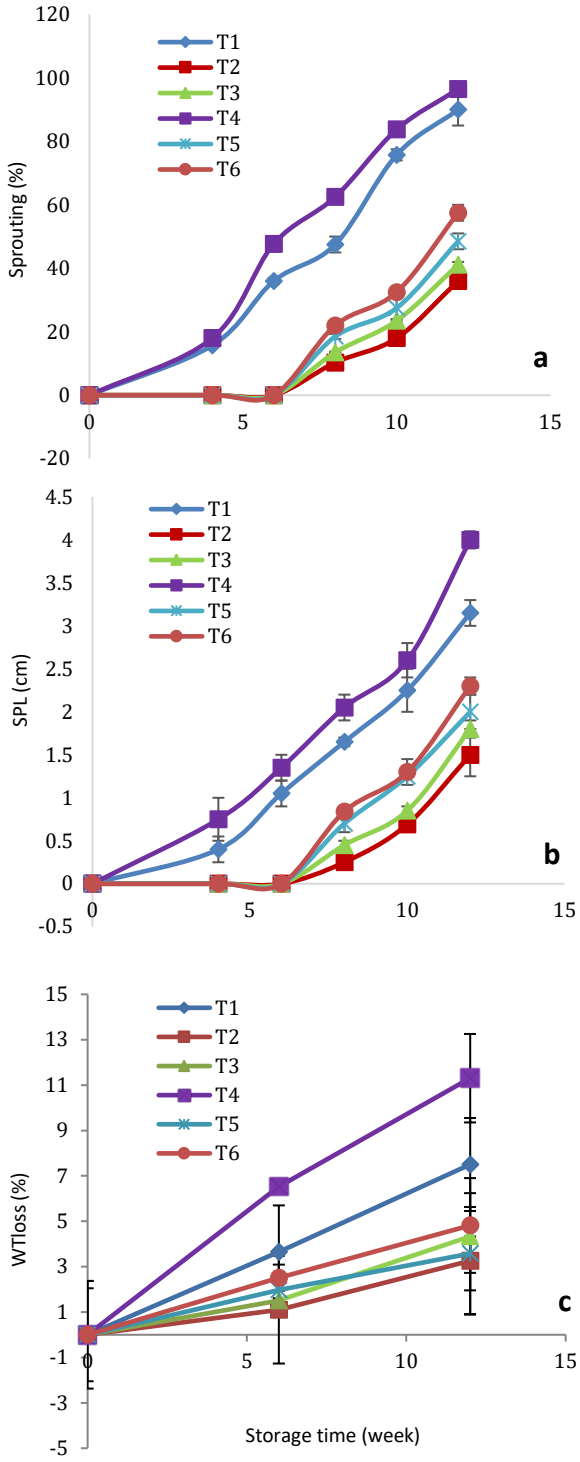


**Figure 2.** Effect of storage temperature (20°C and 30°C) and treatment with either rosemary or coriander extracts on a) sprouting percentage, b) sprout length (SPL), and c) weight (WT) loss of potato tubers for 6 and 12 weeks of postharvest. T1: untreated tubers at 20°C; T2: rosemary-treated tubers at 20°C; T3: coriander-treated tubers at 20°C; T4: untreated tubers at 30°C; T5: rosemary-treated tubers at 30°C; and T6: coriander-treated tubers at 30°C. Vertical bars show the ±SE of means (n = 3).

