γ-Aminobutyric Acid and Zeolite as Natural Treatments to Maintain the Fruit Quality, Storability, and Shelf Life in Apricot

Abdullah Alebidi,[a] Hayam M. Elmenofy,[b] Mahmoud Abdel-Sattar,[a,*] Mahmoud G. Abd El-Gawad,[b] Hatem R. M. Kotb,[c] Hail Z. Rihan,[d] Hoda Galal,[e] and Abdel-Moety Salama,[f]

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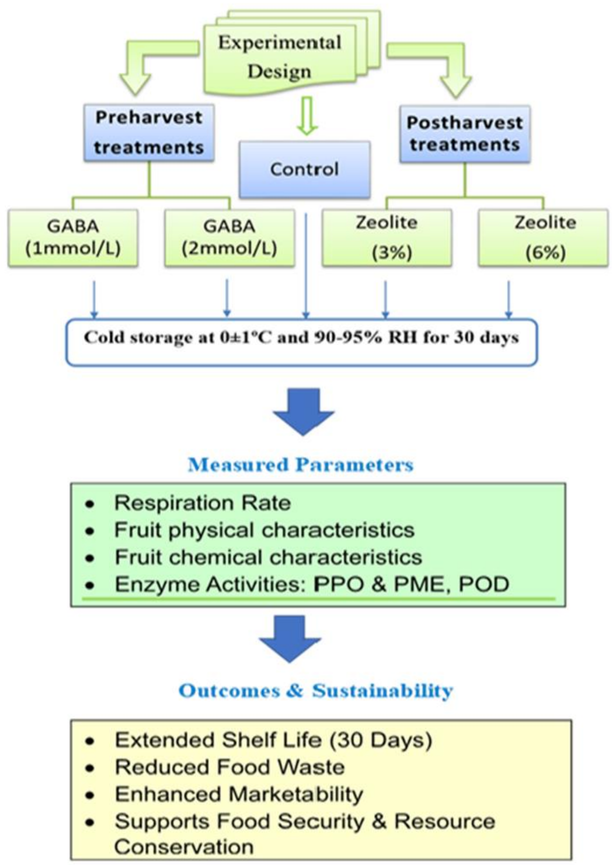
GRAPHICAL ABSTRACT



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The global trend promotes using natural and eco-friendly materials to improve fruit quality and storability. This study was carried out to examine the impact of pre-harvest spraying of γ-aminobutyric acid (GABA) at 1.0 and 2.0 mmol/L, and post-harvest zeolite dipping (3% and 6% levels), on the quality of apricot fruits stored at 0±1 °C and 90-95% relative humidity. The results indicated that different levels of GABA and zeolite treatments significantly reduced the respiration rate, decay percentage, and fruit weight loss of stored apricots. Moreover, all experimental treatments notably slowed down the changes in fruit firmness, total soluble solid content, total sugars, total acidity, total phenols, and ascorbic acid, compared to the control. Applying GABA and zeolite evidently decreased the activities of pectin methylesterase and polyphenol oxidase enzymes. On the other hand, they increased the peroxidase activity compared to the control treatment for both seasons. Moreover, the application of zeolite and GABA at a concentration of 6% and 2 mmol/L, respectively, are recommended to enhance the storability and extend the shelf life of 'Canino' apricot fruits and preserve their quality. This study contributes to the Sustainable Development aims by reducing postharvest losses, food waste, and increasing marketability, as well as supporting food security by conserving resources and increasing marketing income.

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Keywords: Antioxidative capacity; Chemical characteristics; Enzyme activity, Fruit decay; GABA; Preharvest; Postharvest; Physical characteristics; Respiration rate

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INTRODUCTION

Apricot (*Prunus armeniaca* L.) is one of the popular diploid stone fruit trees (Rodríguez-Robles *et al.* 2024). Apricots originated in China and Central Asia belonging to the Rosaceae family and have been cultivated in China since 2000 BC (Yuan *et al.* 2007). The apricot is a significant fruit crop that gradually made its way into the Mediterranean where it shows impressive resilience to varied environmental circumstances (Milošević and Milošević 2023). The plants thrive in humid areas in northern Egypt (Rodríguez-

Robles *et al.* 2024), and the 'Canino' cultivar of apricots holds particular importance in the newly reclaimed fields of Egypt. Apricots are categorized as climacteric fruits with relatively high respiration rates and short postharvest life (Muzzaffar *et al.* 2018). Apricot fruit has a crucial role in disease prevention and health maintenance due to its nutritional and functional properties, as it is abundant in nutrients and substances that are biologically active (Al-Soufi *et al.* 2022).

Excessive softening, rapid deterioration, and high susceptibility to spoilage are the primary factors limiting the postharvest life of apricot fruits (Ali *et al.* 2020). This results in a restricted market handling period and limits their commercial significance (Opara and Ogra 2024). Consequently, various pre- and post-harvest treatments have been employed to prolong the shelf life of apricot fruits, maintain their quality, and reduce losses during storage or marketing by influencing fruit physiology, ripening, and senescence processes. These treatments include cold storage (Aglar *et al.* 2017), storage at near-freezing temperatures (Fan *et al.* 2018), coating (Ghasemnezhad *et al.* 2010), as well as chemical and natural treatments (Pan *et al.* 2016; Abd El-Gawad and El-Moghazy 2018; Elmenofy *et al.* 2021). The use of natural remedies is especially important, not just in nations where there is widespread public concern about chemical inputs, but also because of their vital role in environmental conservation and sustainable agricultural approaches (Abdel-Sattar *et al.* 2025). The need to focus on sustainable methods to preserve nutritional, textural, and sensory properties in an environmentally friendly manner compared to traditional preservation methods has increased, along with progress in extending the shelf life of food products more sustainably (Malik *et al.* 2025). Therefore, there is a need to discover natural, non-toxic, readily available, and cost-effective products to extend the shelf life, maintain quality, and preserve the nutritional value of stored fruits. Hence, γ-aminobutyric acid (GABA) has been proposed as a natural treatment by some researchers (Shang *et al*. 2011; Yu *et al*. 2014; Solimani-Aghdam *et al*. 2016a; Badiche-El Hilali *et al.* 2023; Badiche *et al.* 2023; Carrión-Antolí *et al*. 2024; Ruiz-Aracil *et al*. 2024a; Zhang *et al.* 2024; Barakat and Aljutaily 2025) and zeolite as natural treatments by de Bruijn *et al.* (2019) and Kim *et al.* (2022).

γ-Aminobutyric acid (GABA) is a water-soluble non-protein amino acid composed of four carbon atoms and an amino group on the γ-carbon (Dietzen 2018). It is ubiquitously present in bacteria, plants, and animals. Although the GABA content in plant tissue is typically low, ranging between 0.03 and 2 μmol/g of fresh weight (Ramos-Ruiz *et al.* 2018), it has been identified to impart anti-stress properties. GABA can rapidly accumulate in plants when exposed to adverse biotic and abiotic conditions such as heat, chilling, salinity, drought, ultraviolet radiation, low oxygen levels, and infections (Yang *et al.* 2011; Wang *et al.* 2014). Additionally, GABA has been associated with various physiological functions, including pH modulation, plant development, and nitrogen storage (Yu *et al.* 2015; Barakat and Aljutaily 2025). Consequently, GABA has found widespread application in horticultural crops to mitigate chilling injury and oxidative damage, as well as to enhance resistance against pathogens (Shang *et al*. 2011; Yu *et al.* 2014; Badiche-El Hilali *et al.* 2023). The application of GABA distinctly suppressed respiratory rate and decreased titratable acidity, and ethylene release in Golden Delicious apples (Li *et al.* 2021), furthermore enhancing resistance to pathogens decay in pear fruit (*Pyrus pyrifolia* Nakai. cultivar "Shuijing") by increasing enzyme activity, including β-1,3-glucanase, peroxidase, phenylalanine ammonia-lyase, chitinase, and polyphenol oxidase compared to the control (Yu *et al.* 2014). Moreover, the application of GABA preserved the quality of peach fruits during cold storage, maintaining firmness, and enhancing antioxidant capacity by increasing levels of ascorbic acid, total phenols, and flavonoids, as well as improving DPPH scavenging ability (Solimani-Aghdam *et al.* 2018a).

