

Thesis of doctoral (PhD) dissertation

**POMOLOGICAL EVALUATION OF APRICOT CULTIVARS AND
THE ROLES OF POSTHARVEST APPLICATION OF SALICYLIC
ACID AND METHYL JASMONATE ON STRESS RESISTANCE**

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1. Introduction

The apricot (*Prunusarmeniaca* L.) is one of the most important fruit species grown in the world, as apricot fruit is highly appreciated by consumers. Consumers cherish the flavour and aroma of high quality apricots, with the sugar content being one of the most appreciable quality characteristics (Ruiz and Egea, 2008).

Apricot fruit is usually stored in cold storage and many apricot cultivars can be stored for 4-6 weeks and these cultivars are able to keep an acceptable level of fresh firmness and other quality attributes. However, once the fruit is taken out from cold chamber the fruit start to deteriorate (Stanley *et al.*, 2010). Apricot fruits during cold storage were reported to show chilling injury symptoms and a high percentage of fruit decay, such as mealiness development, loss of juiciness and/or gel breakdown (Stanley *et al.*, 2010). Apricot fruit starts to lose its physical and chemical qualities directly after harvest and through the storage period. Fruits start to lose their water content reaching 12% after 28 days at 1 °C. This is accompanied with fruit softening, increased fruit acidity and reduction in soluble solid content (SSC) (Ezzat *et al.*, 2012).

Storage at low temperature to retard tissue respiration is still the most effective postharvest method for extending the shelf-life. But most of cold stored fruit present the chilling injuries (CI)symptoms, and subsequently fruit loss most of qualities parameters.

The use of chemical compounds to potentiate the natural defense of plants represents another alternative, potentially promising way to disease control (Kessmann *et al.*, 1994). Many reports have shown that induced disease resistance in plants by biotic and abiotic elicitors is a very effective method for restricting the spread of fungal infection (Droby *et al.*, 2002; Qin *et al.*, 2003).

Two signaling pathways have been described by Thaler *et al.* (1999), one involving salicylic acid (SA) and another involving jasmonic acid (JA), which participates in the expression of plant resistance to pathogens and insect herbivores. SA is thought to be a key compound in the regulation of resistance to fungal, bacterial and viral pathogens and provides a signal for

expression of PR-proteins and other potential protective compounds (Ryals *et al.*, 1996). However, exogenous application of JA has been demonstrated to induce systemic acquired resistance (SAR) in plants by stimulating many of the systemic metabolites, similar to that which occurs from challenge with pathogens or insects (Kessmann *et al.*, 1994). The importance of the phytohormones SA and JA as critical signals in induced resistance response in plants is recognized (Bostock, 1999). These signal molecules are involved in some signal transduction systems, which induce particular enzymes catalyzing biosynthetic reactions to form defense compounds such as polyphenols, alkaloids or pathogenesis-related (PR) proteins (Tamariet *et al.*, 1995; Van Loon, 1995).

SA has been extensively used for quality improvement in a number of crops (Peng and Jiang, 2006). Research argued the role of phenolic compounds such as SA in physiological or biochemical processes including ion uptake, membrane permeability, enzyme activity, heat production, growth development (Arberg, 1981). SA significantly reduced the quality loss in peaches (Wang *et al.*, 2006), tomato (Ding *et al.*, 2001), sweet peppers (Funget *et al.*, 2004), and loquat fruits (Cai *et al.*, 2005). SA and its derivatives are widely used to enhance pre- and postharvest quality of fruit such as by controlling firmness of harvested peaches during storage, (Wang *et al.*, 2006) and banana fruits during ripening (Srivastava and Dwivedi, 2000). Thus, SA has a remarkable ability to maintain the fruit quality during storage life of fruits.

Several natural volatile compounds, such as methyl jasmonate (MeJA), were reported to maintain fruit quality. For instance, MeJA reduced the development of chilling injury symptoms in mango (González-Aguilar *et al.*, 2000). Treatment of tomato fruit with low concentration of MeJA or methyl salicylate (MeSA) substantially enhanced their resistance to chilling injury and decreased the incidence of decay during low-temperature storage (Ding *et al.*, 2001; Wang *et al.*, 2006).

Phenolic compounds are secondary metabolites that have important contribution to plant-derived food quality as they affect fruits, appearance, flavour and health-promoting properties. Their content in foods is modulated by many factors that influence phenolic stability, biosynthesis and

degradation. In their biosynthesis, the key step is catalyzed by the enzyme phenylalanine ammonia-lyase (PAL), which can be induced by various stress conditions (Dixon and Paiva, 1995).

Two vital antioxidant enzymes, superoxide dismutase (SOD) and catalase (CAT) play significant roles in scavenging free radicals produced as a result of metabolic processes. SOD converts OH^- into H_2O_2 which is converted into H_2O and O_2 by catalase (CAT)(Sala, 1998). Higher peroxidase (POD) activity resulted in lower browning incidence in treated peach fruits compared with control (Wills *et al.*, 1998).

As a consequence, a general requirement is to raise or at least to maintain the acceptable levels of qualities and chemical characters of apricot during a cold storage period and shelf-life.

The aims of this study were to investigate

- The effect of 0, 1, and 2 mmol L^{-1} SA concentrations on ‘Flavor Cot’, ‘Jumbo Cot’, and ‘Bergeron’ apricot cultivars and to understand the mechanism of SA in enhancement the storability and fruit quality attributes.
- The effect of 2 mmol L^{-1} SA and/or 0.2 mmol L^{-1} MeJA on various fruit quality limits of apricot fruit cultivar Bergarouge.
- The effect of 2 mmol L^{-1} SA and 0.4 mmol L^{-1} MeJA on induced resistance to *Monilialaxa* on apricot fruit cv. ‘Bergarouge’.

2. MATERIALS AND METHODS

2.1. Effect of three SA concentrations on fruit three apricot cultivars during cold storage

3.1.2 3.1.1 Fruit sample and tested cultivars

Fruits of apricot cultivars Jumbo Cot, Flavor Cot and Bergeron were hand harvested in a commercial orchard in Boldogkőváralja, Hungary at ripe stage and selected for uniform size, colour and examined to exclude all visual defects.

3.1.3 Chemical treatments

The harvested fruits of each cultivar were divided into three groups. Fruits were dipped into a solutions of 0.5, 1 and 2 mmol L⁻¹ SA for 15 minutes as well as control fruits were submerged into distilled water, for the cold storage treatment, fruit was stored at 1 °C and 90% humidity. The examinations were done on days 7, 14, 21 and 28. Each treatment was replicated three times and experiments were repeated twice.

3.2 Effect of SA and/or MeJA on variousfruit quality parameters , of fruit of apricot cultivar ‘Bergarouge’

3.2.1 Fruit sample

Fruits of apricot cultivar ‘Bergarouge’ were hand harvested in a commercial orchard in Boldogkőváralja, Hungary at ripe stage and selected for uniform size, colour and examined to exclude all visual defects.

3.2.2 Chemical treatments

The harvested fruits were divided into three groups. Fruits were dipped into a solution of 0.2 mmol L⁻¹MeJA and 2 mmol L⁻¹ SA for 15 minutes as well as control fruits were submerged into distilled water. Then for each treatment, fruits were divided into 2 further groups. The first group, as the cold storage treatment, was stored at 1 °C and examinations were done on days 7, 14 and 21. The second group, as the shelf-life treatment, was stored at 1 °C and 95% humidity for 15 days then placed at room temperature (25 °C) and fruits were examined at 4 and 8 days. Each treatment was replicated three times and experiments were repeated twice.

3.3. Effect of SA and/or MeJA on induce resistance to *Monilialaxa* on apricot fruit cultivar Bergarouge

3.3.1 Isolation of fungi

M.laxa were isolated from decayed plum fruit. The fungi were maintained on PDA at 4 °C. Spores of *M. laxa* were obtained from 2-week-old cultures incubated at 25 °C by flooding the cultures with sterile distilled water containing 0.05% (v/v) Tween 80. The suspensions of spores were filtered through four layers of sterilized cheese cloth. The concentrations of spores were adjusted to (1×10^3 spores mL⁻¹) with the aid of a haemocytometer.

3.3.2 Mycelial growth

The concentrations of (0.5, 2 and 5 mmol L⁻¹) of SA and (0.1, 0.4 and 0.7 mmol L⁻¹) of MeJA were used to study the effects on mycelial growth of monilialaxa. The effects were assayed by the method of Yao and Tian (2005a). Each concentrate of SA and MeJA solution mixed with molten PDA-agar to give a total volume of 20 mL per petri plate (diameter: 90mm). After the agar had solidified, 5mm disks of *M. laxa* were placed in the center of each petri plate. Plates were incubated at 25 °C. Colony diameter was determined 6 days after inoculation. Each treatment was replicated three times and the experiment was repeated twice. Mycelial growth of *M. laxa* on PDA was expressed as growth rate, which was calculated according to the following formula:

$$\text{Growth rate (\%)} = (\text{colony diameter after inoculation} - 5\text{mm}) / 5\text{mm} \times 100.$$

After the determination of the appropriate concentration the experiment was repeated as 2 mmol L⁻¹ SA and 0.4 mmol L⁻¹ MeJA solution mixed with molten PDA-agar and the growth rate was measured after 2, 4, 6 and 8 days of incubation.

3.3.3 Sample preparation

Fruits of cv. Bergarouge were hand harvested in the orchard of North-Cot Ltd located in Boldogkőváralja, Hungary at ripe stage and selected for uniform size, colour and examined to exclude all visual defects. Primarily samples were taken from the fruit directly after harvest and undergone for firmness measurements, analysis of totalphenol content, antioxidant capacity, SOD, POD, PAL activities and lignin content and the results was expressed as zero time.

3.3.4 Exploratory experiment

The measurement of the appropriate concentration of SA and MeJA, 30 fruits were dipped into solution of (0.5, 2 and 5 mmol L⁻¹) of SA and (0.1, 0.4 and 0.7 mmol L⁻¹) of MeJA for one hour as inducing treatments and water treated fruit were control. Fruit were sterilized with 2% (v/v) sodium hypochlorite for 4 minutes then washed with tap water and dried by air. Each chemical treated group was divided into two inoculation treatment. One group was wounded (a uniform hole 3mm deep and 3 mm wide) with a sterile borer. After 2 hours, the fruit were inoculated by *M. laxa* suspension. The other was not wounded, after 8 days; the fruit were examined for lesion diameter (mm) and fruit disease incidence (%). After set the tested concentrations the same experiment was repeated with 360 fruit. Divided into three chemical treatments (2 mmol L⁻¹ SA, 0.4 mmol L⁻¹ MeJA and water) then each group was divided into two inoculation treatments (inoculated and non inoculated). There were three replicates for each treatment; fruits were put in 200mmx130mmx50mm plastic boxes at humidity about (95%) at temperature 25 °C.

3.3.5 Effect of salicylic acid on disease severity of apricot fruit

The number of the infected fruit in non-inoculated treatment and the average lesion diameter was measured as increasing diameter over the wound of experiment after 2, 4, 6, and 8 days at 25 °C the diameter of wounds were

considered as zero mm. Apricot fruits showing surface mycelial developing symptoms were considered as decayed fruit. Fruit disease incidences were estimated by the mean proportion of fruit that showed 1 mm decay at fruit surface. Fruit firmness (N) was measured by MagnessTazlor penetrometer (model FT011, QA Supplies LLC, Italy) directly after harvested as zero time and periodically after 2, 4, 6, and 8 days of treatments.

3.4. Measurements of the fruit pomological characters

Measurements for weight loss, fruit firmness, SSC, acidity SSC/acidity ratio and JuicepH were performed on 30 fruits in three replicates immediately after harvest as day zero. Then 30 treated fruits per replicates were examined for each measure according to cold storage and shelf-life treatments.

The following parameters were determined:

- 3.4.1 Weight loss (%) as different between the weight at zero day and the weight at assessment days.
- 3.4.2 Fruit firmness as penetration force (Newton) by Magness Tazlor penetrometer (model FT011, QA Supplies LLC, Italy).
- 3.4.3 Juice SSC (degrees Brix) by portable digital refractometer (Model 53007 TR, TR-Turoni Inc Forli, Italy) at 25 oC.
- 3.4.4 Juice acidity (%) by portable digital acidity meter (Model 53101 TR, TR-Turoni Inc Forli, Italy).
- 3.4.5 SSC/acidity ratio was calculated. The prepared juice of the sample was used for chemical analysis.
- 3.4.6 pH measurements were performed using a (84432 HANNA instruments®, Germany) pH meter.

3.5. Examination of chilling injury, fruit decay, membrane electrolyte, mealiness development and loss of juiciness

Chilling injury and fruit decay were investigated in both cold storage and shelf-life treatments by using 30 fruits per replicates.

3.5.1 The degree of chilling injury (CI) was visually investigated on the fruit surface following a double cut parallel to the axial diameter. The extent of flesh browning was divided into the following classes: 0, no browning; 1, extensive browning covering <25% of the cut surface; 2, extensive browning covering $\geq 25\%$ but <50% of cut surface; 3, extensive browning covering $\geq 50\%$ but <75% of cut surface; 4, extensive browning covering $\geq 75\%$ of cut surface. From this, a CI index was expressed as:

CI index = [(flesh browning class) × (number of fruit at the given flesh browning class)] / (4 × total number of fruit in the treatment).

3.5.2 Fruit decay (FD) was assessed as symptoms of superficial browning on the fruit surface. The severity of the symptoms was assessed visually according to the following scale: 0, no browning; 1, browning $\geq 25\%$ of the fruit surface; 2, browning $\geq 25\%$ but <50% of the fruit surface; 3, browning $\geq 50\%$ but <75% of the fruit surface; 4, browning $\geq 75\%$ of the fruit surface. From this, FD index was expressed as:

FD index = [(superficial browning class) × (number of fruit at the given superficial browning class)] / (4 × total number of fruit in the treatment).

3.5.3 Electrolyte leakage was measured according to the method of Zhao, (2009). 3 mm thick of mesocarp tissue were excised from equator part of 5 fruits. Disks were put into aqueous 0.1M mannitol under constant shaking. The conductivity of

the solution (L1) was measured with a conductivity meter. Solutions were boiled for 10 min and then cooled to 20 °C. The conductivity of tissues (L2) was measured. The percentage of electrolyte leakage was calculated using the following formula: %Electrolyte leakage $(L1/L2) \times 100$.

- 3.5.4 mealiness and juiciness, each fruit was tasted three trained assessors independently and rated. Mealiness was considered to be a woolly or lumpy texture and fruit were scored on a scale from 0 (no mealiness) through to 3 (high mealiness). Juiciness was considered to take into account the amount of free fluid released from the sample during chewing and fruit were scored for juiciness on a scale from 0 (no juice) through to 3 (very juicy).

3.6. Chemical measurements

3.6.1 Total amount of soluble phenols

Total amount of soluble phenols were determined using Folin-Ciocalteu's reagent (Singleton and Rossi, 1965). The content of soluble phenols was calculated from a standard curve obtained from different concentrations of gallic acid.

3.6.2 The total antioxidant capacity

The total antioxidant capacity related to ascorbic acid was determined spectrophotometrically using the FRAP (Ferric Reducing Antioxidant Power) (Benzie and Strain, 1996). It is based on the reduction of the Fe^{3+} -TPTZ complex to the ferrous form at low pH. This reduction is monitored by measuring the absorption change at 593nm. Results are expressed as mg equivalents of ascorbic acid ($mg\ AA\ g^{-1}\ FW$).

3.6.3 Lignin content

Lignin was gravimetrically determined according the methods of Femenia *et al.*, (1998) with some modification. Samples were dispersed in 72% H₂SO₄ at room temperature for 6 h then diluted to 1 M H₂SO₄ and heated to 100°C for 2.5 h. Insoluble material was recovered by filtration and washed thoroughly with hot water (90°C) until acid free before drying at 105 °C overnight. The residue weight was recorded as lignin content with the results expressed as a percentage.