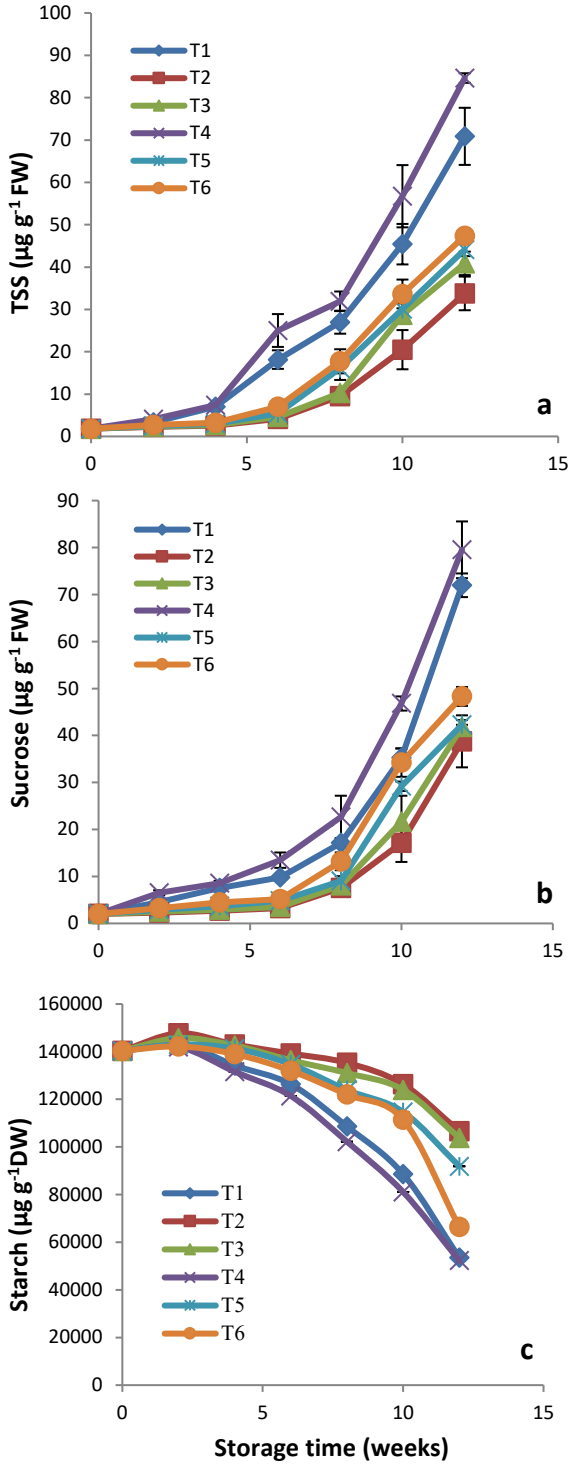


**Figure 3.** Effect of storage temperature (20°C and 30°C) and treatments with either rosemary or coriander extracts on a) total soluble sugar (TSS), b) sucrose, and c) starch contents of potato tubers for 12 weeks of postharvest. T1: untreated tubers at 20°C; T2: rosemary-treated tubers at 20°C; T3: coriander-treated tubers at 20°C; T4: untreated tubers at 30°C; T5: rosemary-treated tubers at 30°C; and T6: coriander-treated tubers at 30°C. Vertical bars show the ±SE of means (n=3).

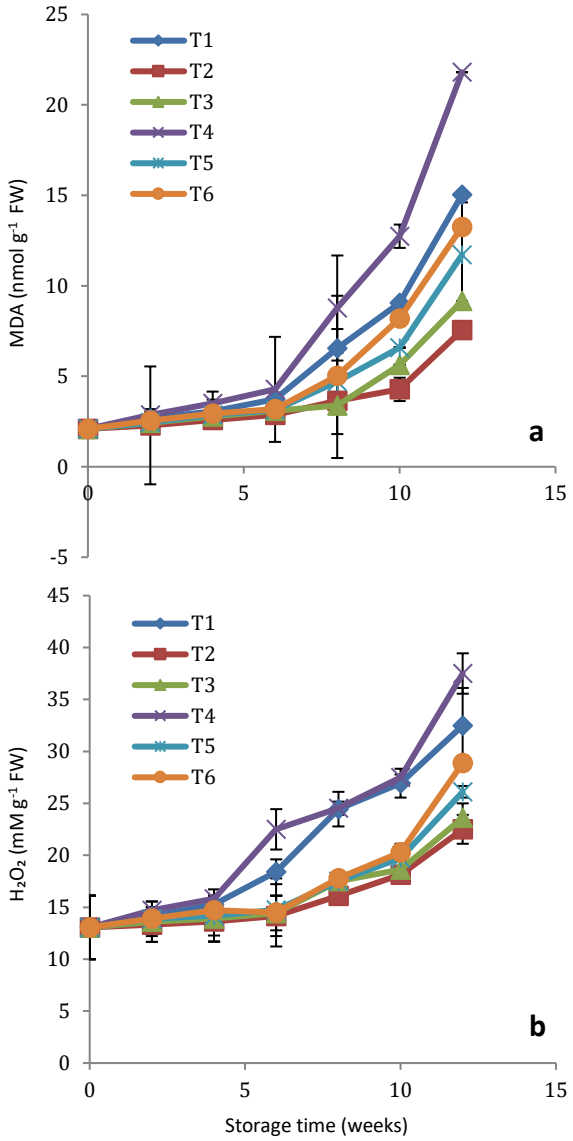


**Figure 4.** Effect of storage temperature (20°C and 30°C) and treatments with either rosemary or coriander extracts on a) malondialdehyde (MDA) content and b) hydrogen peroxide ($H_2O_2$) content of potato tubers for 12 weeks of postharvest. T1: untreated tubers at 20°C; T2: rosemary-treated tubers at 20°C; T3: coriander-treated tubers at 20°C; T4: untreated tubers at 30°C; T5: rosemary-treated tubers at 30°C; and T6: coriander-treated tubers at 30°C. Vertical bars show the ±SE of means (n=3).

tubers kept at 30°C recorded the highest $H_2O_2$ value (37.5 mM/g), rosemary-treated tubers maintained at 20°C recorded the lowest $H_2O_2$ value (22.5 mM/g) (Figure 4b).