Zeolites are crystalline aluminosilicates with a tetrahedral structure composed of SiO_4 and AlO_4 units, linked by sharing all their oxygen atoms (Constantinescu-Aruxandei *et al.* 2020). It is one of the safest natural silicate minerals, characterized by its high adsorption and ion exchange capacities (Wang and Peng 2010). Zeolites have a large surface area and cation exchange capacity, allowing them to act as ethylene scavengers and reduce ethylene production (de Bruijn *et al.* 2019; Kumar *et al.* 2024). By adsorbing ethylene gas, zeolites can slow down the ripening process, delay the respiration peak, and consequently extend the shelf life of stored fruits (Alonso-Salinas *et al.* 2024). The Food and Drug Administration in the USA has approved zeolites for use as food-contact polymers. Additionally, in 2005, the European Food Safety Agency authorized the use of two zeolites containing Ag ions on surfaces that come into contact with food (Llorens *et al.* 2012). Thus, zeolites offer a promising and natural approach to extending the shelf life of fruits.

The goal of this work was to study sustainable methods to preserve nutritional, textural, and sensory properties in an environmentally friendly manner and thereby to improve fruit quality and storability. According to the literature search, this is the first thorough study to examine the impact of two natural and eco-friendly alternative materials on various quality parameters of 'Canino' apricot fruits during cold storage. These alternatives included preharvest spraying with γ-aminobutyric acid (GABA) at two concentrations (1.0 and 2.0 mmol/L) and postharvest dipping with zeolite at 3% and 6% levels. Hence, this methodology provides new insights into the precise approach to pre- and post-harvest usages of zeolite and γ-aminobutyric acid and their effects on fruit quality and storage ability.

EXPERIMENTAL

Experimental Site and Plant Materials

This experiment was performed using 10-year-old apricot cv. 'Canino' (*Prunus armeniaca* L.) grafted onto a local apricot rootstock during the 2022 and 2023 seasons in a private orchard at the El-Nubaria region of the El-Behira governorate in Egypt. The trees were grown in sandy soil with a spacing of 3.5 × 4 m and subjected to standard agricultural procedures. It received irrigation and fertilization using a fertigation system. Twenty similar trees, with the same vigor, good health, and no infections, were chosen for this investigation, which consisted of five treatments. One tree was selected as a unit of replication, for a total of four replicates per treatment.

Experimental Designated Treatments

The experiment was divided into three groups: the first one, a total of eight trees were sprayed by GABA (Loba Chemie Pvt. Ltd., India) at concentrations of 1.0 mmol/L and 2.0 mmol/L (four trees for each concentration). The second group, a total of four trees (the control), was sprayed with water. The third group, a total of eight trees, received only postharvest treatments. In both experimental seasons, Apricot cv. 'Canino' fruits were harvested in the second week of June once they had reached the maturity stage, which is characterized by a yellowish-green color, as described by Dragovic-Uzelac *et al.* (2007). The fruits were promptly taken to the laboratory and meticulously sorted to a uniform size, eliminating any substandard fruits, such as those that were damaged or had other imperfections. The fruits from each treatment were subjected to a two-minute immersion in a water solution containing 0.01% sodium hypochlorite, then dried at room temperature. The fruits of the third group were then submerged for 2 min in a solution of natural zeolite, particle size of <50 µm (Biotraxx, Purple Oak Ltd., Germany) at 3% or 6% concentrations containing polysorbate 80 (Tween-80) at a concentration of 0.05% (v/v). However, fruits from group one and two submerged in solution containing the polysorbate 80 at a concentration of 0.05% (v/v) only. Then, all fruits were allowed to dry at ambient temperature for about half an hour. Subsequently, all treated fruits were stored in cold storage at 0±1 ºC and 90% to 95% RH for 30 days, as presented in the flowchart (Fig. 1), to evaluate their effect on fruit quality during storage.

For each treatment, fruits were immediately and carefully arranged in nine-carton boxes (30×40×20 cm), each box holding 2 kg of fruits. The nine boxes were labelled: three for decay assessment, three for weight loss measurement, and the remaining three for evaluating fruit quality characteristics at 10-day intervals during the storage periods. The boxes containing all treatments were stored at 0±1 °C and a relative humidity (RH) of 90% to 95%.

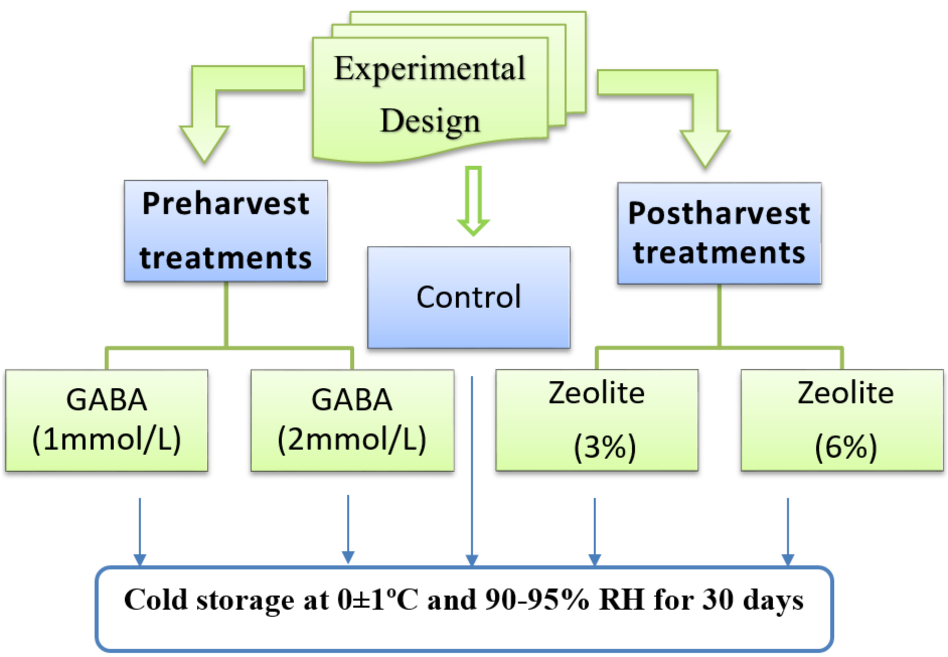

Fig. 1. Flowchart for the experimental design

Measurement of Fruit Characteristics

The respiration rate was determined as mL CO_2/kg/h, according to Lurie and Pesis (1992). For each replicate in each treatment, six fruits were weighed and placed in a 2-liter jar at room temperature (23±1 °C). The jar was tightly closed for three hours using a cap and a rubber septum. A syringe was used to obtain air samples from the jar through the cap. These samples were subsequently inserted into a Servomex Inst. to find out how much CO_2 is generated, a Food Pack Gas Analyzer Model 1450C was used. The respiration rate was assessed on the day of harvest and at ten-day intervals during the cold storage period. The assessment of all fruit quality characteristics and enzyme activities was conducted on the picking day after the fruits were prepared for storage and subsequently every ten days during storage as outlined below.

Fruit physical characteristics

By calculating the weight loss (%), decay (%), and fruit firmness (Ib/inch^2), the physical characteristics of the fruit were assessed. The percentage of disordered fruits, encompassing all ruined fruits due to rot, fungi, bacteria, and pathogens, was assessed, and the decay percentage was determined using the following formula:

$$\text{Decay (\%)} = \frac{\text{Number of decayed fruit}}{\text{Total Number of fruit at beginning of storage}} \times 100 \quad (1)$$

The weight of the fruits was measured at the beginning of storage and every ten days during the cold storage period. The amount of weight lost was then computed using the following Eq. 2:

$$\text{Weight loss (\%)} = \frac{\text{Weight loss value at the sampling date}}{\text{initial apricot weight}} \times 100 \quad (2)$$

A random sample of 15 fruits from each group per replication was selected to determine the firmness. The hand Magness Taylor pressure tester (Lutron Electronic, Taipei, Taiwan) with a 6 mm (Ib/inch^2), was used to measure the firmness on the two opposed sides of flesh apricot fruit samples.