3.6.4 Total carotenoid content

Total carotenoids were extracted according to Akin *et al.*, (2008) with some modifications. Briefly, five grams of sample was extracted with 100 mL of methanol/petroleum ether (1:9, v/v) using a high speed homogenizer, and the homogenized was transferred to a separating funnel. Petroleum ether layer was filtrated through sodium sulphate, transferred to volumetric flask and to a volume of 100 mL with petroleum ether. Finally, total carotenoid content was measured spectrophotometrically (Hitachi UV2800 spectrophotometer) at 450 nm. Carotenoid content was evaluated by using an extinction coefficient of 2500, and results were expressed as β-carotene equivalents (milligrams per 100 g of FW).

3.6.5 Ascorbic acid content

Ascorbic acid content was estimated spectrophotometrically by dinitrophenylhydrazine (DNPH) method (Terada *et al.*, 1978) the ascorbic acid content was expressed as ascorbic acid on fresh weight basis, mg per 100 g fresh weight.

3.7. Enzymes activities assessment

3.7.1 Sampling and enzyme extraction

Fruit samples were collected at the assessment times of each experiment at 1 °C according to cold storage treatment and at 4 and 8 days after cold storage of 15 days at 1 °C according to the shelf-life treatment. Each treatment was replicated three times.

3.7.2 PAL activity

Flesh (10 g) from 10 fruits was homogenized in 25 ml of 50 mmol L⁻¹ sodium borate buffer (pH 8.8, containing 5 mmolβ-mercaptoethanol) containing 0.5 g PVPP. PAL activity was then measured according to the method of Assis *et al.*, (2001) with slight modifications. Enzyme extract (1 ml) was incubated with 2 ml of borate buffer (50 mmol L⁻¹, pH8.8) and 1 ml of L-phenylalanine (20 mmol L⁻¹) for 60 min at 37 °C. The reaction was stopped with 1 ml HCl (1 mol L⁻¹). PAL activity was determined by the production of cinnamate, which was measured at 290 nm. The blank was the crude enzyme preparation mixed with L-phenylalanine with zero time incubation. PAL activity was defined as nmol cinnamic acid h⁻¹ mg⁻¹ protein.

3.7.3 POD activities

0.5 ml of enzyme extract was incubated in 2 ml buffered substrate (100 mmol L⁻¹ sodium phosphate, pH 6.4 and 8 mmol L⁻¹ guaiacol) for 5 min at 30°C and the increasing absorbance was measured at 460 nm every 30 s for 150 s after adding 1 ml of H₂O₂ (24 mmol L⁻¹).

3.7.4 SOD activity

Fruit tissue (1 g) was ground in 5 mL of 50 mmol L⁻¹ sodium phosphate buffer (PH 7.0). The extracts were then homogenized and centrifuged at 10.000 x g for 20 min at 4 °C, the supernatants were used for enzyme assay.

SOD activity was then determined photochemically by the method of Rao *et al.*, (1996) The reaction mixture contained 50 mmol L⁻¹ sodium phosphate (pH 7.8), 14 mmol L⁻¹ methionine, 3 μmol L⁻¹ EDTA, 1 μmol L⁻¹ nitro-blue-tetrazolium (NBT), 60 μmol L⁻¹ riboflavin and 0.1 ml crude enzyme extract in a total volume of 3 ml. The formation of blue formazan was monitored by recording the absorbance at 560 nm. One unit of SOD activity was defined as the amount of enzyme that causes a 50% inhibition of NBT reduction under assay conditions.

3.7.5 CAT activity

According to the method of Abbasi *et al.*, (1998). Two buffer solutions (A and B) were used to carry out the catalase enzyme reaction. A 50 μL enzyme extract was added to each of two cuvettes, one containing 1 mL buffer A and the other containing 1 mL buffer B. The change in optical density at 240 nm was recorded by means of a spectrophotometer after 45 s and 60 s at the time when the extract was added to the cuvettes. The difference in optical density between the 45 s and 60 s reading was used to calculate the CAT activity. CAT activity was expressed as U g^{-m} protein.

3.7.6 Protein content

In the enzyme extracts was estimated using the Bradford, (1976) method, using bovine serum albumin as a standard. Specific activity of all the enzymes was expressed as units per milligram protein.

3.8. Sensory analysis

Each sample was prepared on a white dish by presenting a 30 fruits and prepared short time before sensory testing, to ensure a glossy aspect and to avoid flesh browning. Each dish was marked with a 3-digit code, assigned at random. The evaluation guide provided a continuous scale for each sensory attribute, ranging from 0 to 9, and marked with two anchors (skin color: 0 = very bad, 9 = very good; flesh color: 0 = very bad, 9 = very good; Texture: 0 = very soft, 9 = very hard; Taste: 0= low taste and 9 = good taste; Visual

appearance: 0 = very bad appearance, 9 = very good appearance) and over all acceptability (0 = I dislike the sample, and 9 = I like the sample very much). Scores of 5 or above were considered acceptable for commercial purposes. These scales had been used previously to evaluate harvest maturity stage effects on apricot sensory with some modification (Infant *et al.*, 2008).

3.9. Statistical analysis

Experiments were performed using a completely randomized design. Statistical analyses were performed with SPSS program (SPSS Inc., Chicago, IL, USA). The data were analyzed by one-way ANOVA. Means separation was performed by Duncan's multiple range tests. Differences at $P < 0.05$ were considered as significant.

3. RESULTS AND DISCUSSION

3.1. Effect of three SA concentrations on three apricot cultivars in cold storage treatment

3.1.1 Effect of SA on weight loss and fruit firmness

Different concentration of SA show different effects on fruit weight loss and fruit firmness on tested cultivars. Results in (Figs. 1 and 2) showed that 0.5 mmol L⁻¹ of SA had no significant effects on all the cultivars during all the cold storage dates. Treated fruit with 2 mmol L⁻¹ SA of cvs. Flavor Cot and Jumbo Cot recorded significant values in comparison to water, 0.5 and 1 mmol L⁻¹ SA treated fruit over 2nd and 3rd week of cold storage, respectively. While Bergeron fruit treated with 1 and 2 mmol L⁻¹ SA showed better firmness and lower weight loss over the 1st and 2nd week of storage, respectively ($P < 0.05$). All of 2 mmol L⁻¹ SA treated fruit showed the lowest values of fruit weight loss and highest fruit firmness ($P \leq 0.05$) over 3 weeks of cold storage in all the tested cultivars

3.1.2 Effect of SA on SSC and total acidity

Cultivars Jumbo Cot and Bergeron fruit treated with 2 mmol L⁻¹ SA showed unchanged values for SSC and acidity over the 2nd week of cold storage, and then the values took to reduce slightly over the end time of storage (P<0.05). The 0.5, 1.5 mmol L⁻¹ SA and water treated fruit showed high increase for SSC and acidity (P<0.05) at the 1st storage week then the values decreased dramatically over the 3rd week (Figs. 3 and 4).

Flavor Cot recorded unchanged of SSC for all the chemical treatments during two weeks of cold storage (P≥0.05) then water and 0.5 mmol L⁻¹ SA treated fruit showed decrease for SSC values (P<0.05) over the 3rd storage week. Meanwhile, 1 and 2 mmol L⁻¹ of SA treated fruit showed increase in SSC over the 4th week. Untreated, 0.5 and 1 mmol L⁻¹ treated fruit showed increase of acidity during 3 weeks of cold storage. Meanwhile, 2 mmol L⁻¹ SA treated fruit showed about stable values of acidity over 2 weeks of storage. (Figs.3 and 4).

3.1.3 Effect of SA on total carotenoids content and ascorbic acid content

All the SA concentrations treatments showed better carotenoids content than the water treated fruit. Cv. Flavor Cot fruit treated with 2 mmol L⁻¹ SA showed increase of carotenoids content over the 3rd week of cold storage (P<0.05) in comparison to water treated fruit. The 0.5 and 1 mmol L⁻¹ SA treated fruit showed intermediate values with also, significance differences than control fruit (Fig. 5). The same trend was noticed for cv. Jumbo Cot fruit (Fig. 3), except that the 0.5 SA treatments did not show any enhancement for the carotenoids content with no significance differences with control fruit. Also, the cv. Bergeron fruit (Fig. 5) treated with 1 and 2 mmol L⁻¹ SA showed high carotenoids content all over the storage times (P<0.05) in comparison to water and 0.5 mmol L⁻¹ SA treated fruit. Control fruit showed the highest increase of ascorbic acid during the 2 weeks of storage and then the values decreased dramatically over the 3 weeks (P<0.05) in all the tested cultivars.

2 mmol L⁻¹ SA Jumbo Cot treated fruit showed slightly unchanged ascorbic acid values over the 3rd week storage the slight decrease was noticed while the 1 mmol L⁻¹ SA treatments showed decrease of ascorbic acid at the 2nd week of storage. The same trend was noticed for cv. Bergeron fruit (Fig. 6).

The Flavor Cot fruit treated with 2 mmol L⁻¹ exhibited about unchanged values of AS over all the assessment times with significance differences with all of other treatments. The 0.5 and 1 mmol L⁻¹ SA Flavor Cot treated fruit showed increase of ascorbic acid early of storage while recorded deep reduction at the 3rd week (Fig. 8).

3.1.4 Effect of SA on total soluble phenol, antioxidant capacity, DI, CI and membrane electrolyte leakage

Water treated fruit showed decrease in total soluble phenol content during the 3 weeks of storage followed with increase in 4th storage week with significant differences. Low concentration of SA (0.5 mmol L⁻¹) showed non significance differences with the control fruit in all tested varieties.

1 and 2 mmol L⁻¹ SA treated Jumbo Cot and Flavor Cot fruit showed about stable total soluble phenol content during the 3 weeks of storage then the values increased (Fig. 7).

The same trend was noticed for Bergeron while, treated fruit with 2 mmol L⁻¹ SA showed increase in the total phenol content at the 1st storage week then the values took to be roughly stable over the 4th week (Fig. 7). Antioxidant capacity of SA treated fruit in all the tested cultivars, increased gradually over the 1st, 2nd and 3rd storage week then the deep depression was noticed with significant differences with control, 0.5 and 1 mmol L⁻¹ SA treated fruit all over the storage periods (Fig. 8). The data of DI and CI (Table 1) showed that all the SA concentrations had positive effect in reducing the fruit decay. Jumbo Cot and Flavor Cot fruit treated with 1 and 2 mmol L⁻¹ SA showed significant reducing of CI over the 3rd week of storage and then the values increased ($P \geq 0.05$) in comparison to 0.5 SA and control fruit. Bergeron treated fruit with 2 mmol L⁻¹ SA showed the lowest values of CI at early of the storage periods and till the 4th week followed by values of 1 and 0.5 mmol L⁻¹ SA treated fruit.

The fruit decay data (Table 1) showed the same trend of CI, the values reduces with the increase of SA concentration and the differences between 1 and 2 mmol not found in all cultivars over all the storage times.

Fruit treated with 1 and/or mmol SA treatments exhibited low membrane electrolyte leakage ($P < 0.01$) at early storage time (1st and 2nd week) in comparison to 0.5 mmol SA and control fruit then the significance not found between the treatments in all the cultivars. 0.5 mmol L⁻¹ treated fruit showed the same behavior like untreated fruit in all the cultivars all over the storage time (Fig. 9).

Table 1 Effect of treatments of 0, 1, and 2 mmol L⁻¹ salicylic acid (SA) on chilling injuries (CI) and decay index (DI) of cvs. 'Flavor Cot', 'Jumbo Cot', and 'Bergeron' apricot fruit

| Varieties | SA conc. | CI ^a | | | | FD(%) ^b | | | |
|------------|----------|------------------------------|------------|------------|------------|------------------------------|------------|------------|------------|
| | | Cold storage assessment date | | | | Cold storage assessment date | | | |
| | | Day 7 | Day 14 | Day 21 | Day 28 | Day 7 | Day 14 | Day 21 | Day 28 |
| Flavor Cot | water | 05.26 A ^c | 18.12 A | 29.12 A | 38.24 A | 17.25 A | 22.35 A | 30.25 A | 45.58 A |
| | 0.5 mmol | 04.21 A | 16.24 A | 25.25 A | 35.12 A | 17.52 A | 21.25 A | 32.25 A | 40.25 A |
| | 1 mmol | 02.01 B | 10.26 B | 16.24 B | 29.25 A | 13.22 A | 15.15 A | 20.52 A | 28.25 A |
| | 2 mmol | 02.51 B | 05.62 B | 10.25 C | 26.25 A | 09.25 A | 12.35 A | 18.12 A | 20.01 A |
| Jumbo Cot | water | 4.23 A | 17.25 A | 30.25 A | 39.24 A | 16.58 A | 25.25 A | 38.25 A | 55.25 A |
| | 0.5 mmol | 4.25 A | 17.25 A | 25.23 A | 36.12 A | 16.25 A | 23.25 A | 38.01 A | 55.68 A |
| | 1 mmol | 3.12 B | 9.15 B | 10.57 B | 26.15 A | 10.12 A | 12.25 A | 22.52 A | 40.68 A |
| | 2 mmol | 2.01 C | 5.36 B | 13.25 B | 20.15 B | 8.12 A | 11.15 A | 19.24 A | 31.25 A |
| Bergeron | water | 5.12 A | 16.57 A | 28.24 A | 36.25 A | 18.25 A | 30.25 A | 42.25 A | 53.24 A |
| | 0.5 mmol | 4.05 B | 8.25 B | 18.35 B | 22.54 A | 17.25 A | 32.25 A | 34.58 A | 40.25 A |
| | 1 mmol | 4.20 B | 7.65 B | 15.24 B | 21.25 A | 11.02 A | 15.25 B | 21.35 B | 30.25 B |

^a CI index: chilling injury index.

^bFD (%) index: decay index percentage of the fruit

^cValues within a column followed by different letters are significantly different at $P < 0.05$ according to Duncan's multiple range tests. The results represent the means \pm SD of triplicate assay.

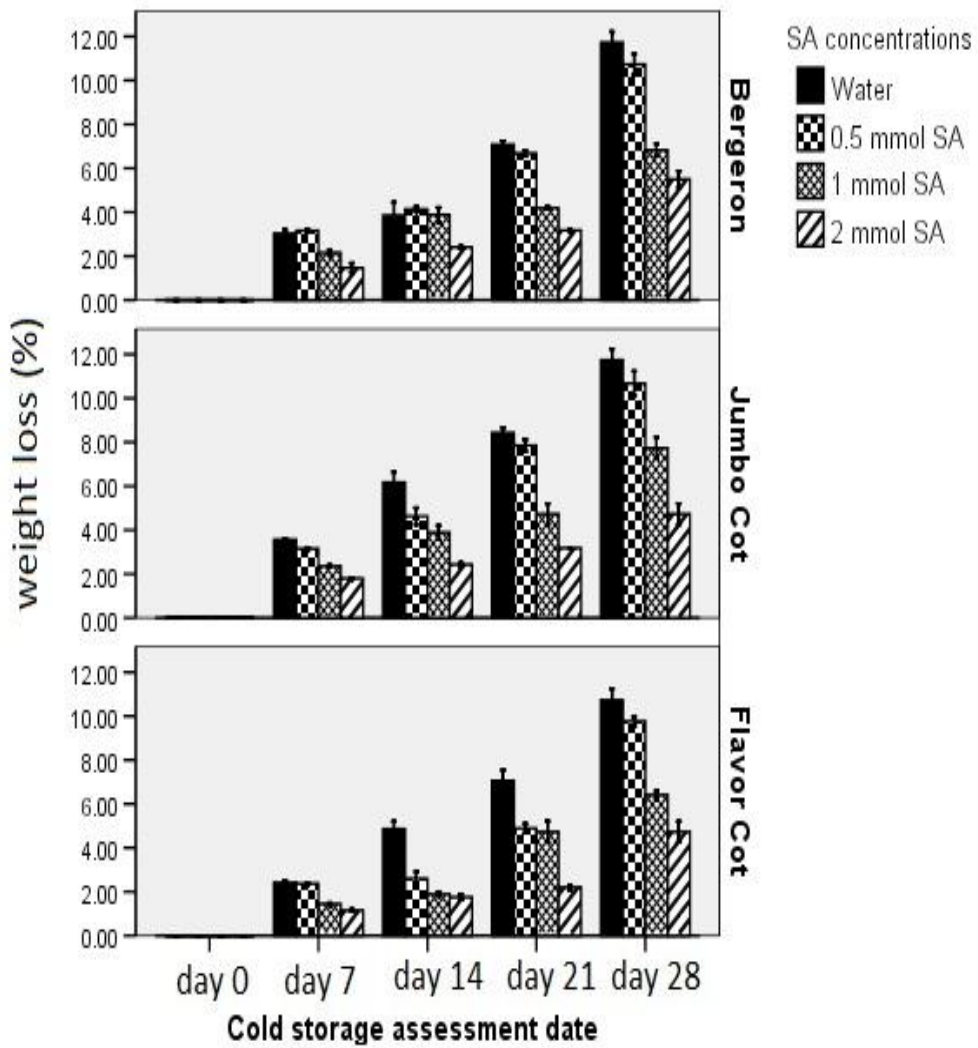


Fig. 1 The effect of treatments of 0, 1, and 2 mmol L⁻¹ salicylic acid (SA) on on weight loss percentage of apricot fruit (cvs. 'Flavor Cot', 'Jumbo Cot', and 'Bergeron') in cold storage treatment at days 7, 14, 21 and 28 at 1 °C.