### Ascorbic acid (AsA), total phenolics (TPC), and total flavonoids (TFC)

The results showed a gradual decrease in the AsA levels of all samples stored at 20°C and 30°C over time (Figure 5a). Nevertheless, exposure of potato tubers

to either rosemary or coriander extract retarded the reduction of AsA contents compared with untreated ones. The tubers treated with rosemary, specifically those stored at a temperature of 20°C, showed the highest level of AsA (18.2 mg $g^{-1}$) at the end of the storage period (Figure 5a). The results also demonstrated initial increases in total phenol and flavonoid contents of untreated stored tubers, followed by a significant decrease until the end of the storage period (Figure 5b and c). Furthermore, the TPC and TFC of the treated tubers, particularly those stored at a temperature of 20°C, were maintained by applying either rosemary or coriander after harvest (Figure 5b and c).

**Antioxidant capacity (DPPH and FRAP)**

The DPPH radical scavenging activities exhibited a gradual increase until the 6$^{th}$ week for untreated potatoes and until the 10$^{th}$ week for treated potatoes. Subsequently, there was a sharp decline in scavenging activities until the end of the storage period. However, both rosemary and coriander-treated tubers exhibited higher DPPH at the same conditions compared with untreated ones (Figure 6a). At the end of storage, potatoes treated with rosemary at 20°C had the highest DPPH value, coming in at around 63.9%, followed by potatoes treated with coriander at the same temperature (59.1%) (Figure 6a). A similar pattern was observed in FRAP levels in stored-untreated and treated tubers at both studied temperatures. The effects were more pronounced for the treatment with rosemary than coriander and at a temperature of 20°C than 30°C (Figure 6b).

**Antioxidant enzyme activities**

The catalase activity exhibited a progressive increase in all samples over a period of 12 weeks of storage (Figure 7a). The treatments with rosemary and coriander extracts markedly retarded the observed increases from the 4$^{th}$ week until the end of the storage period. The highest level of CAT activity was observed in untreated tubers stored at 30$^{o}$C, with a value of 1.31 $Ug^{-1}$ FW. In contrast, the lowest level of CAT activity was found in rosemary-treated tubers stored at 20$^{o}$C, with a value of 0.69 $Ug^{-1}$ FW, at the end of the storage period (Figure 7a).

At both temperatures under investigation, potatoes left untreated showed increased PPO activity; however, the application of rosemary and coriander extracts retarded it (Figure 7b). By the end of the storage period, the PPO activity in the tubers treated with rosemary and coriander at 20°C showed the lowest values (0.55 and 0.59 $Ug^{-1}$ FW, respectively). However, the untreated tubers at 30°C (1.36 $Ug^{-1}$ FW) showed the highest PPO activity (Figure 7b).

As shown in figure 7c, POD activities increased gradually with the progression of storage time at both studied temperatures. However, treatment with either rosemary or coriander reduced such increments, particularly at 20°C (Figure 7c). At the end of the storage period, the activity of POD in rosemary and coriander-treated tubers at 20°C recorded the lowest levels (24.1 and 25.9 $Ug^{-1}$ FW, respectively). Conversely, untreated potatoes stored at 30°C recorded the highest level of POD activity (38.06 $Ug^{-1}$ FW) (Figure 7c).

Significant increases in the APX activity of untreated and treated potatoes were observed at both storage temperatures throughout the storage period (Figure 7d). At the end of storage time, the highest value of APX activity was recorded in control tubers stored at 30°C (1.15 mM $g^{-1}$ FW). However, the lowest value was recorded in rosemary-treated ones at 20°C (0.76 mM $g^{-1}$ FW) (Figure 7d).

Results indicated that ASO activity increased markedly from the sixth week until the end of storage time for all treatments (Figure 7e). The highest activity of ASO was recorded in untreated tubers stored at 30°C (32.3 $mMg^{-1}$ FW). However, rosemary-treated tubers stored at 20 °C showed the lowest activity of ASO (12.45 mM $g^{-1}$ FW) (Figure 7e).

**Correlation between physicochemical traits**

Table 1 shows substantial positive correlations between the sprouting process, SPL (r=0.99**), TSS (r=0.95**), $H_2O_2$ (r=0.97**), MDA (r=0.9**), and WT loss (r=0.81**), as well as the antioxidant enzymes; CAT (r=0.97**), POD (r=0.94**), PPO (r=0.95**), APX (r=0.95**), and ASO (r=0.88**). Conversely, sprouting, starch (r=0.95**), ASA (r=0.94**), TPC (r=0.67**), and DPPH radical scavenging activity (r=0.46**) exhibited a considerable negative correlation.