Fruit chemical characteristics

Each apricot fruit was squeezed individually to get its fresh juice to determine the chemical properties of the fruit. The soluble solids content (TSS) was measured in 5 mL of apricot juice filtrate using a digital refractometer (Milwaukee, model MA871, Milano, Italy). Following the AOAC method (2019), 5 mL of juice was titrated with 0.1N sodium hydroxide, and phenolphthalein was used as an indicator to find the total acidity (TA), which was expressed as a percentage of malic acid. The total sugar content was determined in one g of fresh samples using the phenol-sulfuric acid method (Dubois *et al.* 1956). A titration was conducted to determine the concentration of L- ascorbic acid (vitamin C) in 5.0 g of apricot pericarp using a 2,6 -dichlorophenolindophenol (DCPIP) method (Shang *et al.* 2011). The concentration was therefore calculated as mg of ascorbic acid per 100 g of fresh weight (mg/ 100 g FW). To determine total phenols (mg/g FW), one gram of fresh apricot samples underwent the Folin-Ciocalteu colorimetric method (Lester *et al.* 2012). Using a double beam UV/visible spectrophotometer (Libra S80 PC, Biochrome Ltd., Cambridge, UK), the absorbance at 765 nm was used to measure the total phenols. A standard curve derived from *p*-hydroxybenzoic acid was employed to quantify the concentration of phenols as mg/g fresh weight.

Determination of Enzyme Activities

Peroxidase (POD) and polyphenol oxidase (PPO) activity were estimated for apricot fruits. Fifty grams of fruits were homogenized with 0.1 M sodium phosphate buffer pH 7.0 in ice-cold at 4 °C, then centrifugated at 11200 g for 10 min at 4 °C, the clear supernatant was used for enzyme assay. Peroxidase (POD) activity was estimated according to Abdel-Sattar *et al.* (2023) with some modifications. A reaction mixture comprising 0.5 mL of enzyme extract, 0.2 mL of pyrogallol, 0.1 mL of hydrogen peroxide

(1% *v*/*v*), and 2.2 mL of phosphate buffer (0.1 M, pH 6.0) was used. In the blank cuvette, distilled water was used in place of hydrogen peroxide. One unit of POD was defined as producing 1.0 mg of purpurogallin from pyrogallol in 20 s at pH 6.0 and 20 °C. At 420 nm, the purpurogallin's absorbance was measured. With some modifications, the polyphenol oxidase (PPO) activity was measured using Abdel-Sattar *et al.* (2023) methodology. A reaction mixture comprising 0.2 mL of 0.001 M catechol, 2.3 mL of potassium phosphate buffer (0.1 M, pH 6.8), and 0.1 mL of enzyme extract was used to measure the activity of polyphenol oxidase (PPO). The activity was evaluated spectrophotometrically at 15-s intervals, as variations in absorbance occurred at 495 nm. The amount of enzyme that induced a 0.001 absorbance increase at 495 nm in 1.0 min was defined as one unit of PPO activity. Regarding pectin methylesterase (PME), it was estimated according to Anthon and Barrett (2006), based on 50 g of fruit in an equal amount of the solution of (50% 2 M NaCl and 50% 10 mM phosphate buffer with pH (7.5). The samples were filtrated and then added to 2.5 mL of 0.5% pectin solutions. The pH of the solution was adjusted to 7.5 by adding 0.1M NaOH. The PME activity was measured in µmol of hydrophilic ester per 50 g of fresh fruit over one minute (µmol.g^{-1} FW.min^{-1}).

Statistical analysis

The design of the experiment was completely randomized (Gomez and Gomez 1984) as a factorial experiment with two factors. The first factor included five treatments, namely GABA at concentrations of 1.0 mmol/L and 2.0 mmol/L, zeolite at concentrations of 3% and 6%, and a control group. The second factor included four storage periods (0, 10, 20, and 30 days of storage). The analysis of variance (ANOVA) and Duncan's multiple range tests at a significance level of $P \leq 0.05$ were performed using SPSS software version 16, 2007 (SPSS, Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION

The effect of preharvest γ-aminobutyric acid (GABA) spraying at two concentrations (1.0 and 2.0 mmol/L) and postharvest zeolite immersion at 3% and 6% was investigated for 'Canino' apricots during storage at 0±1 °C and 90% to 95% RH. The data from the 2022 and 2023 seasons indicated that all studied treatments prolonged apricot storage life by up to 30 days. In contrast, untreated fruits (control) exhibited shrinkage and loss of their fresh appearance after only 20 days of storage.

The Respiration Rate of Stored Apricot Fruits

The respiration rate of fruits significantly impacts their postharvest life. Hence, it is vital to reduce this process to prolong the duration of storage (Valero and Serrano 2010). The data presented in Table 1 revealed that cold storage significantly and sharply decreased the respiration rate of both treated and untreated apricot fruit at the beginning of the storage period. With prolonged storage period, the respiration rate of the fruit increased gradually and reached its highest rate after 30 days of cold storage. All treatments caused a significant decrease in fruit respiration rate, compared to the control, except for GABA at 1.0 mmol/L in the second season. The lowest fruit respiration rates were recorded in the first season with treatments of 6% or 3% zeolite and 2 mmol/L GABA, with no significant differences ($P \leq 0.05$). In the second season, the lowest values were observed with zeolite at 6% and GABA at 2 mmol/L, followed by zeolite at 3%.

Table 1. Impact of Preharvest Treatment of GABA and Postharvest Treatment of Zeolite on Respiration Rate (mL CO_2/kg/h) of 'Canino' Apricot Fruits*

	Season 2022					Season 2023				
	Storage Periods (Days)					Storage Periods (Days)				
Treatments	**0**	**10**	**20**	**30**	**Mean**	**0**	**10**	**20**	**30**	**Mean**
Control	31.70±0.2	3.22±0.02	3.85±0.1	4.17±0.1	10.7±1.2[a]	29.07±0.3	3.12±0.1	3.58±0.1	3.81±0.03	9.9±1.22[a]
GABA(1 mmol/L)	30.52±0.4	2.83±0.06	3.25±0.2	3.76±0.1	10.1±1.98[b]	29.79±0.2	2.83±0.1	3.19±0.1	3.52±0.05	9.8±1.68[a]
GABA (2 mmol/L)	29.60±0.6	2.68±0.03	2.83±0.1	3.49±0.1	9.6±1.70[c]	28.60±0.6	2.61±0.3	2.81±0.03	3.33±0.09	9.3±1.28[c]
Zeolite at 3%	29.67±0.3	2.79±0.06	2.49±0.3	3.68±0.1	9.7±1.72[c]	29.48±0.1	2.70±0.1	2.93±0.1	3.38±0.07	9.6±1.62[b]
Zeolite at 6%	29.27±0.2	2.60±0.03	2.41±0.3	3.37±0.1	9.4±1.63[c]	28.52±0.4	2.53±0.1	2.69±0.02	3.09±0.07	9.2±1.31[c]
Mean	30.2±0.96[a]	2.8±0.22[d]	3.0±0.58[c]	3.7±0.28[b]		29.1±0.61[a]	2.8±0.22[d]	3.0±0.33[c]	3.4±0.25[b]	
LSD at $_{0.05}$	**Treatments (T) Storage Periods (D) Interaction (T×D)**				**= 0.21 = 0.19 = 0.42**	**Treatments (T) Storage Periods (D) Interaction (T×D)**				**= 0.18 = 0.16 = 0.36**

Mean values followed by different letters are significantly different at P < 0.05 according to Duncan's multiple range tests. *Fruits were stored at 0±1 ºC and 90%-95% RH during the 2022 and 2023 seasons.