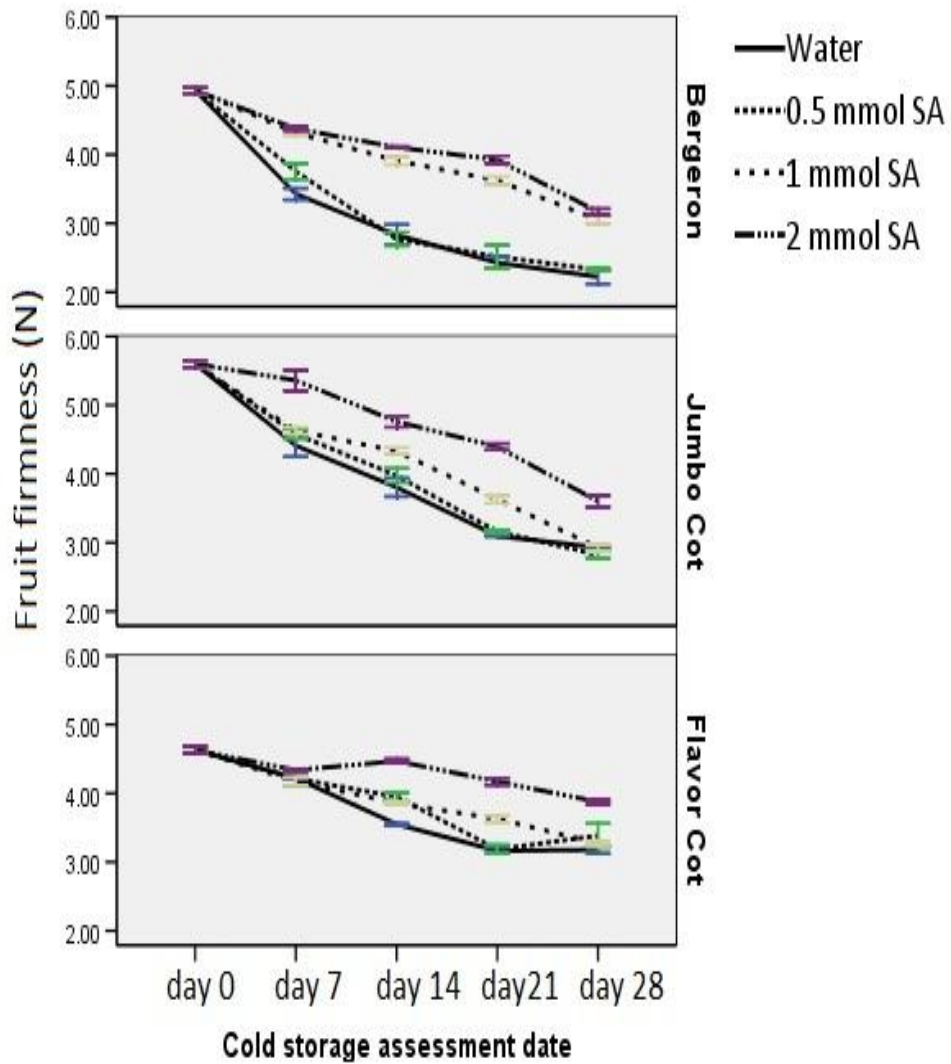


Fig. 2 The effect of treatments of 0, 1, and 2 mmol L⁻¹ salicylic acid (SA) on on fruit firmness (N) of apricot fruit (cvs. ‘Flavor Cot’, ‘Jumbo Cot’, and ‘Bergeron) in cold storage treatment at days 7, 14, 21 and 28 at 1 °C.

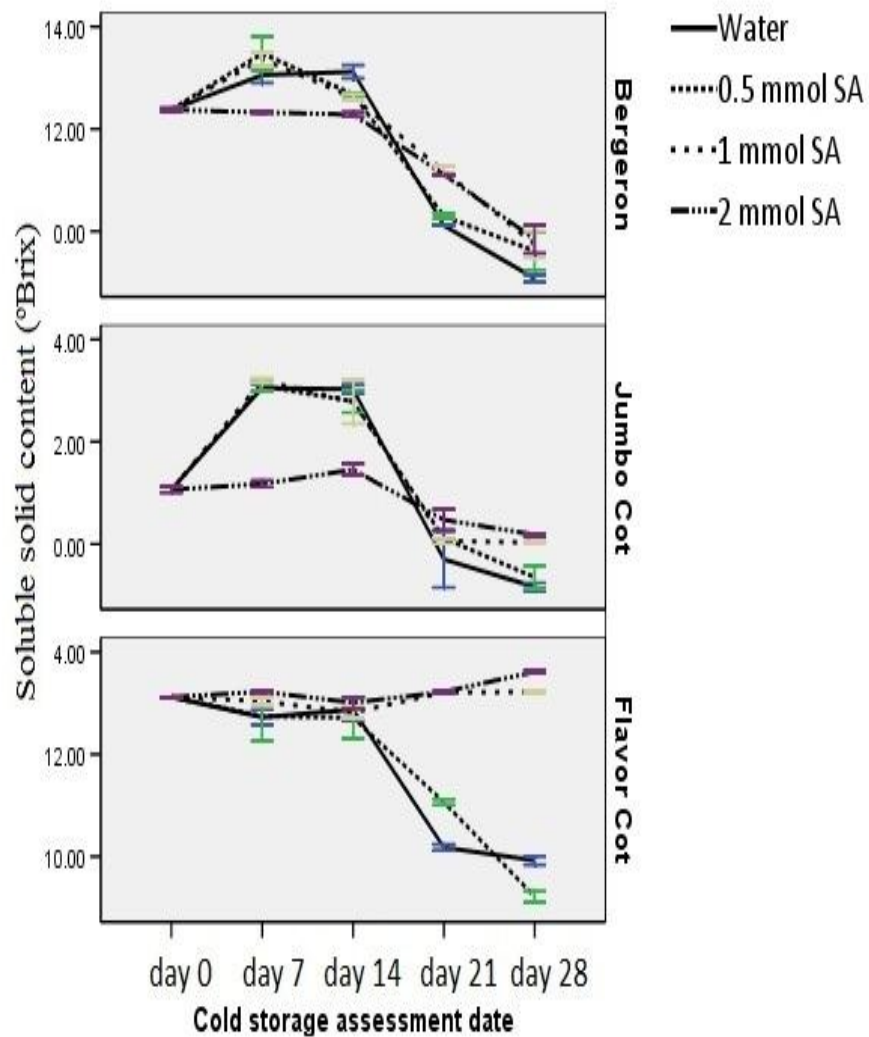


Fig. 3 The effect of treatments of 0, 1, and 2 mmol L⁻¹ salicylic acid (SA) on soluble solid content (°Brix) of apricot fruit (cvs. 'Flavor Cot', 'Jumbo Cot', and 'Bergeron') in cold storage treatment at days 7, 14, 21 and 28 at 1 °C.

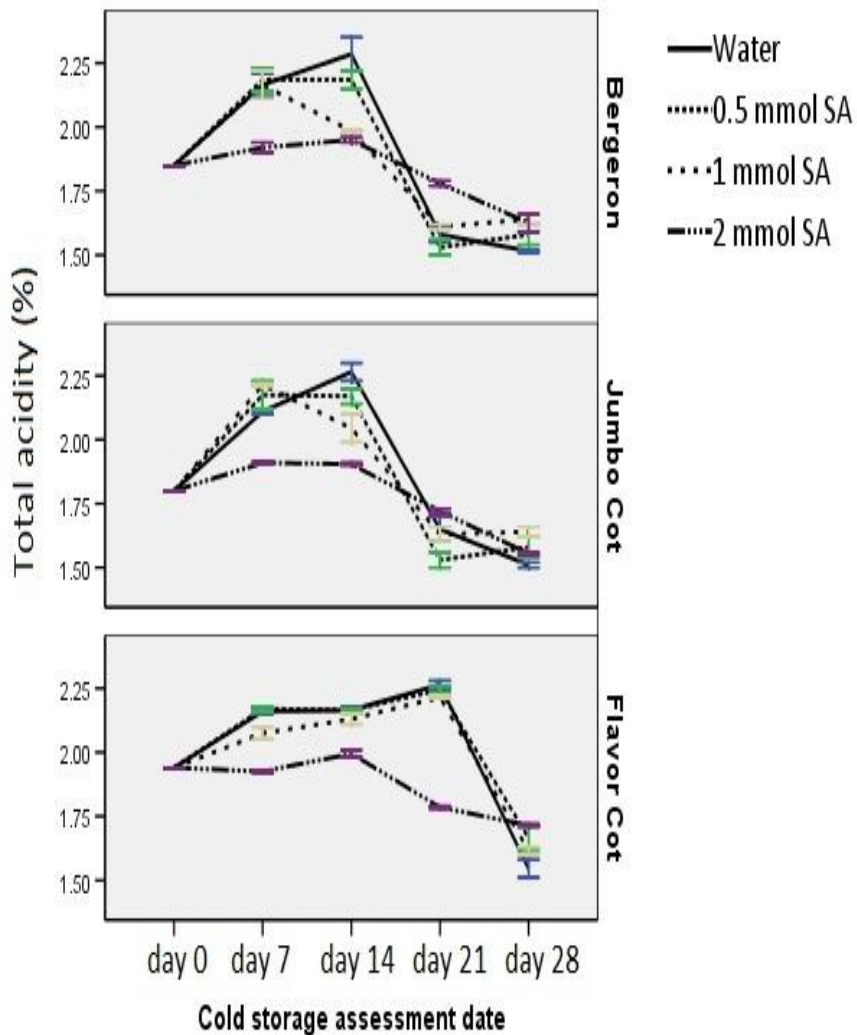


Fig. 4 The effect of treatments of 0, 1, and 2 mmol L⁻¹ salicylic acid (SA) on on fruit acidity (%) of apricot fruit (cvs. 'Flavor Cot', 'Jumbo Cot', and 'Bergeron) in cold storage treatment at days 7, 14, 21 and 28 at 1 °C.

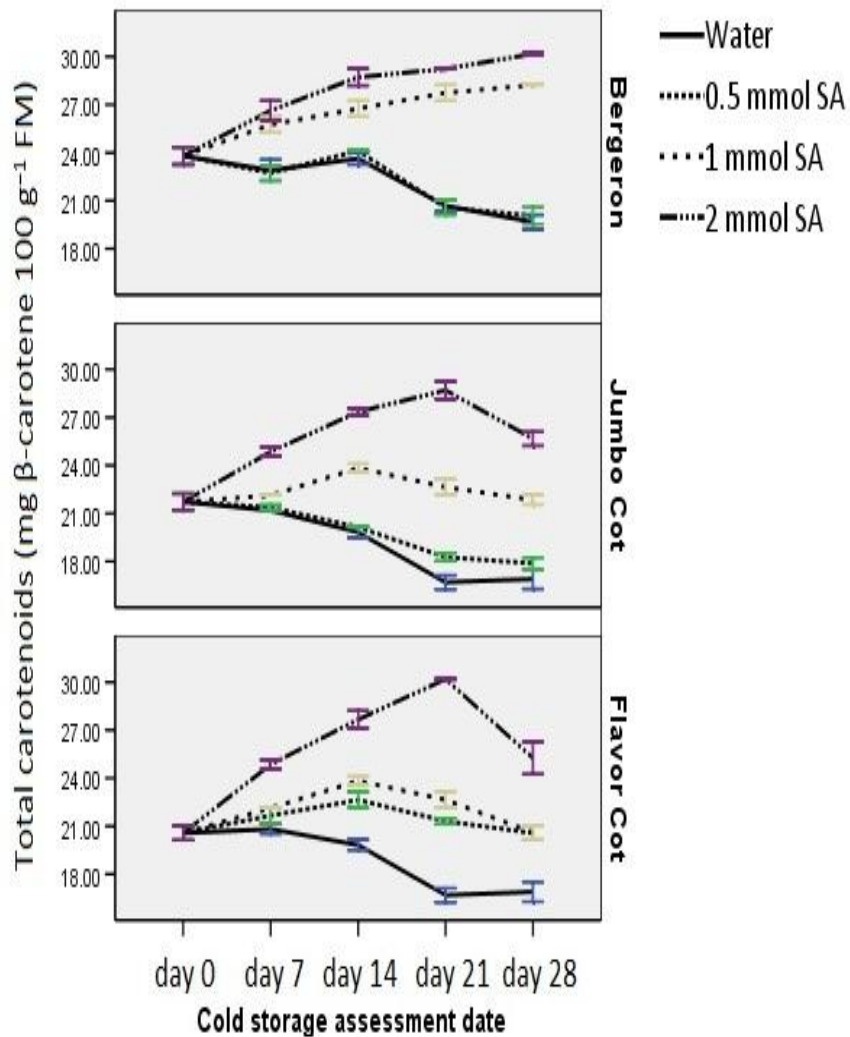


Fig. 5 The effect of treatments of 0, 1, and 2 mmol L⁻¹ salicylic acid (SA) on on fruit Total carotenoids (mg β-carotene 100 g⁻¹ FM) in apricot fruit (cvs. ‘Flavor Cot’, ‘Jumbo Cot’, and ‘Bergeron’) in cold storage treatment at days 7, 14, 21 and 28 at 1 °C.