## DISCUSSION

In the present study, sprouting was accelerated in the control tubers stored at 30°C two weeks earlier than at 20°C. This finding is consistent with several reports by Matar et al. (2012), Tavakoli et al. (2014), and Draie & Abdul-Mohsen (2021), who demonstrated that elevated temperatures accelerate sprouting and increase sprout length. However, the delayed sprouting until the eighth week of storage, along with

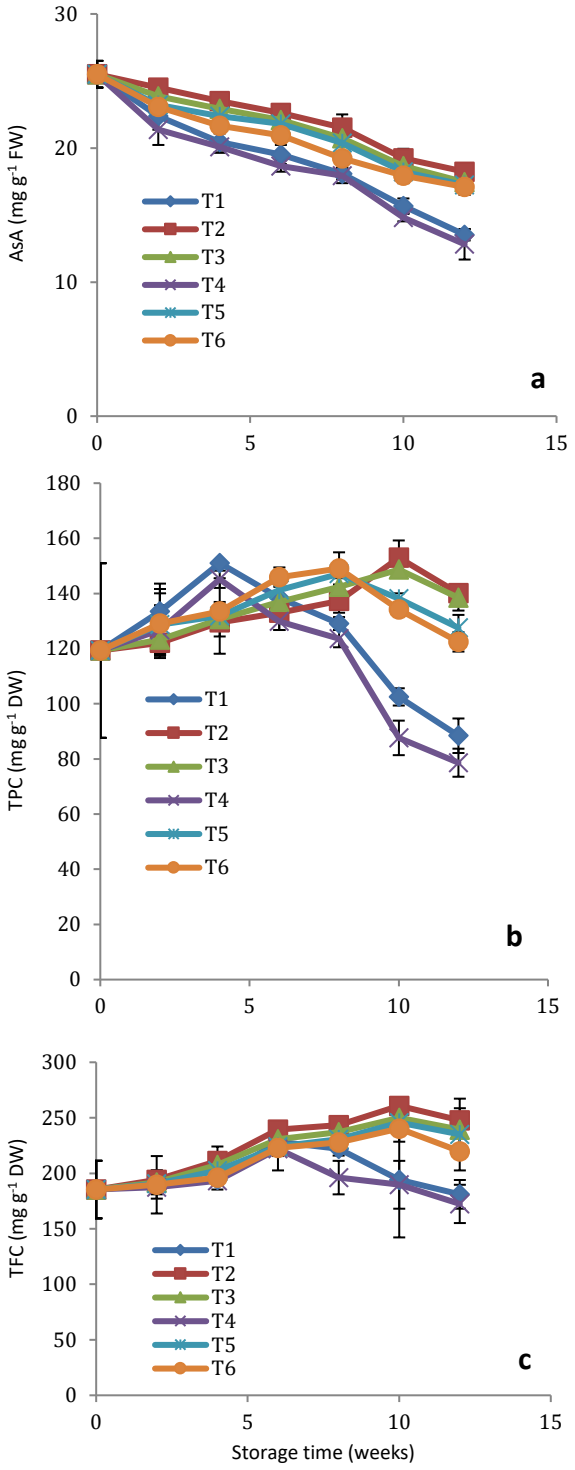


**Figure 5.** Effect of storage temperature (20°C and 30°C) and treatment with either rosemary or coriander extract on a) ascorbic acid (ASA) content, b) total phenols content (TPC), and c) total flavonoids content (TFC) of potato tubers for 12 weeks of postharvest. T1: untreated tubers at 20°C; T2: rosemary-treated tubers at 20°C; T3: coriander-treated tubers at 20°C; T4: untreated tubers at 30°C; T5: rosemary-treated tubers at 30°C; and T6: coriander-treated tubers at 30°C. Vertical bars show the ±SE of means (n = 3).