The results from this study were in harmony with previous works, indicating that cold storage is the most efficient and secure approach to prolonging the postharvest senescence of apricots (Nguyen *et al.* 2016). Zeolite can adsorb gases such as ethylene and oxygen from the storage environment, leading to a reduction in respiration processes (Khosravi *et al.* 2015; de Bruijn *et al.* 2019; Hosseinnia *et al.* 2024). On the other hand, GABA application effectively reduced the respiration rate of peaches and apples by enhancing antioxidant enzymes, inhibiting the degradation of sugars and carbohydrates (Yang *et al.* 2011; Han, *et al.* 2018), and decreasing ethylene release (Li *et al.* 2021). Furthermore, higher levels of GABA are linked to the reduction of oxidative damage to cellular membranes. They can attach to negatively charged molecules in cell membranes, such as phospholipids. This attachment helps stabilize the membrane's two layers and restricts the exchange of gases (Malekzadeh *et al.* 2014; Zhang *et al.* 2024). Apricot fruit is a climacteric fruit with a relatively high respiration rate accompanied by high ethylene production during ripening (Elmenofy *et al.* 2021). In the 2nd season, 1 mmol/L of GABA did not significantly reduce the respiration rate, which may be explained by the fact that the lower dose of GABA was insufficient to reduce respiration.

Fruit Physical Characteristics

The impact of preharvest treatment of GABA and postharvest treatment of zeolite on the decay percentage of 'Canino' apricot fruits during cold storage is presented in Fig. 2. According to data collected from both seasons, fruit decay increased with longer storage times in both seasons. The control group had the highest extent of decay (38.02% and 40.93% in 2022 and 2023, respectively), whereas all other treatments had percentages of not more than 18%. In the first season, GABA at a concentration of 2.0 mmol/L was the most efficacious treatment for preventing fruit decay. This was followed by 1.0 mmol/L GABA and zeolite at 6%. Meanwhile, GABA at a concentration of 1.0 or 2.0 mmol/L and zeolite at a concentration of 6% showed equal effectiveness in decreasing deterioration in the second season.

In this regard, prior studies have demonstrated the role of GABA in extending the storage life of fruits and enhancing their resistance against pathogens. Li *et al.* (2021) showed that GABA dipping treatments can improve the firmness of apple fruits and make them more resistant to pathogen invasion. Yu *et al.* (2014) reported that applying GABA to pear fruits stopped *Penicillium expansum* spores (blue mold rot) from germinating and prevented germ tube elongation. It also activated the expression of defense genes and enzymes that combat pathogens. In addition, GABA has a role in enhancing the activity of the phenylalanine ammonialyase enzyme (Wang *et al.* 2014), which removes ammonia from phenylalanine to produce *trans*-cinnamic acid, a precursor for the synthesis of lignins, flavonoids, and coumarins (Davidson 2009). On the other hand, the effect of zeolite on reducing decay could be attributed to its porous structure, which allows it to absorb moisture from the surrounding environment. Thus, it can be beneficial for inhibiting spoilage caused by excess moisture (de Bruijn *et al.* 2019).

The degree of inhibition was highly associated with the concentration of GABA. According to Zhu *et al.* (2022), immersing apples in a solution of GABA at 1.0 mmol/L and 2.0 mmol/L after harvesting decreased the infected zone caused by *P. expansum* infection (blue mold). GABA treatment also induced resistance against *Alternaria alternate* (Yang *et al.* 2017) and *B. cinerea* in tomato fruit (Sun *et al.* 2019).

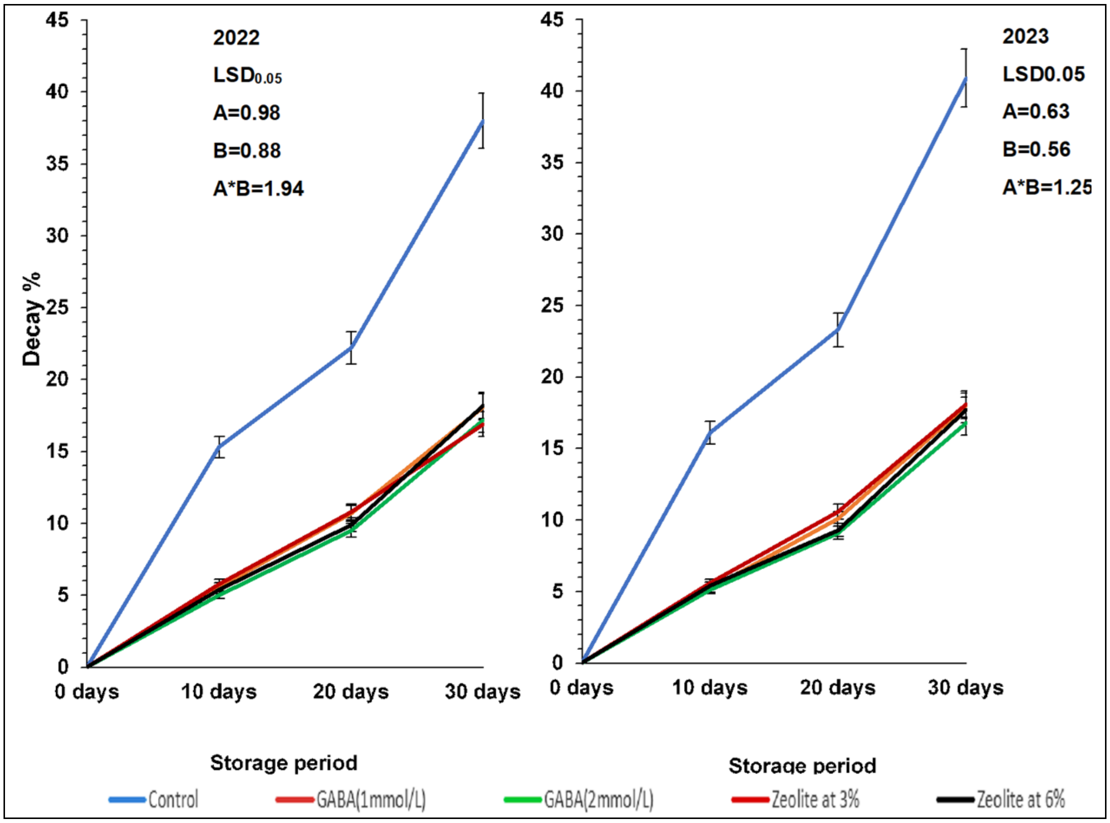

Fig. 2. Impact of preharvest treatment of γ-aminobutyric acid (GABA) and postharvest treatment of zeolite on decay percentage of 'Canino' apricot fruits stored at 0±1 ºC and 90% to 95% RH during the 2022 and 2023 seasons. Error bars represent the standard deviation. LSD $_{0.05}$ (A= treatments, B= storage period, A*B= interaction).

Climacteric fruits lose weight by losing water during respiration and transpiration. GABA and zeolite treatments significantly decreased apricot fruit weight loss compared with control in both seasons (Fig. 3). Zeolite at a concentration of 6% had superior efficacy in reducing fruit weight loss, followed by zeolite at 3% and GABA at 2.0 mmol/L. These results could be attributed to the effect of the applied treatments on reducing the respiration rate of stored apricots (Table 2). Higher respiration leads to higher weight loss as each carbon dioxide molecule created from an absorbed oxygen molecule results in the loss of a carbon atom from the fruit, which is then released into the atmosphere (de Bruijn *et al.* 2020).