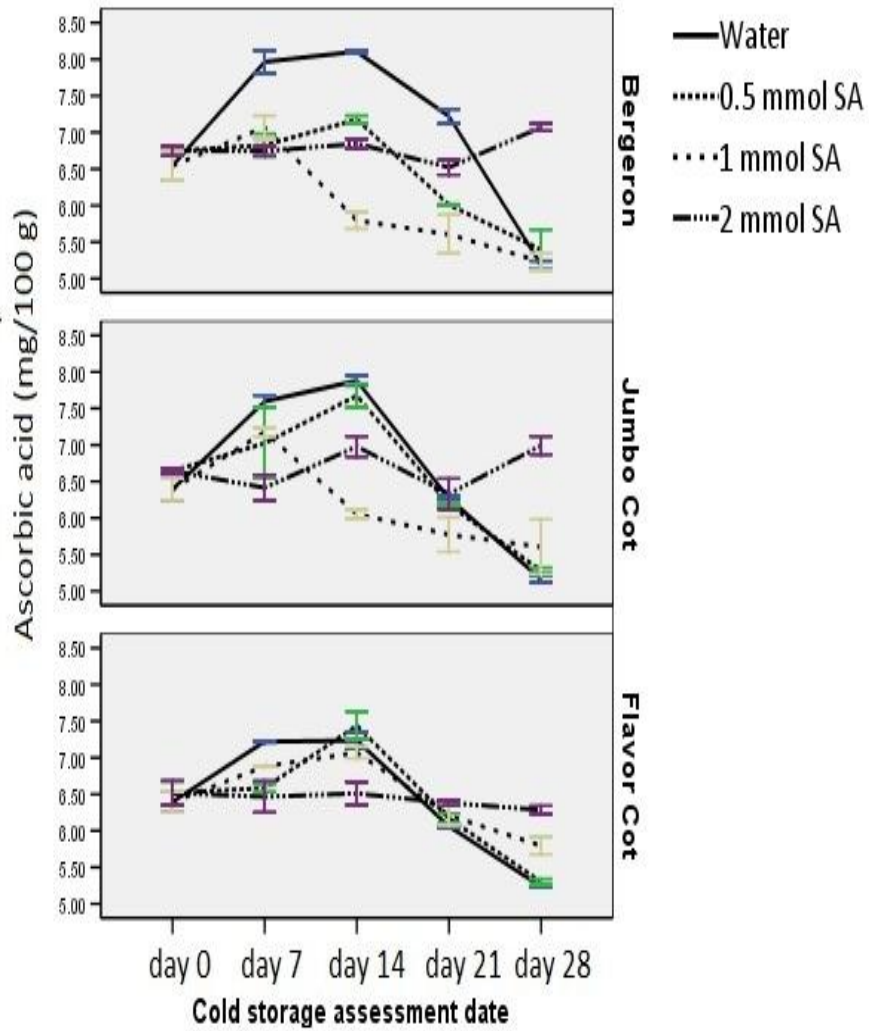


Fig. 6 The effect of treatments of 0, 1, and 2 mmol L⁻¹ salicylic acid (SA) on ascorbic acid (mg/100 g) in apricot fruit (cvs. ‘Flavor Cot’, ‘Jumbo Cot’, and ‘Bergeron’) in cold storage treatment at days 7, 14, 21 and 28 at 1 °C.

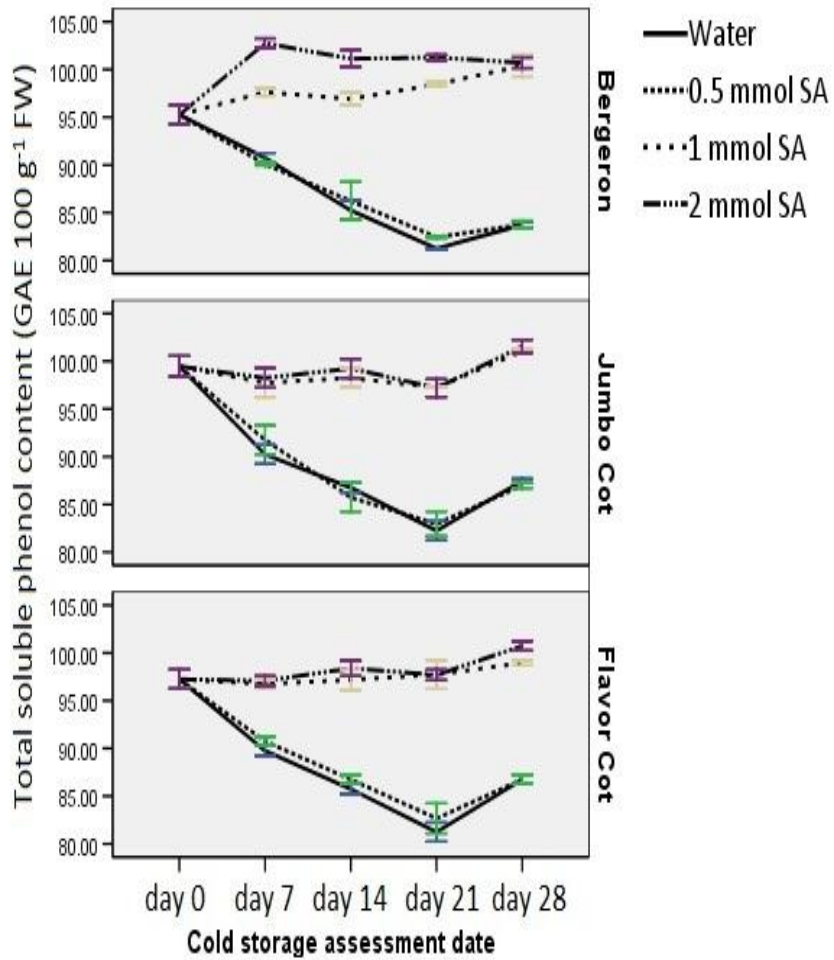


Fig. 7 The effect of treatments of 0, 1, and 2 mmol L⁻¹ salicylic acid (SA) on total soluble phenol content (GAE 100 g⁻¹ FW) in apricot fruit (cvs. 'Flavor Cot', 'Jumbo Cot', and 'Bergeron) in cold storage treatment at days 7, 14, 21 and 28 at 1 °C.

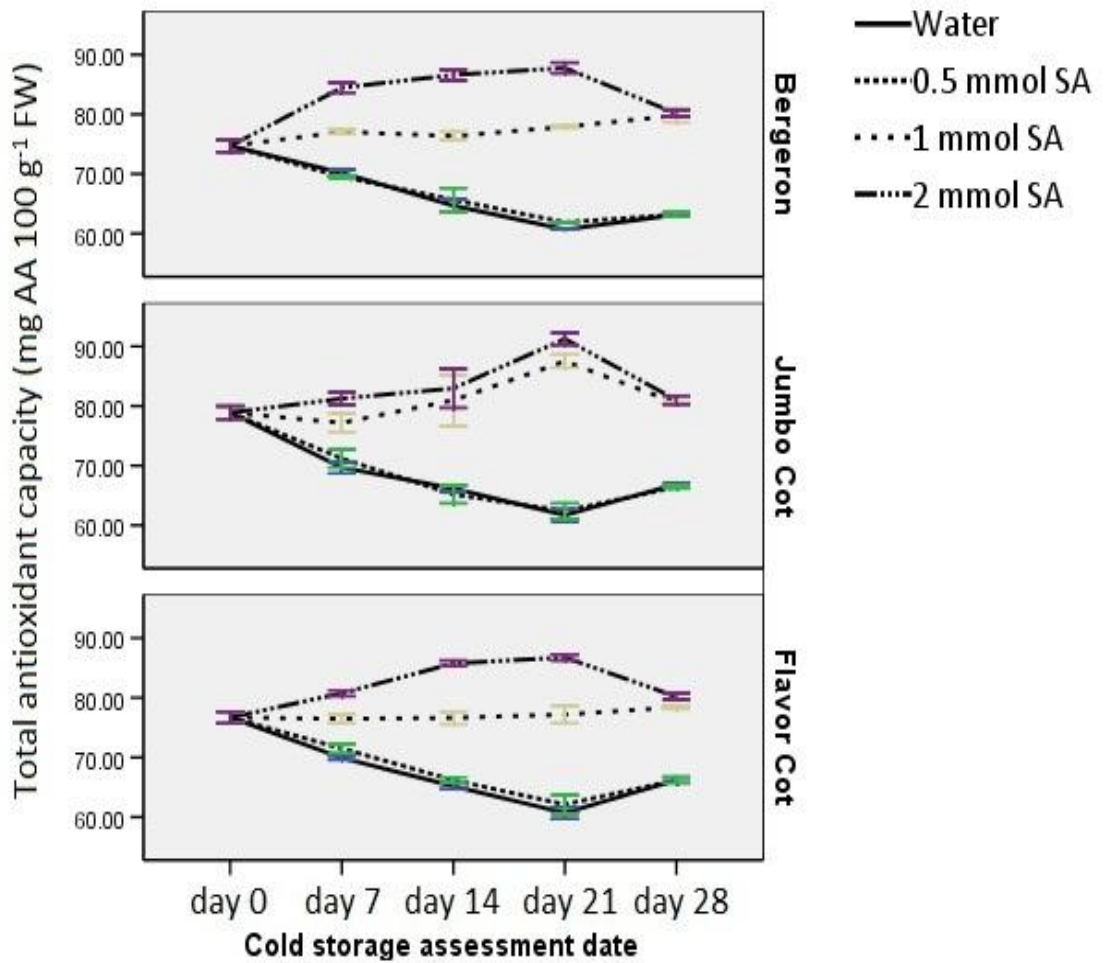


Fig. 8 The effect of treatments of 0, 1, and 2 mmol L⁻¹ salicylic acid (SA) on total antioxidant capacity (mg AA 100 g⁻¹ FW) in apricot fruit (cvs. 'Flavor Cot', 'Jumbo Cot', and 'Bergeron) in cold storage treatment at days 7, 14, 21 and 28 at 1 °C.

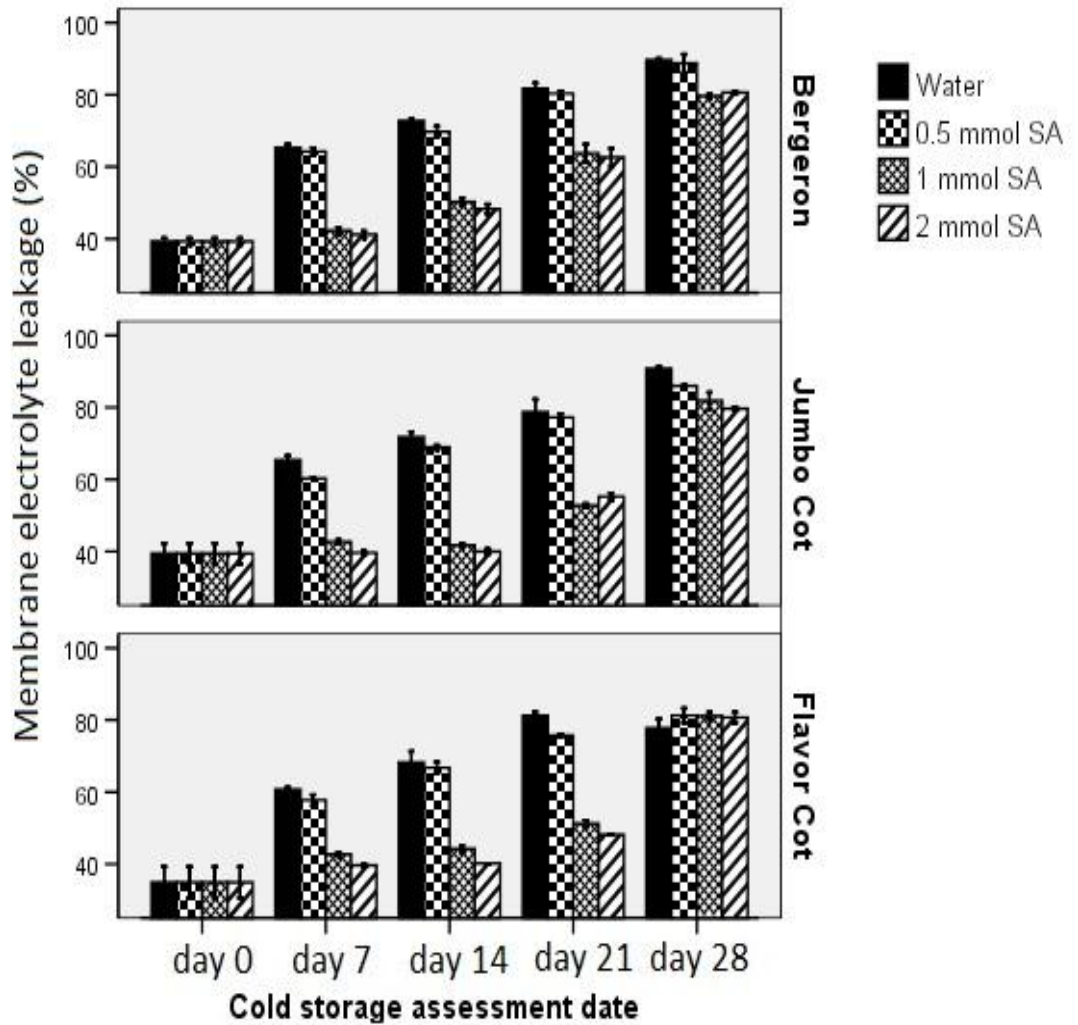


Fig. 9 The effect of treatments of 0, 1, and 2 mmol L⁻¹ salicylic acid (SA) on membrane electrolyte leakage (%) of apricot fruit (cvs. 'Flavor Cot', 'Jumbo Cot', and 'Bergeron') in cold storage treatment at days 7, 14, 21 and 28 at 1 °C.

3.2. Effect of SA and/or MeJA on various fruit quality parameters of apricot cultivar Bergarouge

3.2.1 Effect of SA and MeJA on weight loss, fruit firmness, SSC, acidity, SSC/acidity ratio and PH

Apricot fruits tended to lose weight either during cold storage or shelf-life treatment (Fig. 10). In the cold storage treatment, the weight reduction in control treatment was higher ($P < 0.05$) than for treatments with 0.2 mmol L^{-1} MeJA or 2 mmol L^{-1} SA. Significant differences between water treated fruit and the either MeJA or SA treatments appeared at days 14 and 21. In the shelf-life treatment, significant differences between control and chemically treated fruit occurred from day 4 at $25 \text{ }^{\circ}\text{C}$.

Fruit firmness was decreased in three- week periods of the cold storage treatments and values of fruit firmness in both chemical treatments were higher ($P < 0.05$) compared to the water treated fruits (Fig. 11a). The same trend was observed in the shelf-life treatments (Fig. 11b). The differences between SA and MeJA treatments were not significant though MeJA treatment seems to be more successful in reducing fruit softening than SA.

MeJA and SA treated fruits recorded roughly stable values of SSC at days 7 and 14 in the cold storage treatment. Meanwhile, control treatment showed SSC increasing values then sharp decreased at day 21 (Fig. 11c). Acidity decreased slightly after 7 and 14 days of cold storage for MeJA and SA treated fruit with significant differences to the control (Fig. 11e). In the shelf-life treatments at $25 \text{ }^{\circ}\text{C}$, the SSC and acidity values decreased with the experiment time and were higher in both chemical treatments in regard to control ($P < 0.05$). The results of SSC and acidity reflexed on the of SSC/acidity ratio (Fig. 12a,b) as, the SA and MeJA showed high ratio than the control treatment ($P < 0.05$). Juice pH values were increased with the storage time, water treated fruit recorded the highest pH values ($P < 0.05$) at 14 and 21 day of cold storage or at room temperature (Fig. 12c, d).

3.2.2 Effect of SA and MeJA on chilling injury, fruit decay, mealiness development and lose of juiceness

Degree of CI index increased with storage time in the control, MeJA and SA treatments (Table 2). Meanwhile, fruit pre-treated with MeJA and SA showed significantly ($P<0.05$) lower CI indices than water treated control fruit throughout the whole storage period. After a three-week storage at 1 °C, fruit treated with MeJA had 53.7 and 74.3% lower CI index compared to those of the SA-treated and control fruit, respectively ($P<0.05$). After 8 days of 25 °C, MeJA significantly ($P<0.05$) enhanced the resistance of apricot fruits to chilling injuries compared to either SA or water control treatment. SA treated fruit showed better and lower result for CI index in comparison to control fruit ($P<0.05$)

Non-treated apricot fruit showed a great increase in FD index at 1 °C as it reached to $96.25\pm 2.3\%$ after 21 days (Table 3). In contrast, MeJA and SA treatments ($P<0.05$) reduced the development of superficial browning symptoms. In addition, both MeJA and SA significantly decreased FD index in the shelf-life treatment at after 8 days of 25 °C.

Similar results were reported for mealiness development, as water treated fruit developed mealiness faster and with higher ($P<0.05$) values than SA and MeJA treatments (Fig.13a,b).

Juiciness measurements (Fig.13c,d) showed the priority of chemical treatment in comparison to control treatment to keep the juiciness. SA and MeJA treatments had positive effects in keeping juiciness with cold storage or shelf treatment.