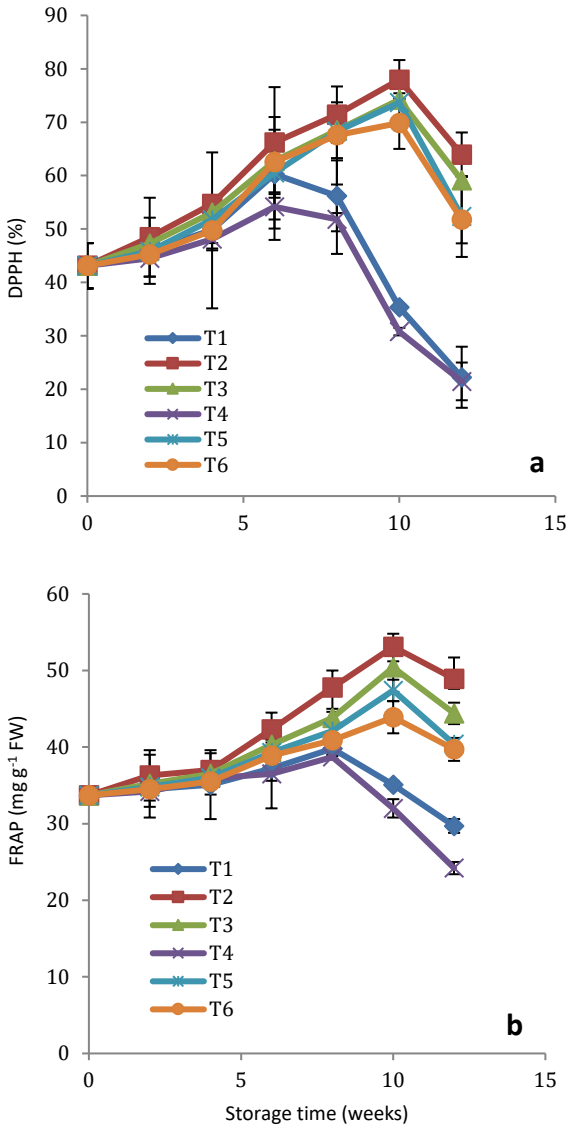


**Figure 6.** Effect of storage temperature (20°C and 30°C) and treatment with either rosemary or coriander extracts on a) DPPH radical scavenging activity and b) Ferric reducing antioxidant power (FRAP) of potato tubers for 12 weeks of postharvest. T1: untreated tubers at 20°C; T2: rosemary-treated tubers at 20°C; T3: coriander-treated tubers at 20°C; T4: untreated tubers at 30°C; T5: rosemary-treated tubers at 30°C; and T6: coriander-treated tubers at 30°C. Vertical bars show the ±SE of means (n = 3).

the limited elongation of sprouts of tubers treated with coriander and rosemary essential oil at the same temperature, might be attributed to the ability of monoterpene-rich coriander (Song & Ko, 2022) as well as rosemary essential oils (Mezza et al., 2018). These oils could restrict the activities of meristematic cell division (Pierre-Jerome et al., 2018). Similarly, other authors illustrated the sprout suppressant activity of potato tubers treated with essential oils (Afify et al.,