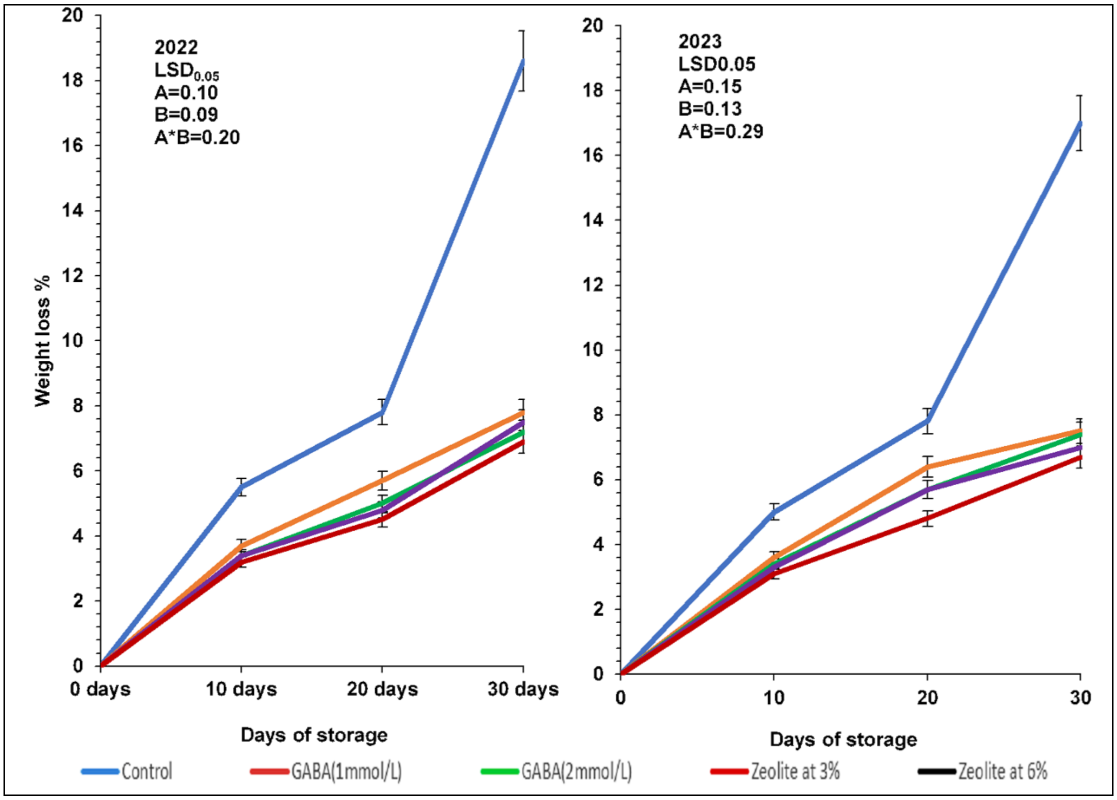

Fig. 3. Impact of preharvest treatment of γ-aminobutyric acid (GABA) and postharvest treatment of zeolite on weight loss % of 'Canino' apricot fruits stored at 0±1 ºC and 90%-95% RH during the 2022 and 2023 seasons. Error bars represent the standard deviation. LSD $_{0.05}$ (A= treatments, B= storage period, A*B= interaction).

GABA has also been shown to lower fruit weight loss by preserving fruit hardness (Saeedi *et al.* 2022), thereby protecting the cell membrane, and slowing down metabolism during storage (Solimani-Aghdam *et al.* 2016b; Ruiz-Aracil *et al.* 2024a; Zhang *et al.* 2024). According to Habibi *et al.* (2019) and Habibi *et al.* (2020), the effect of GABA on reducing weight loss in blood oranges depends on its concentration. These results suggest that applying zeolite or GABA could be practical in reducing the weight loss of stored apricots.

In both seasons, fruit weight loss increased significantly with prolonged storage periods compared with the initial time (Fig. 3). Weight loss commonly occurs due to water loss through evaporation, transpiration, respiratory processes, and metabolic activity (Valero and Serrano 2010). Regardless of whether fruits received any treatments or not, researchers noticed a significant increase in the amount of weight loss as the storage period progressed in different fruits, such as apricots (Davarynejad *et al.* 2013), peach (Sohail *et al.* 2015), and plum (Abd El-Gawad *et al.* 2020).

The data from Table 2 showed a notable reduction in fruit firmness as the storage duration was extended. At the end of storage periods, the control group showed the lowest levels of fruit firmness (4.49 and 4.62 lb/inch^2 in 2002 and 2003, respectively). Fruits treated with zeolite and GABA had higher levels of fruit firmness compared to the control group. Zeolite postharvest treatment at 3% and 6% maintained the maximum firmness for apricots during various storage periods in both seasons.

Table 2. Impact of Preharvest Treatment of GABA and Postharvest Treatment of Zeolite on Firmness (lb/inch^2) of 'Canino' Apricot Fruits*

	Season 2022					Season 2023				
	Storage Periods (Days)					Storage Periods (Days)				
Treatments	**0**	**10**	**20**	**30**	**Mean**	**0**	**10**	**20**	**30**	**Mean**
Control	7.5±0.10	6.1±0.05	5.1±0.10	4.5±0.03	5.8±1..14^{e}	7.6±0.06	6.1±0.10	5.3±0.09	4.6±0.10	5.9±1.33^{e}
GABA(1mmol/L)	7.6±0.04	6.3±0.04	5.4±0.06	4.6±0.07	6.0±1.12^{d}	7.8±0.04	6.4±0.04	5.4±0.06	4.7±0.03	6.0±1.15^{d}
GABA(2mmol/L)	7.7±0.04	6.5±0.04	5.4±0.04	4.7±0.06	6.1±1.17^{c}	7.8±0.03	6.4±0.04	5.5±0.10	4.9±0.10	6.1±1.12^{c}
Zeolite at 3%	7.7±0.02	7.0±0.10	6.6±0.04	5.8±0.50	6.8±0.77^{b}	7.8±0.02	6.8±0.10	6.3±0.10	5.1±0.10	6.5±0.99^{b}
Zeolite at 6%	7.9±0.07	7.17±0.06	6.9±0.10	6.5±0.08	7.1±0.53^{a}	7.9±0.04	7.3±0.25	6.6±0.04	5.7±0.10	6.9±0.86^{a}
Mean	7.7±0.13^{a}	6.6±0.42^{b}	5.9±0.72^{c}	5.2±0.81^{d}		7.8±0.10^{a}	6.6±0.45^{b}	5.8±0.52^{c}	5.0±0.38^{d}	
LSD at $_{0.05}$	**Treatments (T)** **Storage Periods (D)** **Interaction (T×D)**				**= 0.13** **= 0.12** **= 0.57**	**Treatments (T)** **Storage Periods (D)** **Interaction (T×D)**				**= 0.09** **= 0.08** **= 0.17**

Mean values followed by different letters are significantly different at $P < 0.05$ according to Duncan's multiple range tests. *Fruits were stored at 0±1 ºC and 90%-95% RH during the 2022 and 2023 seasons.

Loss of firmness is one of the most important problems during the postharvest period. The gradual decrease in fruit firmness is an inherent process of fruit ripening due to biochemical changes, such as the enzymatic hydrolysis of cell walls by pectinase and pectin methylesterase composition (Dharmasenal and Kumari 2006; Zeinalipour and Saadati 2024). Furthermore, the decrease in turgor pressure of cells caused by water loss is an additional factor that decreases firmness during storage (Beaulieu and Gorny 2001). Zeinalipour and Saadati (2024) reported that the preharvest application of cinnamic acid 200 µM + nano zeolite 60 mg/L, cinnamic showed the highest relative water contents compared to the control. As shown in Tables 2 and Fig. 3, zeolite treatments were more effective than other treatments in slowing down respiration rate and fruit weight loss, which may explain why it has a significant effect on reducing firmness loss. This is in addition to its additive effect on slowing down ripening by adsorbing oxygen and ethylene from the surrounding air (Khosravi *et al.* 2015). These findings are similar to Huwei *et al.* (2021), who noticed that applying 6% zeolite on grapes before harvest improves the firmness of stored fruits for 60 days. Zeolite helps adsorb moisture and ethylene, reducing the respiration rate and delaying senescence. (de Bruijn *et al.* 2019), and maintained firmness by lowering water activity and reducing oxidative stress (Alonso-Salinas *et al.* 2024). GABA treatments enhanced antioxidant enzyme activity, reducing decay and improving storage quality, as well as enhancing chilling tolerance and preventing decay through metabolic regulation (Zhou *et al.* 2022).