3.2.3 Effect of SA and MeJA on total soluble phenol content, antioxidant capacity, carotenoids content and ascorbic acid content

Total soluble phenol content of apricot fruits was higher ($P<0.05$) in the MeJA and SA treatments compared to the control treatment in both cold storage and shelf-life treatments (Fig. 14 a,b). In the cold storage treatments, apricot fruit treated with MeJA showed increased phenol contents after 7 days of storage at 1 °C with significant differences in regard to SA treatment (Fig. 14a).

The antioxidant capacity levels increased significantly in fruit treated with MeJA and SA after 2 weeks and 4 days of cold storage and shelf-life treatments, respectively, and then it started to decrease. While the antioxidant capacity of control fruits decreased continuously in both cold storage and shelf-life treatments (Fig. 14c,d).

The carotenoids content started to increase with the time in all treatments. The SA had the pronounced values over MeJA treated fruit ($P<0.05$). The same line was observed for shelf-life treatment (Fig. 15a,b).

Results showed that apricot fruits treated with SA had the lowest ascorbic acid then MeJA treated fruit. Untreated fruit showed higher content of ascorbic acid during the early time of storage or shelf-life treatment ($P<0.05$). The difference between SA or MeJA treatments was not significant (Fig. 15c, d).

3.2.4 Effect of SA and MeJA on enzyme activity

PAL activity in MeJA and SA treated fruits increased with storage time and was significantly higher in all dates of cold storage and shelf-life treatments compared to water treated fruits (Fig. 16a, b). PAL activity showed a significantly higher increase in MeJA treatments compared to SA treatments by day 21 and by day 8 in the cold storage and shelf-life treatments, respectively.

SA and MeJA treatment recorded increasing in POD activity for cold storage or shelf-life treatment, while control treatment resulted in fluctuated values between decreasing and increasing during the experiment time (Fig. 16 c, d).

SOD activity increased gradually after the onset of cold storage treatment in MeJA and SA treated fruit ($P<0.05$), while failed to show any increase in control fruits (Fig. 17a,b). The effect of MeJA was more pronounced than that of SA ($P<0.05$).

CAT activity increased for all the treatments, the SA and MeJA treated fruit showed higher activity than control treatment ($P<0.05$). The effect of SA was superior over MeJA at 14 and 21 days of cold storage or at 8 days of shelf-life treatments (Fig. 17c, d).

3.2.5 Effect of SA and/ or MeJA on sensory characters

All the treated fruit tended to achieve low scores of most of sensory parameters with the time (Table 4). The control fruit received score below the acceptability limit (5 point) for taste and visual appearance at 7 day of cold storage and continued to decline with prolong of storage time. While, the MeJA or/ SA treated fruit had scores over the acceptability limit up to 14 days of cold storage ($P < 0.05$). For shelf-life treatment, the control fruit received scores below ($P < 0.05$) the acceptability limit in flesh color, texture, taste and visual appearance attributes up to 4 days at room temperature at the same time SA and MeJA treatment saved the scores over the 5 points. Overall acceptability score were above the 5 points for either SA or MeJA treatment up to 14 days of cold storage or at 4 day at room temperature.

Table 2 The effect of treatments of 0.2 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on chilling injury of cv. 'Bergarouge' apricot fruit

| Treatment | CI index (%) ^a | | | | |
|--------------|---------------------------|---------------|----------------|---------------------|-------------|
| | Cold storage at 1 °C | | | Shelf-life at 25 °C | |
| | Day 7 | Day 14 | Day 21 | Day 4 | Day 8 |
| Control | 3.12 ± 0.87a ^b | 16.68 ± 1.45a | 37.65 ± 4.56 a | 18.67±2.35a | 30.24±3.65a |
| 0.2 mmolMeJA | 1.35 ± 0.21a | 4.52 ± 1.98b | 9.68 ± 3.65c | 8.65±1.09b | 14.35±1.35c |
| 2 mmol SA | 1.64 ± 0.34a | 5.58 ± 0.68b | 20.91 ± 5.09b | 7.68±2.34b | 19.26±2.65b |

^a CI index: chilling injury index.

^bValues within a column followed by different letters are significantly different at $P<0.05$ according to Duncan's multiple range tests. The results represent the means ± SD of triplicate assay

Table 3 Theeffect of treatments of 0.2 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on apricot fruit decay of cv. 'Bergarouge'

| Treatment | FD index (%) ^a | | | | |
|--------------|----------------------------|---------------|---------------|---------------------|------------|
| | Cold storage at 1 °C | | | Shelf-life at 25 °C | |
| | Day 7 | Day 14 | Day 21 | Day 4 | Day 8 |
| Control | 16.05 ± 1.07a ^b | 56.24 ± 5.35a | 96.25 ± 2.3 a | 66.36±2.65 | 100±3.05 |
| 0.2 mmolMeJA | 2.11 ± 0.98b | 6.57 ± 1.08b | 16.98 ± 6.65b | 16.35±3.65 | 36.65±2.03 |
| 2 mmol SA | 2.33 ± 1.03b | 7.58 ± 2.08b | 15.61 ± 4.19b | 20.36±4.09 | 35.36±3.65 |

^a FD index (%): fruit decay index in percentage

^bValues within a column followed by different letters are significantly different at $P<0.05$ according to Duncan's multiple range tests. The results represent the means ± SD of triplicate assay.

Table 4 The effect of treatments of 0.2 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on sensory properties and overall liking of cv. ‘Bergarouge’ apricot fruit.

| Parameters | Chemical treatment | Cold storage assessment date | | | | Shelf-life assessment date | |
|-----------------------|--------------------|------------------------------|--------|--------|--------|----------------------------|--------|
| | | Day 0 | Day 7 | Day 14 | Day 21 | Day 4 | Day 8 |
| Skin color | Control | 7.20aA | 7.83aA | 7.95bB | 7.56bB | 7.10aC | 7.67bB |
| | MeJA | 7.20aA | 7.40aB | 6.50aA | 6.10aA | 6.20aB | 6.30aA |
| | SA | 7.20aA | 7.90aB | 6.80aA | 6.20aA | 6.00aB | 6.40aA |
| Flesh color | Control | 8.00aA | 4.20bB | 3.90cB | 3.10cB | 2.20dB | 1.90dB |
| | MeJA | 8.00aA | 7.30aA | 6.90aA | 5.30bA | 6.20bA | 4.30cA |
| | SA | 8.00aA | 7.09aA | 6.30bA | 5.30bA | 5.90bA | 4.10cA |
| Texture | Control | 8.90aA | 5.20bB | 4.30bC | 2.90cB | 4.30bB | 3.10cC |
| | MeJA | 8.90aA | 7.10aA | 6.10bA | 4.30cA | 6.10bA | 4.10cB |
| | SA | 8.90aA | 6.90aA | 5.20bB | 4.70cA | 6.30bA | 5.10cA |
| Taste | Control | 7.80aA | 4.30bB | 3.10cB | 2.30cB | 3.90bB | 2.90cA |
| | MeJA | 7.80aA | 6.90aA | 5.30bA | 3.90cA | 5.20bA | 3.10cA |
| | SA | 7.80aA | 7.10aA | 5.20bA | 4.20cA | 5.30bA | 3.20cA |
| Visual appearance | Control | 7.30aA | 4.50bB | 3.90bB | 2.90cC | 2.70cB | 1.70dB |
| | MeJA | 7.30aA | 6.80aA | 5.90bA | 3.80cB | 5.50bA | 3.80cA |
| | SA | 7.30aA | 7.10aA | 5.90bA | 4.90cA | 5.20bA | 4.30cA |
| Overall acceptability | Control | 8.00aA | 4.10bB | 3.20cB | 1.80dB | 2.10dC | 1.20dC |
| | MeJA | 8.00aA | 6.20bA | 5.30bA | 3.90cA | 5.30bB | 4.20cB |
| | SA | 8.00Aa | 6.40bA | 5.70bA | 4.20cA | 6.10bA | 4.20bA |

For each column, similar capital letters are not significantly different at $P \leq 0.05$ among Chemical treatments for each parameter. Similar small letters in rows are not significantly different at $P \leq 0.05$ during storage.

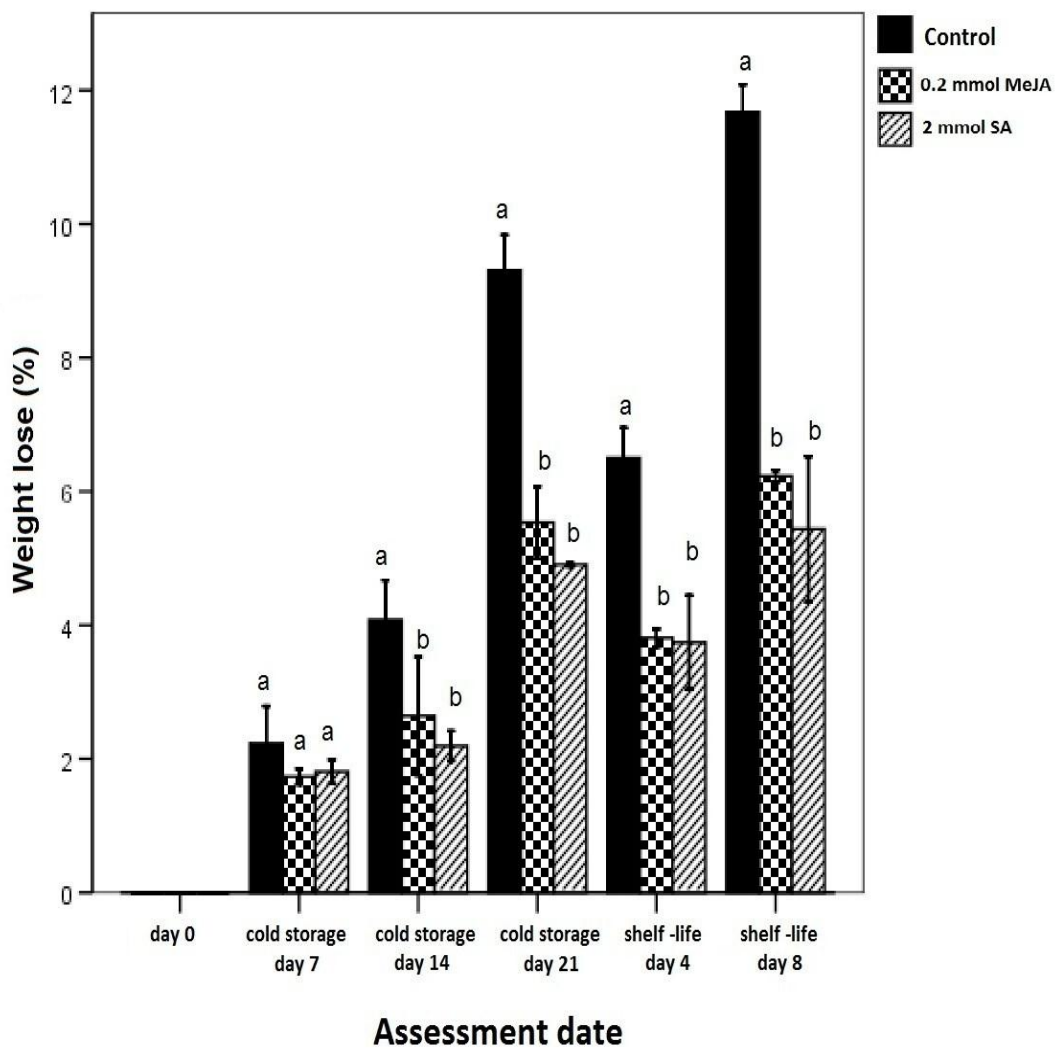


Fig. 10 Effect of 0.2 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on weight loss percentage of apricot fruit (cv. 'Bergarouge') in cold storage treatment at days 7, 14 and 21 at 1 °C and in shelf-life treatment at days 4 and 8 at 25 °C. Values within a column for the given days followed by different letters are significantly different at $P < 0.05$ according to Duncan's multiple range tests. Error bars represent the SD values.

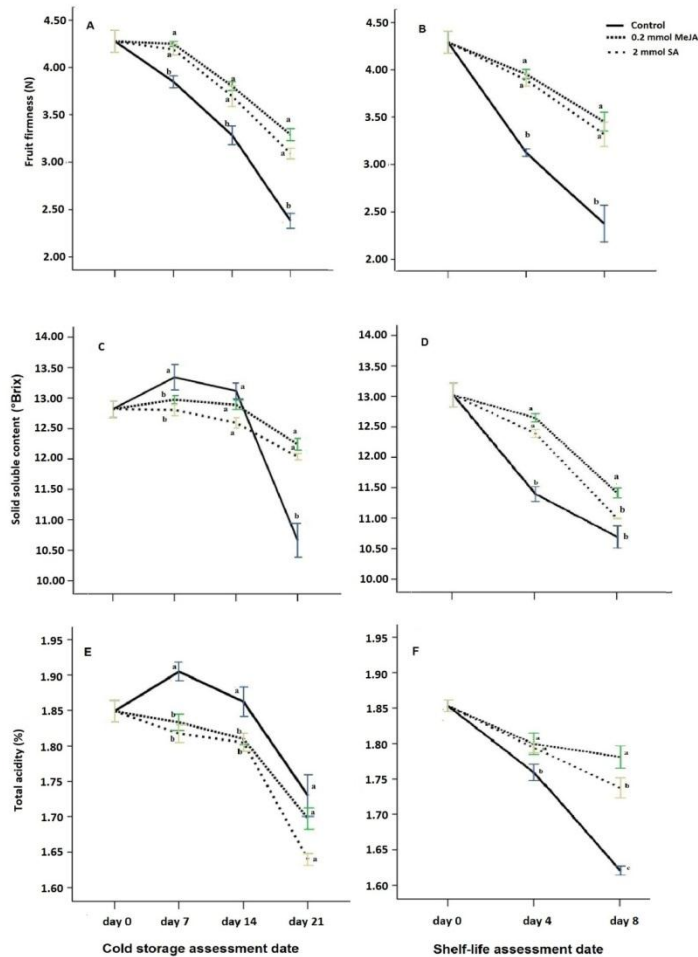


Fig.11 Effect of 0.2 mmol L^{-1} methyl jasmonate (MeJA) and 2 mmol L^{-1} salicylic acid (SA) on fruit firmness (N), soluble solid content ($^{\circ}\text{Brix}$) and total acidity (%) of apricot fruit (cv. 'Bergarouge') in cold storage treatment at days 7, 14 and 21 at 1°C (A, C, and E), and in shelf-life treatment at days 4 and 8 at 25°C (B, D and F). Values within the given days followed by different letters are significantly different at $P < 0.05$ according to Duncan's multiple range tests. Error bars represent the SD values.