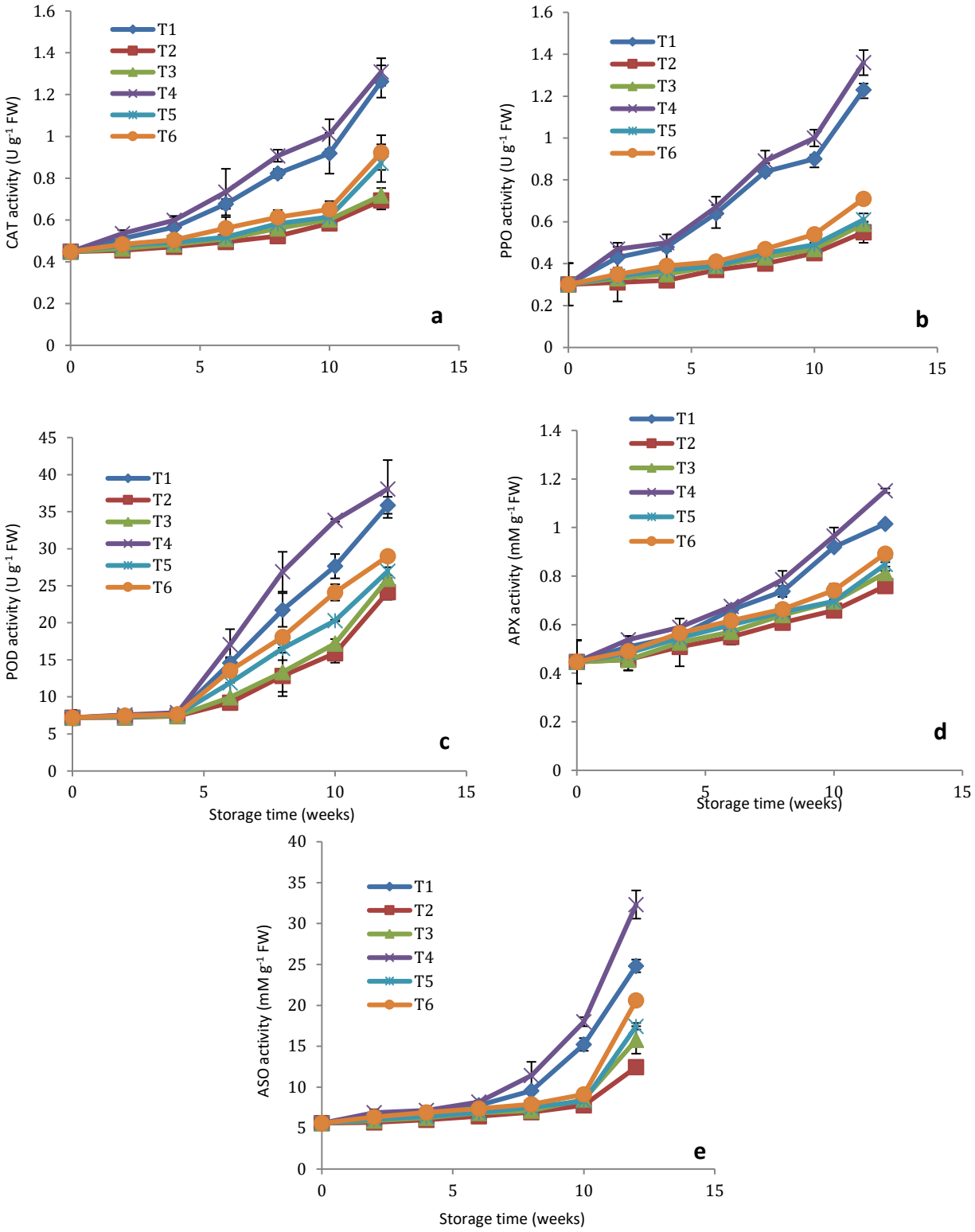


**Figure 7.** Effect of storage temperature (20°C and 30°C) and treatments with either rosemary or coriander extracts on the activities of a) catalase (CAT), b) polyphenol oxidase (PPO), c) peroxidase (POD), d) ascorbate peroxidase (APX), and e) ascorbate oxidase (ASO) of potato tubers for 12 weeks postharvest. T1: untreated tubers at 20°C; T2: rosemary-treated tubers at 20°C; T3: coriander-treated tubers at 20°C; T4: untreated tubers at 30°C; T5: rosemary-treated tubers at 30°C; and T6: coriander-treated tubers at 30°C. Vertical bars show the ±SE of means (n = 3).

**Table 1.** Correlation coefficient comparison for various analyses among coriander- and rosemary-treated and untreated potato tubers for 12 weeks of postharvest storage at 20°C and 30°C

| | Sprouting | SPL | WT loss | TSS | Sucrose | Starch | MDA | $H_2O_2$ | ASA | TPC | TFC | DPPH | FRAP | CAT | PPO | POD | APX | ASO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sprouting | 1 | | | | | | | | | | | | | | | | | |
| SPL | 0.99** | 1 | | | | | | | | | | | | | | | | |
| WT loss | 0.81** | 0.83** | 1 | | | | | | | | | | | | | | | |
| TSS | 0.95** | 0.95** | 0.91** | 1 | | | | | | | | | | | | | | |
| sucrose | 0.9** | 0.9** | 0.95** | 0.98** | 1 | | | | | | | | | | | | | |
| starch | -0.95** | -0.95** | -0.8** | -0.97** | -0.96** | 1 | | | | | | | | | | | | |
| MDA | 0.9** | 0.92** | 0.96** | 0.97** | 0.97** | -0.97** | 1 | | | | | | | | | | | |
| $H_2O_2$ | 0.97** | 0.97** | 0.96** | 0.98** | 0.95** | -0.98** | 0.96** | 1 | | | | | | | | | | |
| ASA | -0.94** | -0.92** | -0.9** | -0.95** | -0.91** | 0.93** | -0.89** | -0.94** | 1 | | | | | | | | | |
| TPC | -0.67** | -0.72** | 0.83** | -0.65** | -0.64** | 0.64** | -0.69** | -0.65** | 0.48 | 1 | | | | | | | | |
| TFC | -0.13 | -0.21 | 0.08 | -0.04 | -0.06 | 0.08 | -0.14 | -0.08 | -0.06 | 0.63** | 1 | | | | | | | |
| DPPH | -0.46 | -0.53* | 0.19 | -0.4 | -0.41 | 0.423 | -0.46 | -0.43 | 0.27 | 0.85** | 0.89** | 1 | | | | | | |
| FRAP | -0.23 | -0.32 | 0.17 | -0.15 | -0.15 | 0.19 | -0.25 | -0.2 | 0.05 | 0.69** | 0.93** | 0.91** | 1 | | | | | |
| CAT | 0.97** | 0.99** | 0.97** | 0.96** | 0.92** | -0.97** | 0.95** | 0.98** | -0.92** | -0.71** | -0.21 | -0.54* | -0.33 | 1 | | | | |
| PPO | 0.95** | 0.98** | 0.91** | 0.91** | 0.86** | -0.91** | 0.89** | 0.94** | -0.9** | -0.73** | -0.28 | -0.57* | -0.389 | 0.98** | 1 | | | |
| POD | 0.94** | 0.93** | 0.92** | 0.97** | 0.94** | -0.97** | 0.94** | 0.96** | -0.94** | -0.57* | 0.06 | -0.29 | -0.046 | 0.93** | 0.88** | 1 | | |
| APX | 0.95** | 0.94** | 0.89** | 0.98** | 0.946** | -0.97** | 0.95** | 0.97** | -0.97** | -0.59* | 0.007 | -0.35 | -0.12 | 0.95** | 0.91** | 0.97** | 1 | |
| ASO | 0.88** | 0.9** | 0.91** | 0.94** | 0.96** | -0.95** | 0.98** | 0.94** | -0.85** | -0.73** | -0.21 | -0.55* | -0.336 | 0.94** | 0.88** | 0.89** | 0.93** | 1 |