Furthermore, many studies have shown that proper concentrations of postharvest treatments of GABA reduced the loss of firmness in stored fruit, such as mango at 200 µM (Rastegar *et al.* 2020), blood orange at 20 mM and 40 mM (Habibi *et al.* 2019, 2020), and pistachio fruit at 10 mM w/v (Khosravi *et al.* 2015). Yu *et al.* (2014) reported that GABA can increase the stability of the cell wall and improve fruit firmness by inhibiting the activity of the lipoxygenase enzyme and suppressing the process of membrane lipid peroxidation. Also, Aghdam *et al.* (2019) attributed the significance of GABA in preserving the firmness of cornelian cherry fruits to its ability to decrease the activity of cell wall-degrading enzymes, specifically polygalacturonase and pectin methylesterase.

Fruit Chemical Characteristics

The impact of preharvest spraying of GABA and zeolite postharvest treatments on TSS and total sugar content (mg/g fresh weight) of ‘Canino’ apricot fruits during cold storage are shown in Tables 3 and 4, respectively. At harvest time, GABA reduced TSS and total sugar compared to untreated fruit. In the first season, TSS exhibited a decrease from 12 in the control group to 11.8 and 11.6 with GABA treatments at 1.0 and 2 mmol/L, respectively (Table 3). In the second season, TSS decreased from 11.5 to 11.1 and 10.9 with both concentrations of GABA. With the progress of the storage period, the data indicated a gradual rise in TSS and total sugars and these variations were statistically significant at $P \leq 0.05$ when compared to the beginning date. The increase in sugar levels observed during storage might be attributed to the ripening process, which results in the conversion of some carbohydrates, such as starch, into sugars through enzymatic activity (Karemera and Habimana 2014; Ruiz-Aracil *et al.* 2024a). Using GABA and zeolite treatments was effective in lowering the rise in TSS and total sugar levels. Zeolite at 6% and GABA at 2 mmol/L notably slowed the progressive rise in TSS and total sugar levels over the storage period, compared to the control and lower concentrations of zeolite and GABA (Tables 3 and 4). These effects might be due to the observed effect of GABA and zeolite, especially at higher concentrations, in slowing down the rate of respiration and delaying the ripening process in stored apricots (Ruiz-Aracil *et al.* 2024a; Ruiz-Aracil *et al.* 2024b; Zeinalipour and Saadati 2024).

Concerning total acidity (TA), data in Table 5 indicate that TA contents significantly decreased with prolonging cold storage period as compared with the initial time during both research seasons of the study. These results agree with the fact that organic acids, like malic and citric acids, accumulate in fruits during their early development. As ripening progresses, these acids are metabolized. Some are converted into sugars, contributing to the sweetness, while others are used in cellular respiration (Valero and Serrano 2010; Abd El-Gawad *et al.* 2020).

Data also showed that all treatments slightly inhibited the loss of TA in comparison to the control (Table 5). Compared to other treatments, zeolite at 6% and GABA at 2 mmol/L were more effective in enhancing the retention of TA. These results are in harmony with earlier studies on different fruits. Huwei *et al.* (2021) found that treatment with 6% zeolite on Thompson seedless grapes decreased the loss of TA during cold storage for 60 days. According to Fan *et al.* (2022), GABA treatments at 0.5, 1.0, 1.5, and 2.0 mM inhibited the loss of titratable acidity in Chinese olives stored at 2 °C for 100 days compared to untreated fruits. Compared to the initial date, GABA at 0.1 mM decreased TA by 38%, while it decreased in control by 58%. Additionally, Habibi *et al.* (2019) and Habibi *et al.* (2020) found a concentration-dependent pattern of the same effect in blood orange fruit after dipping with 20- and 40-mM GABA. The effect of zeolite on reducing the degradation of organic acids during storage was previously observed.

Table 3. Impact of Preharvest Treatment of GABA and postharvest treatment of Zeolite on TSS% of 'Canino' Apricot Fruits*

	Season 2022					Season 2023				
	Storage Periods (Days)					Storage Periods (Days)				
Treatments	**0**	**10**	**20**	**30**	**Mean**	**0**	**10**	**20**	**30**	**Mean**
Control	12.0±0.06	13.5±0.13	14.3±0.13	14.8±0.08	13.6±0.96[a]	11.5±0.05	13.7±0.23	14.2±0.12	15.2±0.22	13.7±1.05[a]
GABA (1.0 mmol/L)	11.8±0.21	13.2±0.13	14.2±0.10	14.7±0.08	13.5±1.10[b]	11.1±0.10	13.1±0.08	13.7±0.13	15.0±0.46	13.2±1.45[b]
GABA (2.0 mmol/L)	11.6±0.08	12.9±0.10	13.8±0.15	14.3±0.04	13.1±1..07[c]	10.9±0.12	12.8±0.15	13.4±0.13	14.6±0.46	12.9±1.37[c]
Zeolite at 3%	12.0±0.11	13.3±0.08	14.1±0.10	14.4±0.05	13.5±0..98[b]	11.7±0.39	13.5±0.13	14.1±0.11	14.9±0.51	13.6±1..37[b]
Zeolite at 6%	11.9±0.06	12.4±0.13	13.4±0.08	14.4±0.13	13.0±1.12[d]	11.5±0.31	12.5±0.08	13. 3±0.13	14.1±0.11	12.9±1.22[c]
Mean	11.9±0.21[d]	13.1±0.40[c]	14.0±0.18[b]	14.5±0.19[a]		11.3±0.37[d]	13.1±0.45[c]	13.7±0.36[b]	14.7±0.47[a]	
LSD at $_{0.05}$	**Treatments (T) Storage Periods (D) Interaction (T×D)**				**= 0.10 = 0.09 = 0.21**	**Treatments (T) Storage Periods (D) Interaction (T×D)**				**= 0.22 = 0.20 = 0.44**

Mean values followed by different letters are significantly different at P < 0.05 according to Duncan's multiple range tests. *Fruits were stored at 0±1 ºC and 90%-95% RH during the 2022 and 2023 seasons.

Table 4. Impact of Preharvest Treatment of GABA and Postharvest Treatment of Zeolite on Total Sugars (mg/g FW) of 'Canino' Apricot Fruits*

	Season 2022					Season 2023				
	Storage Periods (Days)					Storage Periods (Days)				
Treatments	**0**	**10**	**20**	**30**	**Mean**	**0**	**10**	**20**	**30**	**Mean**
Control	6.97±0.13	8.33±0.10	8.83±0.13	9.31±0.04	8.3±1.23[b]	7.25±0.10	8.77±0.12	9.57±0.04	9.87±0.04	8.9±0.1.23[a]
GABA (1mmol/L)	6.65±0.10	7.62±0.11	8.20±0.11	8.80±0.15	7.8±0.81[c]	6.58±0.13	8.05±0.07	9.28±0.18	9.69±0.04	8.4±1.01[c]
GABA (2mmol/L)	6.55±0.13	7.38±0.24	7.99±0.12	8.55±0.22	7.6±1.0[d]	6.31±0.11	7.99±0.12	8.90±0.08	9.24±0.10	8.1±1.15[d]
Zeolite at 3%	7.03±0.12	8.58±0.14	9.12±0.11	9.65±0.08	8.6±0..77[a]	7.13±0.08	8.39±0.05	9.30±0.18	9.62±0.11	8.6±0.97[b]
Zeolite at 6%	6.92±0.11	7.01±0.08	7.35±0.08	7.80±0.15	7.1±0.93[e]	7.00±0.23	7.56±0.14	8.32±0.10	8.67±0.12	7.9±0.56[e]
Mean	6.8±0.19[d]	7.7±0.77[c]	8.3±0.64[b]	8.8±0.66[a]		6.9±0.43[d]	8.2±0.42[c]	9.1±0.44[b]	9.4±0.44[a]	
LSD at $_{0.05}$	**Treatments (T) Storage Periods (D) Interaction (T×D)**				**= 0.13 = 0.12 = 0.26**	**Treatments (T) Storage Periods (D) Interaction (T×D)**				**= 0.12 = 0.11 = 0.24**

Mean values followed by different letters are significantly different at P < 0.05 according to Duncan's multiple range tests. *Fruits were stored at 0±1 ºC and 90%-95% RH during the 2022 and 2023 seasons.