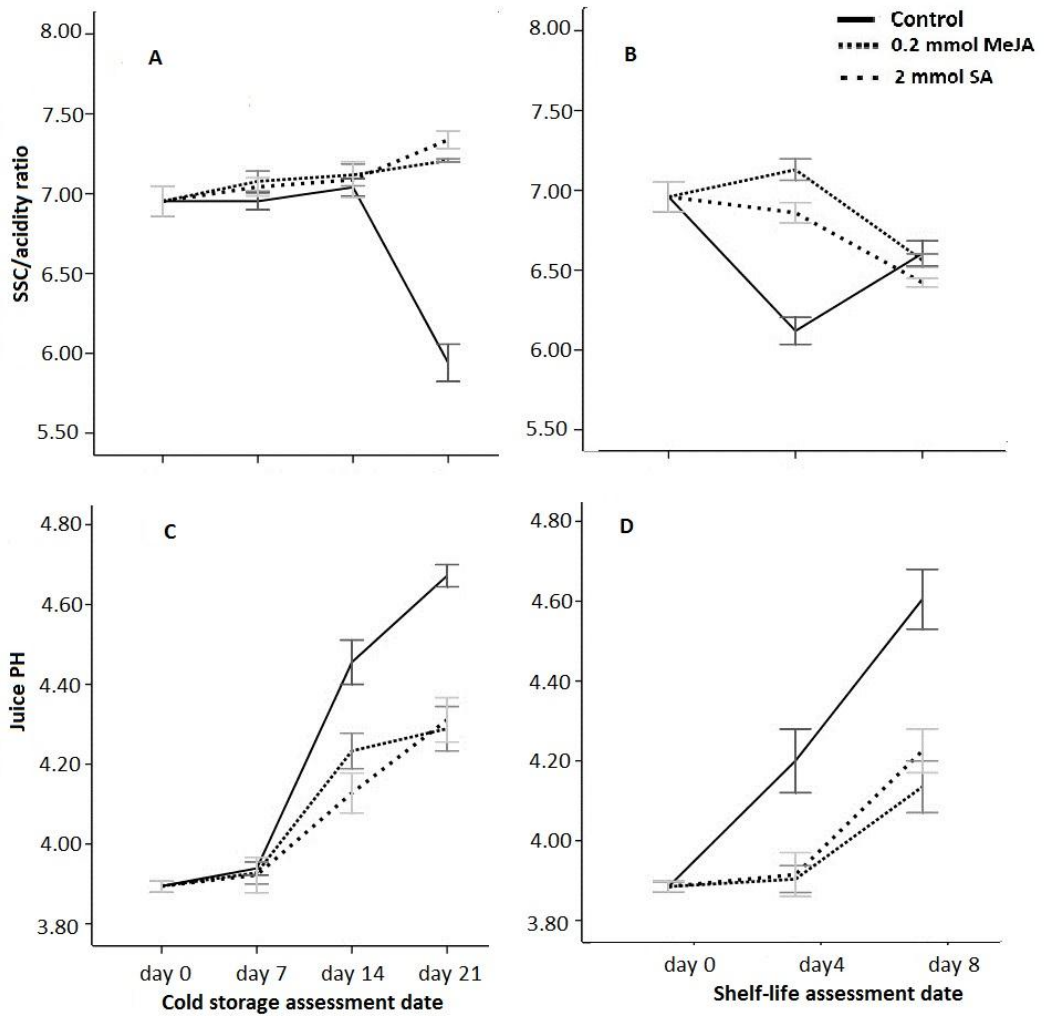


Fig. 12 Effect of 0.2 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on SSC/acidity ratio, juice pH of apricot fruit (cv. 'Bergarouge') in cold storage treatment at days 7, 14 and 21 at 1 °C (A and C), and in shelf-life treatment at days 4 and 8 at 25 °C (B and D). Values within the given days followed by different letters are significantly different at $P < 0.05$ according to Duncan's multiple range tests. Error bars represent the SD values.

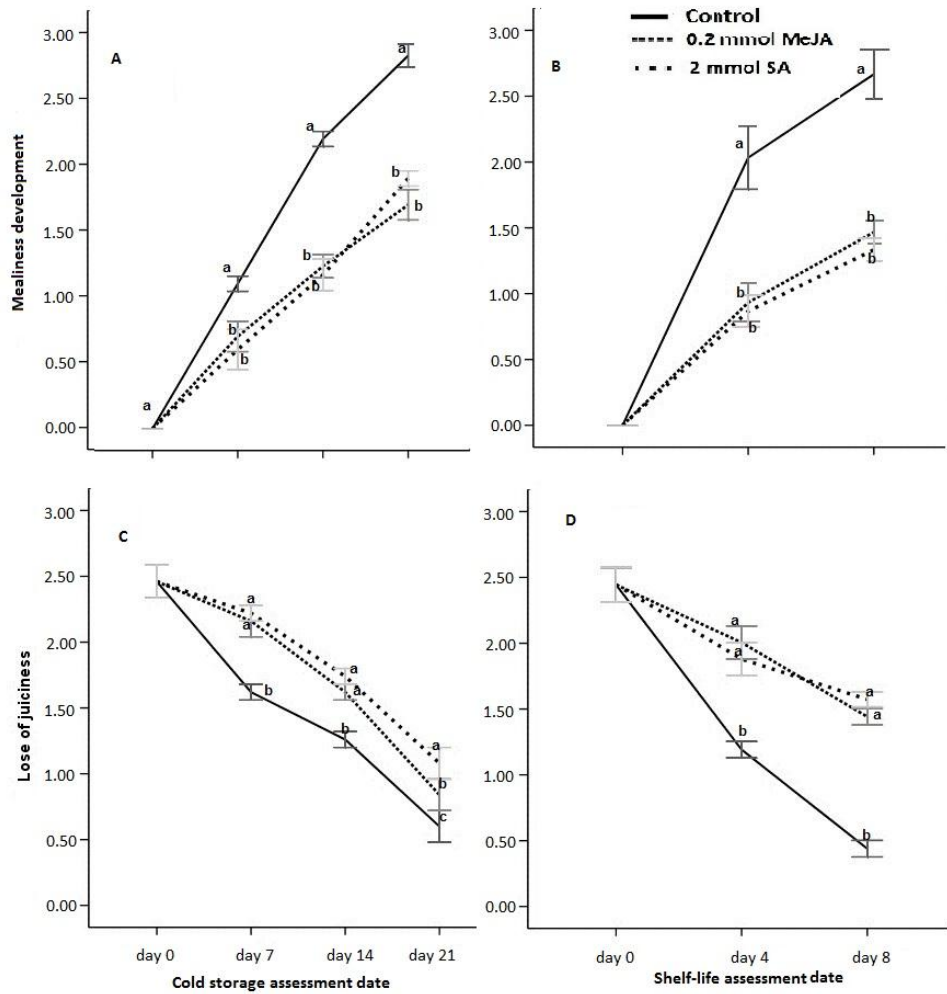


Fig. 13 Effect of 0.2 mmol L^{-1} methyl jasmonate (MeJA) and 2 mmol L^{-1} salicylic acid (SA) on Mealiness development and lose of juiciness of apricot fruit (cv. 'Bergarouge') in cold storage treatment at days 7, 14 and 21 at $1 \text{ }^\circ\text{C}$ (A and C), and in shelf-life treatment at days 4 and 8 at $25 \text{ }^\circ\text{C}$ (B and D). Values within the given days followed by different letters are significantly different at $P < 0.05$ according to Duncan's multiple range tests. Error bars represent the SD values.

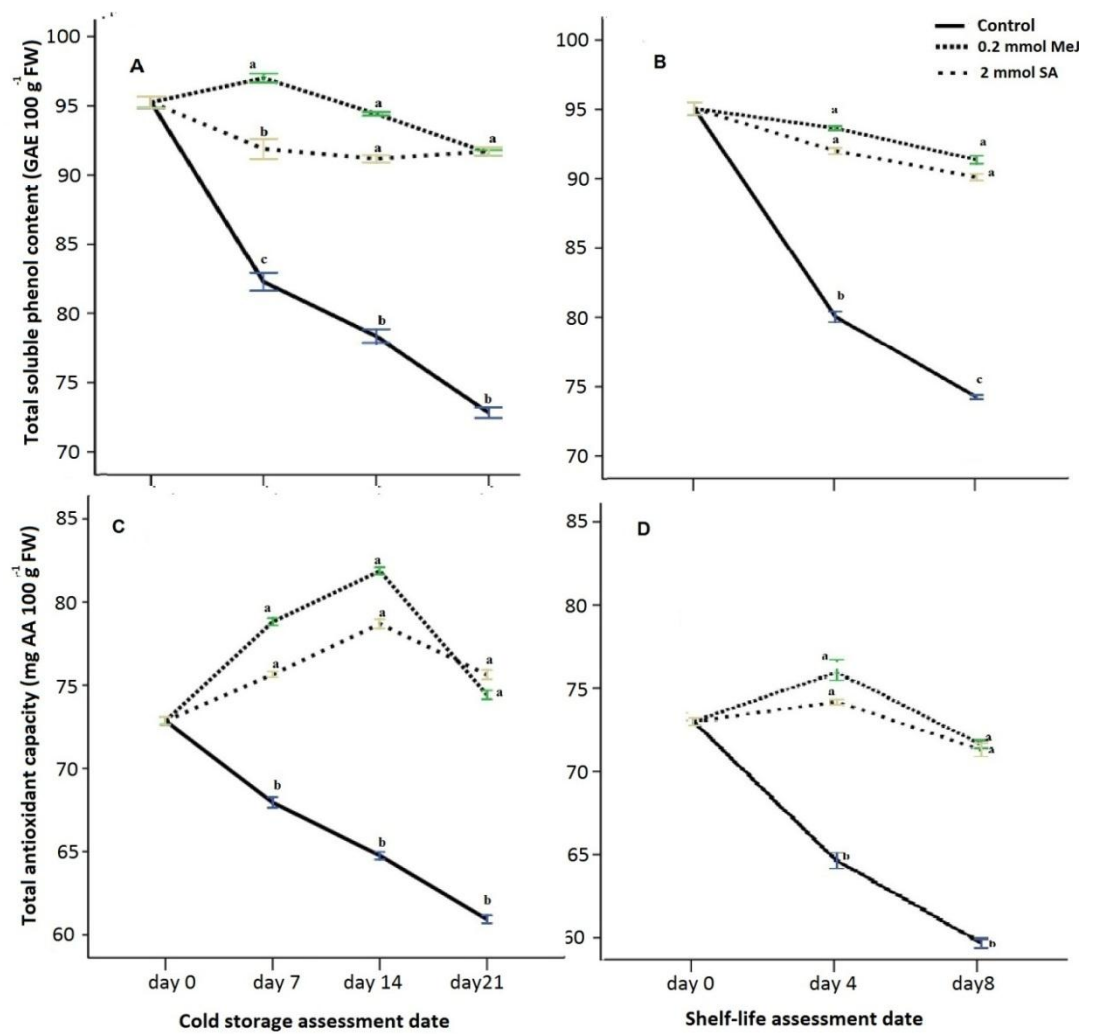


Fig. 14 Effect of 0.2 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on total soluble phenol content (GAE 100 g⁻¹ FW) and total antioxidant capacity (mg AA 100 g⁻¹ FW) in apricot fruit (cv. 'Bergarouge') in cold storage treatment at days 7, 14 and 21 at 1 °C (A and C), and in shelf-life treatment at days 4 and 8 at 25 °C (B and D). Values within the given days followed by different letters are significantly different at $P < 0.05$ according to Duncan's multiple range tests. Error bars represent the SD values.

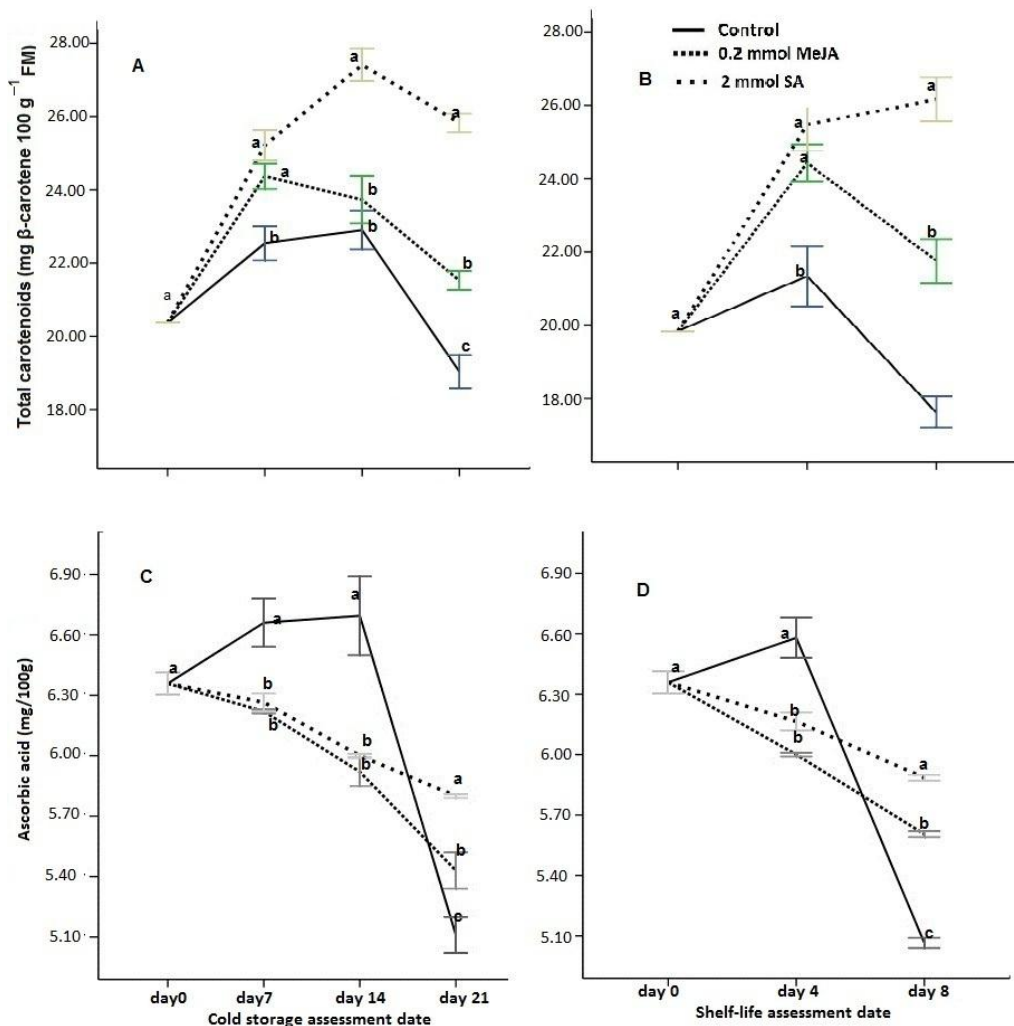


Fig. 15 Effect of 0.2 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on Total carotenoids (mg β -carotene 100 g⁻¹ FM) and ascorbic acid (mg/100 g) in apricot fruit (cv. 'Bergarouge') in cold storage treatment at days 7, 14 and 21 at 1 °C (A and C), and in shelf-life treatment at days 4 and 8 at 25 °C (B and D). Values within the given days followed by different letters are significantly different at $P < 0.05$ according to Duncan's multiple range tests. Error bars represent the SD values.

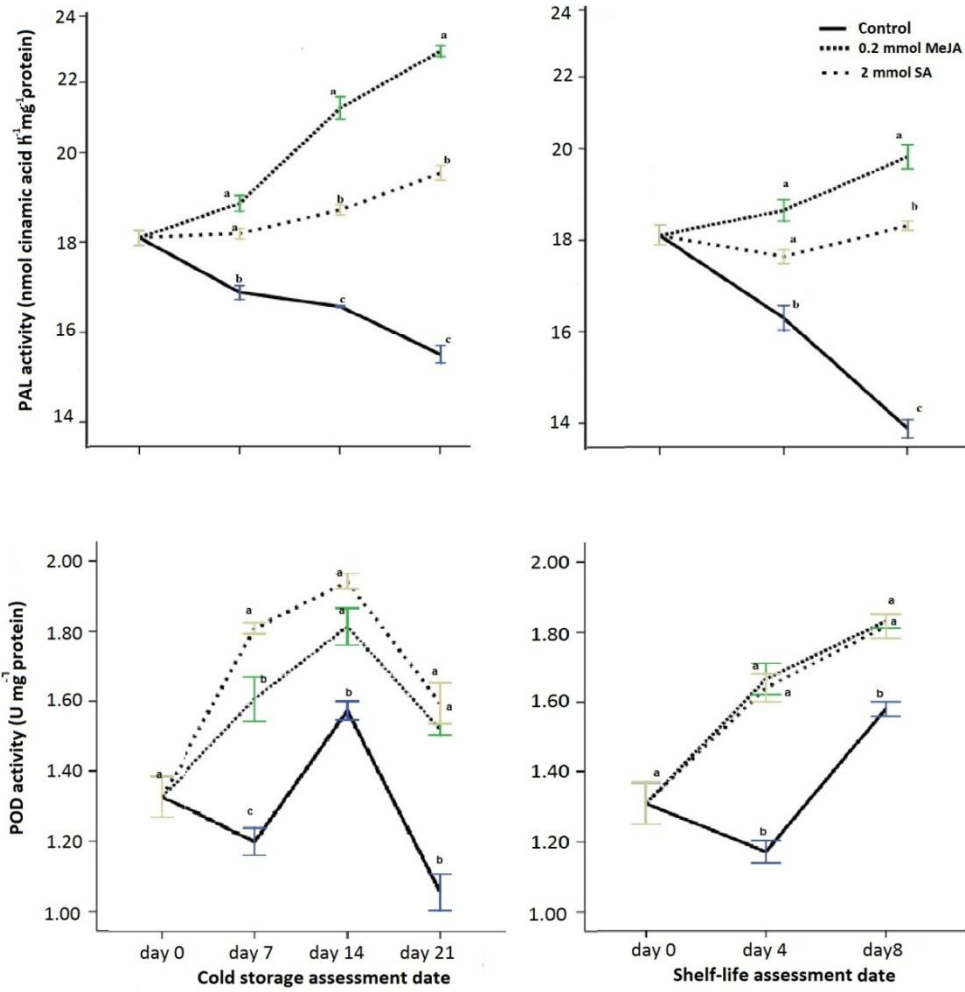


Fig. 16 Effect of 0.2 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on phenylalanine ammonia-lyase (PAL; nmolcinamic acid h⁻¹ mg⁻¹ protein) and peroxidase (POD) activity in apricot fruit (cv. 'Bergarouge') in cold storage treatment at days 7, 14 and 21 at 1 °C (A), and in shelf-life treatment at days 4 and 8 at 25 °C (B). Values within the given days followed by different letters are significantly different at *P*<0.05 according to Duncan's multiple range tests. Error bars represent the SD values.