Means significant correlation (P≤0.05) using a multivariate analysis *

2012; Gómez-Castillo et al., 2013; Goodarzi et al., 2016; Talei et al., 2017). As the duration of storage increases, weight loss can be attributed to tuber sprouting, as observed in the current study. According to Pandey et al. (2011), sprouting causes buds to expand, and these buds are exposed to transpiration accompanied by respiration, which results in weight loss (Edmunds & Holmes, 2008). Moreover, weight loss occurs due to carbohydrates and other nutrients released from the stored tissues into the developing buds (Sergeeva et al., 2012). The application of rosemary essential oil and coriander effectively controlled sprouting in the tubers and significantly reducing their weight loss. These treatments reduce biochemical activities, leading to decreased respiration and water losses from the surfaces of potato tubers. This is due to their antioxidant properties, as demonstrated by Etemadipoor et al. (2019) and Shehata et al. (2020). Additionally, these treatments help maintain the physical appearance of the potato tubers, thus indicating their quality (Belay et al., 2022).

Our results revealed that soluble sugar accumulation in untreated tubers, concomitant with starch degradation during storage, was associated with sprouting (Benkeblia et al., 2008). Starch decomposition leads to the formation of sucrose, one prerequisite for bud break, which is then transformed into reducing sugars, helping sprouts' growth (Sonnewald & Sonnewald, 2014). These results are consistent with those of Abbasi et al. (2015), who demonstrated that the enhanced sprouting was accompanied by a higher sugar content at the expense of starch depletion in the stored control tubers. In contrast, tubers treated with rosemary essential oil and coriander extracts maintained lower sugar contents, concomitant with a higher level of starch during storage, related to their lowest percentage of sprouting. Similarly, the sprout suppressant effect of essential oils on starch-sugar metabolism has been confirmed by Gómez-Castillo et al. (2013), Abbasi et al. (2015), Goodarzi et al. (2016), and Talei et al. (2017).

The current study revealed a gradual rise in lipid peroxidation in stored tubers under normal conditions, coinciding with the beginning of sprouting. This was accompanied by a decrease in weight and an increase in reducing sugar accumulation with advancing age. These results align with the studies conducted by Afify et al. (2012) and Raigond et al. (2018), which found that the deterioration of the amyloplast membrane due to aging could enhance the enzymatic hydrolysis of starch. Furthermore, lipid peroxidation generally occurs when ROS reaches a threshold level, which reflects high levels of $H_2O_2$ accumulated in control tubers and triggers the breaking of dormancy in the current study. The mechanism through which $H_2O_2$ breaks dormancy has been the subject of several studies (Hamdi et al., 2009). Leymarie et al. (2007) found that $H_2O_2$ functions at the genomic level by enhancing the expression of genes responsible for

transitioning a plant from a dormant state to the sprouting stage. In addition, the natural sprouting inhibitors present in plants are oxidized by $H_2O_2$, which subsequently stimulates sprouting (Macheix et al., 2005). Additionally, biochemical research suggested that $H_2O_2$ may function as a mediator by stimulating the synthesis of ethylene and abscisic acid, leading to the sprouting of potatoes (Bailly, 2004). Conversely, the use of coriander and rosemary resulted in decreased levels of $H_2O_2$ in tubers, leading to enhanced antioxidant defense. This effect can be attributed to the antioxidant properties of monoterpene compounds present in coriander (Song & Ko, 2022) as well as in rosemary essential oils (Mezza et al., 2018).