Table 5. Impact of Preharvest Treatment of GABA and Postharvest Treatment of Zeolite on Total Acidity% of 'Canino' Apricot Fruits*

	Season 2022					Season 2023				
	Storage Periods (Days)					Storage Periods (Days)				
Treatments	**0**	**10**	**20**	**30**	**Mean**	**0**	**10**	**20**	**30**	**Mean**
Control	1.12±0.01	0.84±0.01	0.74±0.01	0.63±0.01	0.83±0..18^{e}	1.13±0.01	0.82±0.10	0.54±0.02	0.44±0.02	0.73±0.27^{e}
GABA(1mmol/L)	1.15±0.01	0.90±0.01	0.79±0.01	0.69±0.02	0.88±0.17^{d}	1.15±0.02	0.88±0.11	0.61±0.03	0.52±0.01	0.79±0.25^{c}
GABA(2mmol/L)	1.17±0.01	0.93±0.03	0.84±0.05	0.76±0.01	0.93±0.16^{b}	1.17±0.01	0.90±0.02	0.66±0.02	0.57±0.02	0.82±0.24^{b}
Zeolite at 3%	1.17±0.01	0.88±0.03	0.79±0.03	0.74±0.03	0.90±0.17^{c}	1.16±0.03	0.85±0.03	0.57±0.01	0.49±0.02	0.76±0.26^{d}
Zeolite at 6%	1.19±0.01	1.01±0.02	0.86±0.01	0.78±0.01	0.96±0.16^{a}	1.19±0.02	1.00±0.02	0.76±0.03	0.64±0.9	0.90±0.61^{a}
Mean	1.16±0.03^{a}	0.91±0.06^{b}	0.81±0.05^{c}	0.72±0.05^{d}		1.16±0.02^{a}	0.89±0..07^{b}	0.63±0.07^{c}	0.53±0.08^{d}	
LSD at 0.05	**Treatments (T)** **Storage Periods (D)** **Interaction (T×D)**				**= 0.020** **= 0.018** **= 0.040**	**Treatments (T)** **Storage Periods (D)** **Interaction (T×D)**				**= 0.025** **= 0.023** **= 0.050**

Mean values followed by different letters are significantly different at P < 0.05 according to Duncan's multiple range tests. *Fruits were stored at 0±1 ºC and 90%-95% RH during the 2022 and 2023 seasons.

Phenols and ascorbic acid are the antioxidant compounds that play an essential role in fruit quality preservation, as well as their importance in consumer health. The data exhibited in Tables 6 and 7 indicates that the contents of total phenols and ascorbic acid in the fruit decreased gradually and significantly with the progress of storage in both seasons. The data also indicated that GABA and zeolite treatments slowed down the loss of total phenols (Table 6) and ascorbic acid (Table 7) during cold storage periods compared to the control group. GABA preharvest treatments followed by zeolite (6%) postharvest treatments were more effective in preserving total phenol contents in stored apricots. However, zeolite at (3% and 6%) in the first season and zeolite at 6% in the second season showed the highest values of ascorbic acid than all other treatments. In general, the antioxidant content of harvested fruit declines with ripening and with prolonged storage periods, either at ambient or cold temperatures (Tavarini *et al.* 2008; Galal 2022). Davarynejad *et al.* (2013) found that the levels of total phenols in apricots were higher at the beginning of the storage period compared to the end, regardless of the treatment. Davey *et al.* (2000) attributed the decrease in ascorbic acid levels during cold storage to the conversion of L-ascorbic acid into dehydroascorbic acid in the presence of oxidizing enzymes such as ascorbate peroxidase and ascorbic acid oxidase. Zeinalipour and Saadati (2024) reported that the nano-zeolite is effective as a preharvest application in improving the content of anthocyanins, antioxidants, and vitamin C for strawberry fruits.

Table 6. Impact of Preharvest Treatment of GABA and postharvest treatment of Zeolite on Total Phenols (mg/g FW) 'Canino' Apricot Fruits*

	Season 2022					Season 2023				
	Storage Periods (Days)					Storage Periods (Days)				
Treatments	**0**	**10**	**20**	**30**	Mean	**0**	**10**	**20**	**30**	Mean
Control	0.475±0.08	0.390±0.01	0.357±0.01	0.195±0.02	0.354±0.1[e]	0.407±0.01	0.298±0.01	0.253±0.01	0.168±0.01	0.282±0.1[e]
GABA(1mmol/L)	0.486±0.01	0.413±0.02	0.380±0.02	0.218±0.04	0.374±0.1[b]	0.464±0.02	0.326±0.02	0.261±0.02	0.191±0.02	0.310±0.1[c]
GABA(2mmol/L)	0.496±0.03	0.423±0.01	0.399±0.01	0.221±0.01	0.384±0.1[a]	0.498±0.03	0.343±0.01	0.283±0.02	0.208±0.02	0.333±0.1[a]
Zeolite at 3%	0.479±0.04	0.398±0.01	0.365±0.02	0.209±0.01	0.362±0.1[d]	0.457±0.01	0.311±0.02	0.259±0.01	0.177±0.01	0.301±0.1[d]
Zeolite at 6%	0.481±0.01	0.410±0.03	0.386±0.01	0.208±0.03	0.371±0.1[c]	0.463±0.02	0.334±0.03	0.276±0.01	0.198±0.02	0.318±0.1[b]
Mean	0.48±0.01[a]	0.41±0.01[b]	0.38±0.0[c]	0.21±0.0[d]		0.46±0.0[a]	0.32±0.0[b]	0.27±0.0[c]	0.19±0.0[d]	
LSD at $_{0.05}$	**Treatments (T) Storage Periods (D) Interaction (T×D)**				**= 0.004 = 0.003 = 0.007**	**Treatments (T) Storage Periods (D) Interaction (T×D)**				**= 0.015 = 0.014 = 0.030**

Mean values followed by different letters are significantly different at P < 0.05 according to Duncan's multiple range tests. *Fruits were stored at 0±1 ºC and 90%-95% RH during the 2022 and 2023 seasons.

Table 7. Impact of Preharvest Treatment of GABA and Postharvest Treatment of Zeolite on Ascorbic Acid (mg/100 g FW) of 'Canino' Apricot Fruits*

	Season 2022					**Season 2023**				
	Storage Periods (Days)					**Storage Periods (Days)**				
Treatments	**0**	**10**	**20**	**30**	Mean	**0**	**10**	**20**	**30**	Mean
Control	14.81±0.11	10.98±0.47	10.13±0.10	7.35±0.38	10.61±0.1[e]	15.66±0.08	10.80±0.16	10.55±0.08	7.87±0.10	11.04±0.1[d]
GABA (1mmol/L)	14.87±0.17	11.75±0.08	10.80±0.19	9.14±0.02	11.61±0.1[b]	15.45±0.08	11.99±0.11	11.03±0.09	9.13±0.11	11.90±0.1[c]
GABA (2mmol/L)	15.18±0.21	12.13±0.01	11.13±0.11	9.45±0.08	11.97±0.1[a]	15.65±0.08	12.21±0.04	11.24±0.10	9.62±0.13	12.18±0.1[b]
Zeolite at 3%	14.90±0.11	12.12±0.01	11.25±0.08	9.87±0.32	12.03±0.1[d]	15.73±0.21	12.20±0.16	11.25±0.08	9.48±0.13	12.17±0.1[b]
Zeolite at 6%	15.00±0.19	12.35±0.08	11.34±0.01	9.85±0.38	12.21±0.1[c]	15.75±0.08	12.35±0.08	11.52±0.13	9.90±0.10	12.38±0.1[a]
Mean	14.83±0.01[a]	11.87±0.01[b]	10.93±0.0[c]	9.1±0.0[d]		15.51±0.0[a]	11.91±0.0[b]	11.12±0.0[c]	9.20±0.0[d]	
LSD at 0.05	**Treatments (T)** **Storage Periods (D)** **Interaction (T×D)**				**= 0.18** **= 0.16** **= 0.35**	**Treatments (T)** **Storage Periods (D)** **Interaction (T×D)**				**= 0.11** **= 0.09** **= 0.22**