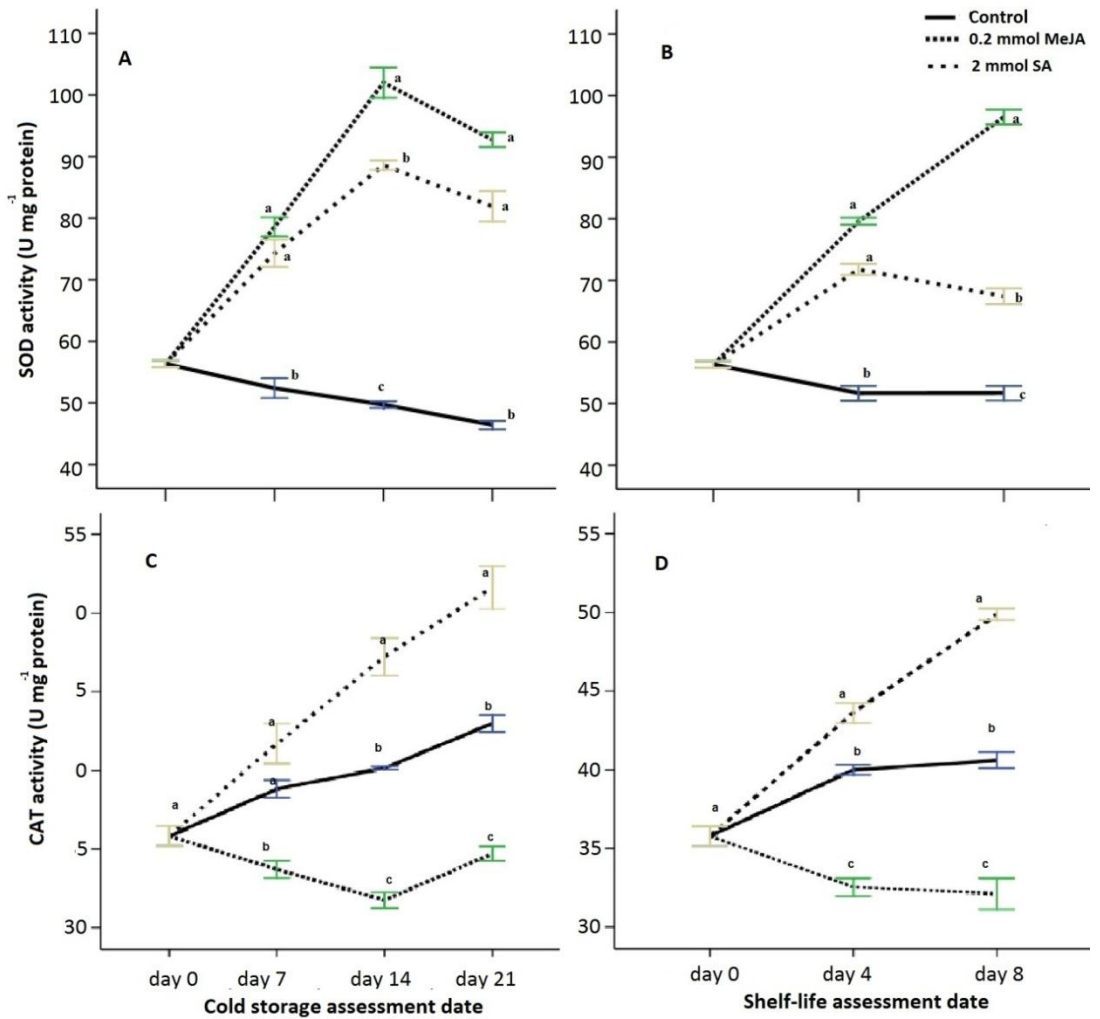


Fig. 17 Effect of 0.2 mmol L^{-1} methyl jasmonate (MeJA) and 2 mmol L^{-1} salicylic acid (SA) on superoxide dismutase (SOD; $\text{U mg}^{-1} \text{ protein}$) and catalase (CAT; $\text{U mg}^{-1} \text{ protein}$) activity in apricot fruit (cv. 'Bergarouge') in cold storage treatment at days 7, 14 and 21 at $1 \text{ }^\circ\text{C}$ (A), and in shelf-life treatment at days 4 and 8 at $25 \text{ }^\circ\text{C}$ (B). Values within the given days followed by different letters are significantly different at $P < 0.05$ according to Duncan's multiple range tests. Error bars represent the SD values.

3.3. Effect of SA and/or MeJA on induce resistance to *Monilinia laxa* on apricot fruit of cv. Bergarouge

3.3.1 Effect of different concentrations of SA and MeJA on mycelia growth of *M. laxa* *in vivo*, lesion diameter (mm) and fruit disease incidence (%)

Data presented in table 5 showed that all concentrations of SA and MeJA reduced the growth rate of monilinia mycelia compared with water treated media. PDA media with 2 or 5 mmol L⁻¹ of SA produced the lowest growth rate of *M. laxa* ($P < 0.05$). The pathogen which incubated with 0.4 or 0.7 mmol L⁻¹ MeJA also achieved lower growth rate with significant differences from the control. The same trend was found for fruit disease incidence as all the concentrations of SA and MeJA reduced the apricot fruit decay with significant differences with water treated fruit. The lesion diameter and disease incidence data revealed that the high concentration of SA and/or MeJA achieved the considered effects on *M. laxa* over the low concentration.

Lesion diameter increased from 0 mm to 15.49 ± 1.01 mm in water treated fruits and the same was for 0.1 mmol L⁻¹ MeJA treated fruit as the lesion diameter arose to 15.77 ± 0.45 mm. Meanwhile with increasing MeJA concentration the lesion diameter reduced to reach to 11.49 ± 0.69 mm in 0.7 mmol MeJA treated fruit which was significantly different from control fruits (Table 6). At the same time fruit treated with 2 or 5 mmol SA recorded the lowest lesion diameter after incubation with fungi ($P < 0.05$) in comparison to low concentration.

3.3.2 Effect of 2 mmol L⁻¹ SA and 0.4 mmol L⁻¹ MeJA treatment on mycelial growth of *M. laxa* *in vitro* at 2, 4, 6 and 8 days of incubation

Data presented in Fig. 18, Indicated that SA and MeJA had inhibitory effects on mycelial growth of *M. laxa* in PDA in comparison to control. SA achieved the lowest growth rate of *M. laxa* with significant differences with other treatments ($P < 0.05$) after 4 days of inoculation. In control treatment,

growth rate of *M. laxa* reached more than 100% after 6 days of incubation. It was also noticed that the effect of 0.4 mmol L⁻¹ MeJA started to disappear at 8 days of inoculation as reached to 93.16% while 2 mmol L⁻¹ SA treated PDA media was only 68.98%.

3.3.3 Effect of 2 mmol L⁻¹ SA and 0.4 mmol L⁻¹ MeJA treatment on disease incidence, lesion diameter, fruit firmness and lignin content of apricot fruit incubated with *M. laxa*

Generally, results in figs. 19 and 20 showed that the postharvest application of SA and MeJA resulted in significantly lower disease percentage and lesion development compared to control.

The decay incidence of water treated and stored fruit at 8th day was about 39.47% with significance differences from 2 mmol L⁻¹ SA and 0.4 mmol L⁻¹ MeJA, as the decay incidence were 20.41 and 22.43%, respectively (Fig. 21). Fruit treated with SA showed more resistance to infection than fruit treated with MeJA, as at days 4 and 6 the differences between SA and MeJA were significant.

Although all the inoculated wounds in both SA or MeJA treated and control fruit showed increase lesion diameter during the incubation times, the lesion diameter in SA and MeJA treated fruit was still significantly lower than that in the control fruit ($P < 0.05$), for example, at 8 days the lesion diameter were 11.84, 12.12 and 16.29 mm for treated fruit with SA, MeJA and water, respectively (Fig. 20).

For inoculated wounds with *M. laxa* in all chemical treatments, the development of fruit softening was noticed at all the incubation times, but the reduction in firmness for MeJA treated fruit was lower ($P > 0.05$) than SA treated at 4 and 8 days of infection (Fig. 21). Meanwhile, control fruit showed sharp deterioration in fruit firmness during all the incubation assessment times. For unwound treatment, SA or MeJA treated fruit, presented approximately unchanged fruit firmness during second, 4th and 6th of storage at 25 °C, while at 8th of storage the reduction in fruit firmness was explicit (Fig. 21) but still better than control treatment ($P < 0.05$). MeJA treatment

showed priority over the SA treatment with significant differences at 4 and 8 days of storage.

3.3.4 Effect of 2 mmol L⁻¹ SA and 0.4 mmol L⁻¹MeJA treatment on lignin content

Lignin content of apricot fruit treated with MeJA recorded the highest value with significant differences from all other treatments (Fig. 22). Unwounded SA treated fruit did not display sensitive enhancement in lignin content in apricot fruit at 2 days of treatment while it increased bit than control fruits at 6 and 8 days of treatment. Meanwhile inoculation with *M. laxa* resulted in lignin content reduction in treated fruit with water or SA.

3.3.5 Effect of 2 mmol L⁻¹ SA and 0.4 mmol L⁻¹MeJA treatment on levels of total phenolic and total antioxidant capacity.

Inoculated and SA or MeJA treated fruits showed slight increase in total phenol content after 2 and 4 days of incubation then it decreased gradually without explicit priority for MeJA or SA ($P>0.05$). While water treated fruit showed sharp decrease in phenols content (Fig. 23).

On the other hand, unwounded and SA or MeJA treated fruit recorder roughly unchanged values of total phenols content over the 6th day of treatment at 25 °C then decrease slightly at 8th day. Control fruit achieved nearly stable values at second day then the value took to decrease ($P<0.05$).

Fruit treated with SA or MeJA showed higher antioxidant capacity than those treated with water at all the assessment times and in both inoculated and non-inoculated treatment ($P<0.05$). The results showed that MeJA treatment keeps the antioxidant higher than SA (over the assessment times in both wounded or unwounded treatments (Fig. 24).

3.3.6 Effect of 2 mmol L⁻¹ SA and 0.4 mmol L⁻¹MeJA treatment on changes in defense-related enzymes in apricot fruit

SOD activity in non-inoculated fruit and treated with SA, MeJA and water, increased with storage time at 25 °C, however, the SOD activity increase was higher in both SA and MeJA than control fruits ($P<0.05$) at all storage times.

Fruit inoculated with *M. laxa* recorded increase in SOD activity at over the 6th day of treatment with SA and MeJA treatments. Meanwhile, control fruit showed a decrease in SOD activity at early inoculation time (Fig. 25). Treated fruit with MeJA recorded the highest SOD activity with significant differences with SA and control fruits at all inoculation times ($P<0.05$).

POD activity increased during the experiment either in inoculated or non-inoculated fruits. The differences were significant among all chemical treatments at all assessment date, except between SA and water treatments after 2 days of storage in non-inoculated fruit ($p>0.05$). MeJA treatment showed the highest POD activity ($P<0.05$) (Fig. 26).

PAL activity (Fig. 27) increased with SA or MeJA treatment at early time of storage, meanwhile the water treated fruit resulted about unchanged PAL values with significant differences from SA or MeJA treatments at all the storage times in non-inoculated fruits. Similarly, for infected fruits SA or MeJA induced PAL activity in comparison to control fruits ($P<0.05$).

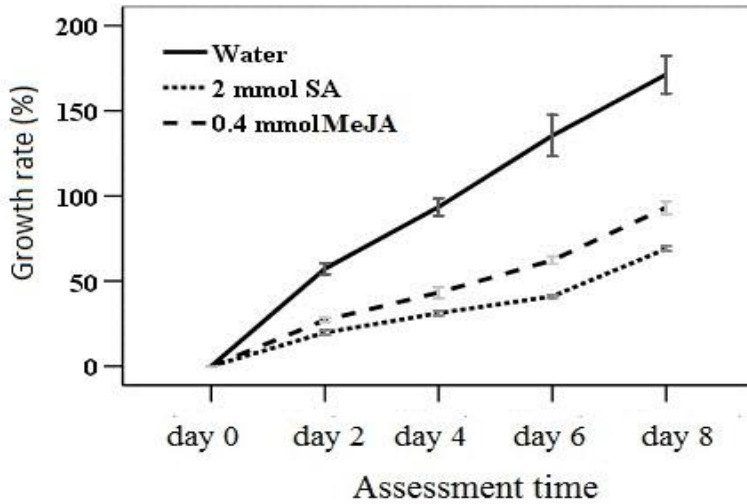


Fig. 18 Effect of 0.4 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on growth rate of *Monilialaxa* in apricot fruit (cv. 'Bergarouge'). Error bars represent the SD values.

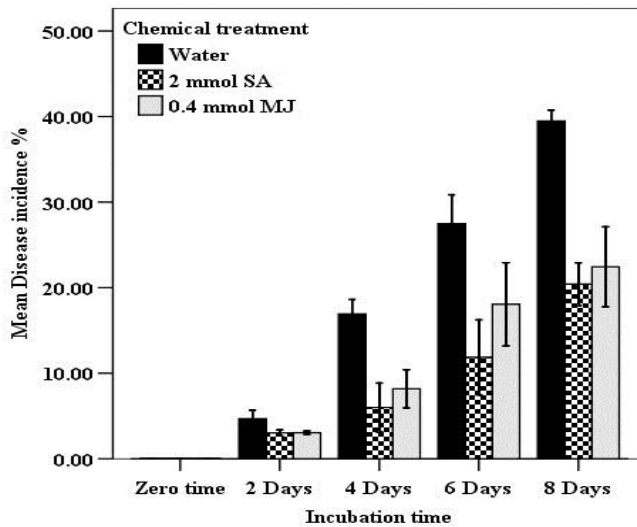


Fig. 19 Effect of 0.4 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on disease incidence in apricot fruit (cv. 'Bergarouge'). Error bars represent the SD values.