The current study revealed a decrease in the ascorbic acid content of all stored potato tubers concurrent with sprouting caused by postharvest storage. This can be attributed to their oxidation during extended storage, as noted by Davies et al. (2002), or to their role in regulating the cellular redox balance during sprouting, as demonstrated by Liu et al. (2017). Similarly, several reports have mentioned a considerable decrease in ascorbic acid levels after harvest in stored potatoes (Rezaee et al., 2011; Abbasi et al., 2016; Yamdeu Galani et al., 2017). Nevertheless, the adequate retention of AsA observed in rosemary and coriander-treated potatoes is most likely correlated to their lower sprouting percentage. Furthermore, our findings revealed initial increases in FRAP and DPPH antioxidant capacity of untreated stored potatoes. However, after the sprouting onset, there was a sharp decline in these parameters until the end of the storage period. Such reductions might imply that TPC and TFC levels were associated with ROS signaling at the onset of sprouting (Liu et al., 2017). These results agree with the results reported by Abbasi et al. (2016), Galani et al. (2017), and Wichrowska (2021). However, the observed retention of TPC and TFC, as well as FRAP and DPPH in coriander and rosemary essential oil-treated tubers, resulted from their retarding sprouting. Similarly, Chauhan et al. (2011) and Abbasi et al. (2016) informed TPC retention in essential oil-treated potato tubers. Furthermore, the capacity of rosemary to donate hydrogen, which is linked to the presence of reductants in its essential oil, may cause greater FRAP levels in the tubers treated with rosemary (Olmedo et al., 2015). Previous research has indicated that the main components of rosemary essential oil, such as oxygenated monoterpenes and sesquiterpene hydrocarbons (Bozin et al., 2007), phenolic compounds (Beretta et al., 2011), 1,8-cineol, trans-caryophyllene, β-thujone, borneol, camphor (Adel et al., 2011), and myrcene (Ojeda-Sana et al., 2013), are primarily responsible for its antioxidant activity.

APX, CAT, and POD are essential antioxidant enzymes in breaking potato tuber dormancy. They play a crucial role in maintaining cell metabolism through the ascorbate-glutathione cycle (Iba, 2002). The current study suggests that the activation of CAT and peroxidases (APX and POD) and the initiation of sprouting are linked to the release of dormancy in potato tubers (Bajji et al., 2007). The study conducted by Sergeeva et al. (2012) found that the enzymes CAT, APX, and POD contribute to an increase in sucrose content in stored potato tubers. This increase in sucrose content improves the tubers' ability to withstand high temperatures and likely promotes the initiation of sprouting (Sergeeva et al., 2012). In contrast, increased ASO and PPO activities corresponded to the depletion of their substrates, ascorbate, and phenolics, respectively, in untreated potatoes at the end of storage time. This may also be associated with increased metabolic activity and high sprouting (Bryant, 2004), as reported by Abbasi et al. (2015). Meanwhile, the lowest ASO and PPO activities observed in coriander and rosemary-treated tubers might be related to their maximum AsA and TPC retention as well as minimum sprouting. Similar findings were reported by Afify et al. (2012) and Abbasi et al. (2015), who observed lesser enzymatic activities concomitant with the lowest sprouting percentage of essential oil-treated potatoes. Overall, the treatment of potato tubers with either rosemary or coriander resulted in a lowering of the activity of studied antioxidant enzymes in treated tubers, consistent with less sprouting, particularly with rosemary due to its antioxidant properties (Mezza et al., 2018).

The study demonstrated a positive correlation between the physicochemical characteristics and the sprouting process. Specifically, weight loss, sugar content, $H_2O_2$ and MDA accumulation, and the enhancement of antioxidant enzymes were all positively correlated with sprouting. However, these correlations exhibited a negative correlation with the content of starch, AsA, TPC, and DPPH. Such correlations significantly reflect starch-sugar metabolism and total phenolic-radical scavenging activity in response to sprouting during the storage of potato tubers. Therefore, sprouting suppression is crucial for preserving the nutritional characteristics of

tubers during storage. Additionally, it can be considered a significant indicator of the enhanced postharvest life of potatoes.

## CONCLUSION

The present study presents novel findings regarding the effects of either rosemary or coriander extracts as natural alternative suppressants and their impacts on biochemical and physiological characteristics of potato (*cv* Barcelona) stored for 12 weeks at 20 and 30°C. The emergence of visible sprouts in untreated tubers stored at 30°C coincided with an increase in their levels of soluble sugar, MDA, and $H_2O_2$, as well as depletion of antioxidants. In contrast, tubers received either rosemary or coriander and stored at 20°C displayed good appearance and excellent nutritional value manifested by minimal sprouting and weight loss. Particularly, Tubers treated with rosemary essential oil showed improved quality, as evidenced by higher antioxidant capacity, increased AsA, TPC, and TFC levels, and higher starch content.

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