Mean values followed by different letters are significantly different at $P < 0.05$ according to Duncan's multiple range tests. *Fruits were stored at 0±1 ºC and 90%-95% RH during the 2022 and 2023 seasons

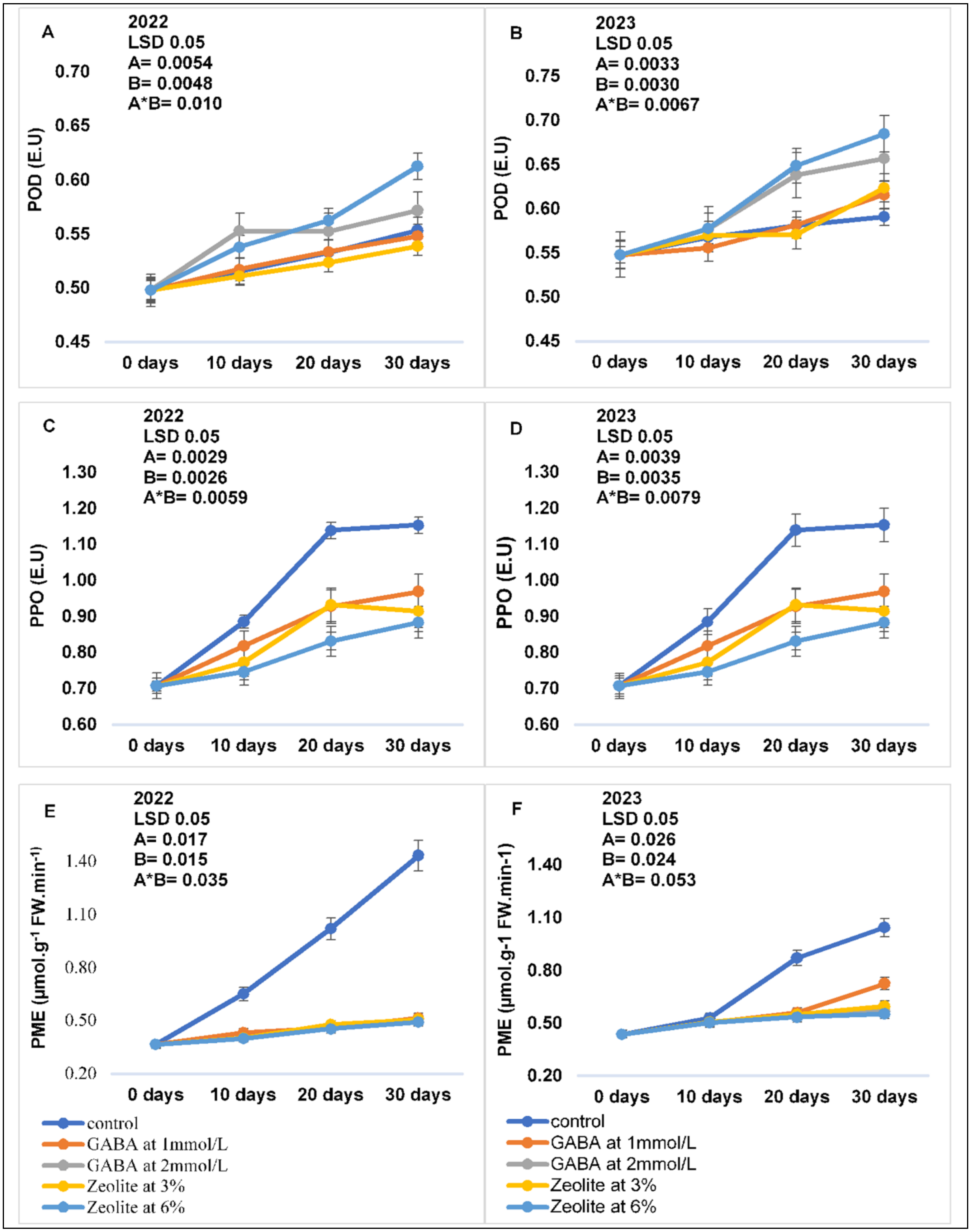

Fig. 4. Impact of preharvest treatment of GABA and postharvest treatment of zeolite on enzyme activity of peroxidase (POD) (A and B), polyphenol oxidase (PPO) (C and D) and pectin methyl esterase (PME) (E and F) of "Canino" Apricot fruits stored at 0±1 ºC and 90% to 95% RH during the 2022 and 2023 seasons respectively. Error bars represent the standard deviation. LSD $_{0.05}$ (A= treatments, B= storage period, A*B= interaction).

Similar findings were reported before that zeolite and GABA treatments increased the antioxidant capacity of treated fruit. Zeolite treatments increased total antioxidant activity including superoxide dismutase, ascorbate peroxidase, phenolics, flavonoids, and carotenoids of grapes for 60 days of storage (Huwei *et al.* 2021). GABA raised the levels of ascorbic acid, total phenol, and flavonoids in peaches (Solimani-Aghdam *et al.* 2016a). Also, Rastegar *et al.* (2020) revealed that the use of GABA postharvest treatments effectively preserved the levels of ascorbic acid, phenols, and flavonoids in mangoes during the storage period at a temperature of 15 °C.

Enzymes Activities

The POD and PPO are key enzymes for supporting plant growth, development, and defense through physiological and structural roles. The activities of enzymes were significantly affected by treatments (Figs. 4, A and B). The application of high concentrations of zeolite and GABA induced the highest POD for both seasons. POD is an antioxidant enzyme that prevents the harmful effects of free radicals by eliminating these molecules, which maintain the integrity of the cell membrane (Zhang *et al.* 2023). On the other hand, the PPO activity was significantly higher by control treatment compared to Zeolite and GABA treatments. However, the data exhibited in Figs. 4 (C and D), indicates that the activity of PPO enzyme increased gradually for all treatments. PPO is responsible for the browning of the peel and flesh of fruit and vegetables. So, the decrease of PPO activity is useful for preventing fruit browning and deterioration (Abdel-Sattar *et al.* 2023). Data in the present study is in harmony with research done by Khaliq *et al.* (2023), on papaya fruits, who found that the GABA application decreased the activity of PPO as well as chilling injury. Moreover, the treatments were effective in decreasing the activity of PME for both seasons (Figs. 4, E, and F). However, the maximum activity of PME was recorded in the control treatment, while the lowest was noticed for the treatments of higher concentrations of zeolite and GABA. PME is one of the pectin solubilization enzymes group that increase during the ripening processes of fruits and vegetables (Kaur *et al.* 2012) and accompanies the fruit softening and shortening of the fruit shelf life (Guzmán *et al.* 2012). The treatments of the present study suppressed the activity of PME compared the control. GABA and Zeolite treatments delay fruit ripening and extend its shelf life (Aghdam *et al.* 2012; Allegro *et al.* 2024). Additionally, they provide a different approach to preserving the nutritional value and aesthetic appeal of fruit during the postharvest phase.

CONCLUSIONS

In this research, the efficacy of pre-harvest spraying with γ-aminobutyric acid (GABA) and postharvest dipping in zeolite was examined to prolong the storage ability and preserve the quality of ‘Canino’ apricot fruits.

1. Application of either 2 mmol/L GABA or 6% zeolite significantly reduced the rate of respiration, weight loss, and fruit decay during cold storage at 0±1 ºC and 90% to 95% RH.
2. Additionally, 2 mmol/L GABA or 6% zeolite effectively mitigated fruit deterioration by enhancing fruit firmness, positively influencing total soluble solids and sugar levels,

and maintaining higher levels of total acidity, total phenols, and vitamin C throughout the cold storage period compared to the control group.

3. Furthermore, the treatments increased peroxidase (POD) and decreased polyphenol oxidase (PPO), and pectin methyl esterase (PME) enzymes' activities compared to the control, which could help in prolonging the apricot postharvest life. However, further investigations are needed to examine more concentrations and the combined effects of both treatments on the quality and storability of apricot fruits.

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Conflicts of Interest

The authors declare that there are no conflicts of interest related to this article.

Data Availability Statement

All the necessary records are included in the document.

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