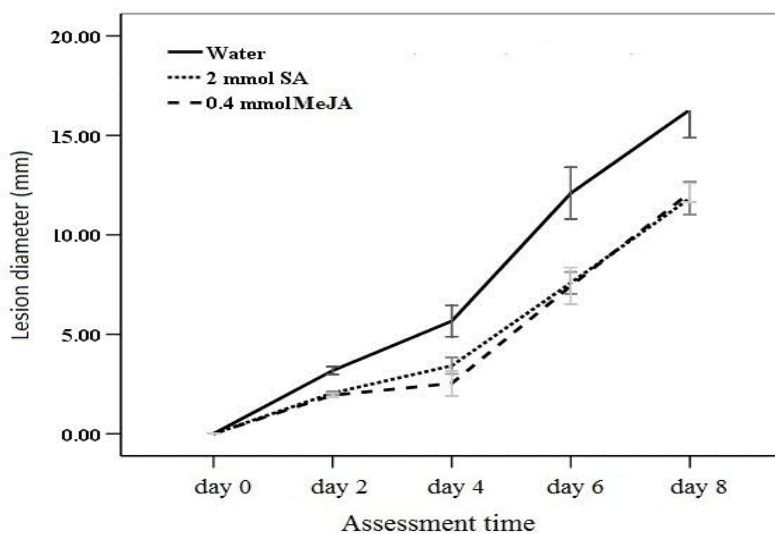


Fig. 20 Effect of 0.4 mmol L^{-1} methyl jasmonate (MeJA) and 2 mmol L^{-1} salicylic acid (SA) on lesion diameter in apricot fruit (cv. 'Bergarouge'). Error bars represent the SD values.

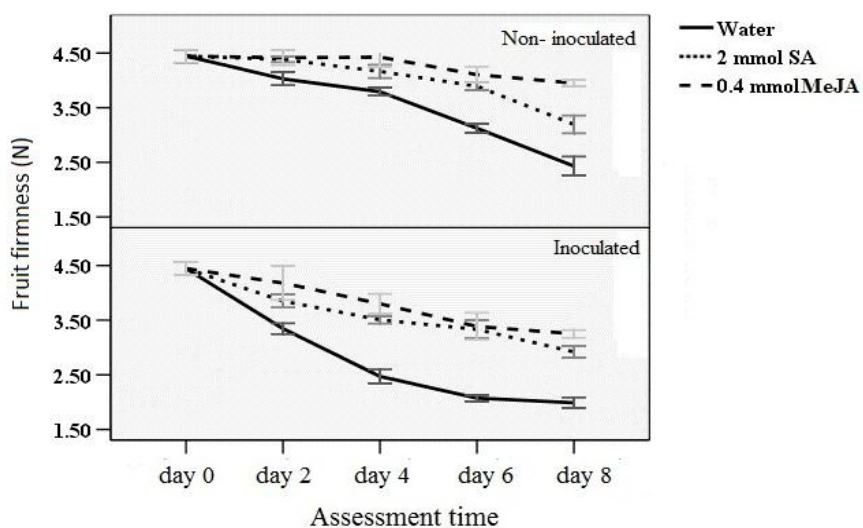


Fig. 21 Effect of 0.4 mmol L^{-1} methyl jasmonate (MeJA) and 2 mmol L^{-1} salicylic acid (SA) on fruit firmness in apricot fruit (cv. 'Bergarouge'). Error bars represent the SD values.

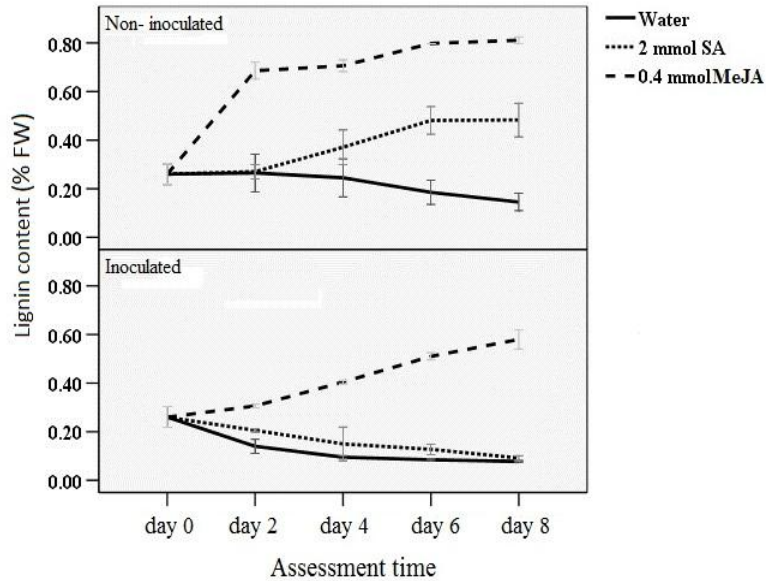


Fig. 22 Effect of 0.4 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on lignin content (%) in apricot fruit (cv. 'Bergarouge'). Error bars represent the SD values.

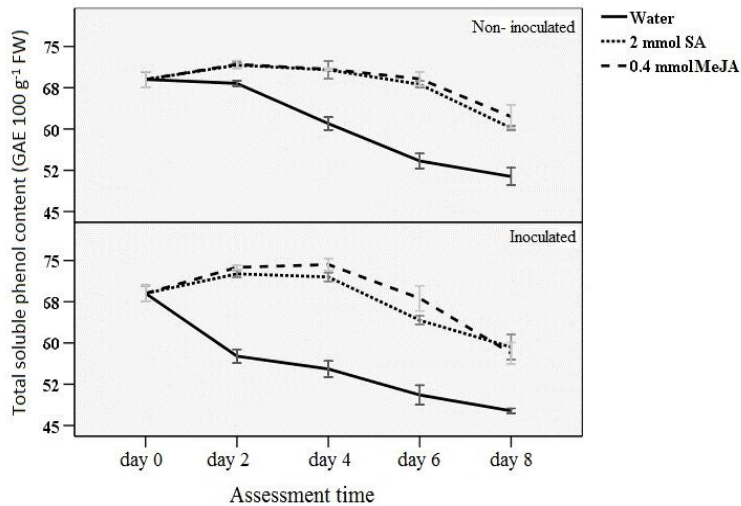


Fig. 23 Effect of 0.4 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on total soluble phenol content (GAE 100 g⁻¹ FW) in apricot fruit (cv. 'Bergarouge'). Error bars represent the SD values.

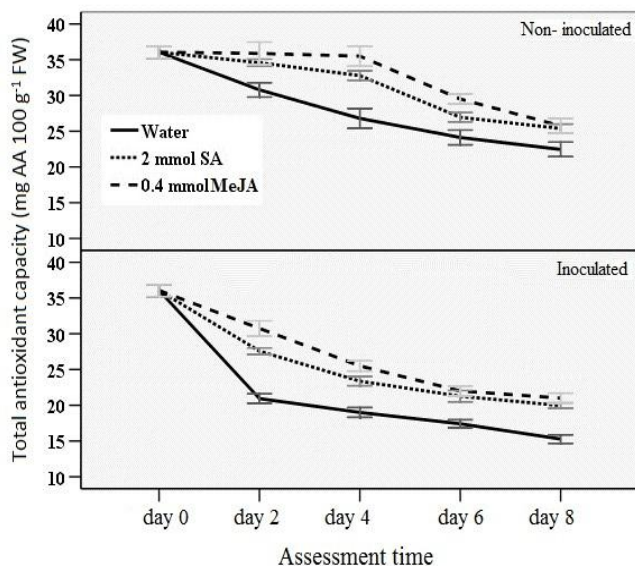


Fig. 24 Effect of 0.4 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on total antioxidant capacity (mg AA 100 g⁻¹ FW) in apricot fruit (cv. 'Bergarouge'). Error bars represent the SD values.

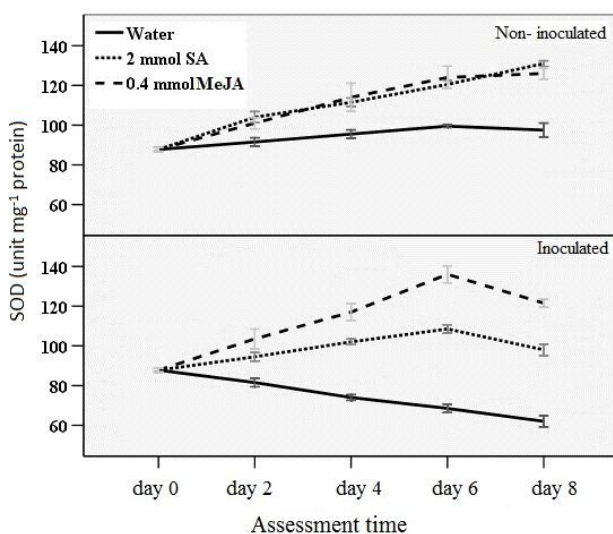


Fig. 25 Effect of 0.4 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on superoxide dismutase (SOD; unit mg⁻¹ protein) activity in apricot fruit (cv. 'Bergarouge'). Error bars represent the SD values

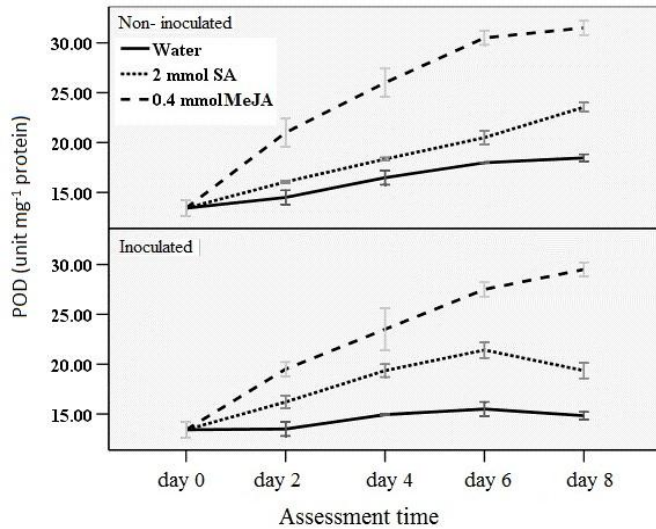


Fig. 26 Effect of 0.4 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on peroxidase (POD; unit mg⁻¹ protein) activity in apricot fruit (cv. 'Bergarouge'). Error bars represent the SD values.

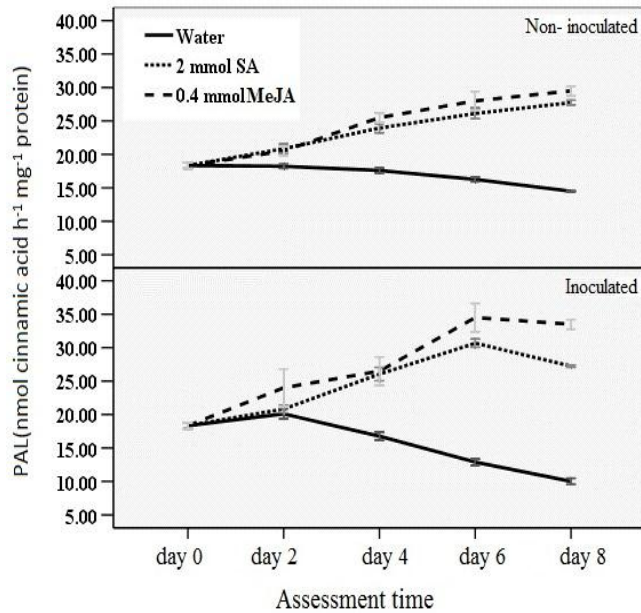


Fig. 27 Effect of 0.4 mmol L⁻¹ methyl jasmonate (MeJA) and 2 mmol L⁻¹ salicylic acid (SA) on phenylalanine ammonia-lyase (PAL; nmol cinnamic acid h⁻¹ mg⁻¹ protein) activity in apricot fruit (cv. 'Bergarouge'). Error bars represent the SD values.

Table 5 The effect of treatments of 0.5, 2, and 5 mmol L⁻¹ salicylic acid (SA) and 0.1, 0.4, and 0.7 mmol L⁻¹ methyl jasmonate (MeJA) on apricot fruit disease incidence and mycelia growth of *Monilinia laxa* *in vitro*.

| Treatments | Control | SA | | | MeJA | | |
|-----------------------|--------------------|-----------------------------|---------------------------|---------------------------|-----------------------------|-----------------------------|-----------------------------|
| Concentrations | Water | 0.5 mmol L ⁻¹ | 2 mmol L ⁻¹ | 5 mmol L ⁻¹ | 0.1 mmol L ⁻¹ | 0.4 mmol L ⁻¹ | 0.7 mmol L ⁻¹ |
| Growth rate (%) | 160.50± 12.02 a | 81.98± 5.65 b | 58.49± 12.01c | 55.03± 5.58c | 89.91± 1.32b | 74.48± 5.10b | 72.37± 2.27b |
| Disease incidence (%) | 58.42± 3.45 a | 32.35± 2.09 b | 22.50± 0.70 c | 21.50± 2.12 c | 36.48± 1.96 b | 23.50± 0.70 c | 22.84± 0.08 c` |
| Lesion diameter (mm) | 15.49± 1.01a | 12.99± 0.61b | 10.31± 0.47 c | 10.44± 0.61 c | 15.77± 0.45 a | 12.81 ± 0.23 b | 11.49± 0.69 b |

Numbers in the rows followed by different letters showing the significance differences (P<0.05)

4. NEW SCIENTIFIC RESULTS

1. Apricot fruit showed positive responses to SA and/or MeJA and we can apply these elicitors as postharvest application for apricot fruit.
2. Chilling injury and fruit decay index indicated SA significantly reduced the deterioration of apricot fruit. Fruit treated 2 mmol L⁻¹ SA had priority to keep the fruit firmness of Flavor cot, Jumbo cot and Bergaraugue and at the same time was able to reduce the chilling injury and decay development.
3. MeJA and SA application helped to keep fruit quality in early phases of storage by reducing fruit weight lost, fruit softening, maintaining soluble solid content (SSC) and acidity over the whole storage period.
4. Fruit treated with MeJA and SA were characterized by high total polyphenolic content and antioxidant capacity while these parameters decreased quickly in control fruits.
5. Treated fruit with MeJA and SA enhanced phenylalanine ammonia-lyase (PAL) and superoxide dismutase (SOD) activities during the early phase of storage period.
6. Sensory parameter data showed that the MeJA and SA recorded the highest score over 2 weeks of cold storage or 8 days at room temperature while the control fruit showed the extreme low texture, and taste score over 2 weeks at 1 °C or 4 days at 25 °C.
7. Fruit loss because of *Monilinia laxa* infection can be reduce with SA and/or MeJA treatment, the disease incidence and lesion diameter were low in SA and MeJA treated fruit than control fruit.
8. MeJA showed high accumulation of lignin than the other treatment, SA did not affect lignin content.

5. Practical results

This study was concerning with increasing the potential marketing of apricot fruit by enhancing the fruit storability in general.

Our results revealed that the SA and/or MeJA can play role in increasing the fruit storability and reducing the chilling and fungi infection stress.

This can be in regular process in the fruit packaging house as directly after fruit harvesting the fruit are sorted to remove the defected fruit then the fruit can be soak into containers contain the solutions of SA and/or MeJA.

The cylinder rotary can bring the fruit out o of the centenaries after 10 minutes. Then the fruit pass under fans to dry the fruit and directly go to packaging unit.

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7. Publication



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Register number: DEENKÉTK/424/2014.
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Candidate: Gaballa Kassem Ahmed Ezzat

Neptun ID: A41JH7

Doctoral School: Kerpely Kálmán Doctoral School of Corp Production, Horticulture and Regional Sciences

List of publications related to the dissertation

Foreign language scientific article(s) in Hungarian journal(s) (7)

1. **Ezzat, A.**, Nessreen, N.B., Ammar, A.K.: Study of some cooking and eating quality characters on some Egyptian rice genotype.
Agrártud. Közl. 59, 77-82, 2014. ISSN: 1587-1282.
2. **Ezzat, A.**, Szabó, Z., Ammar, A.K.: The role of some elicitors in inducing chilling stress resistance in apricot fruit.
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3. **Ezzat, A.**, Szabó, Z., Nyéki, J., Holb, I.: Induce the plant resistance to pathogen infection:(review).
Int. J. Hortic. Sci. 20 (1-2), 89-93, 2014. ISSN: 1585-0404.
4. **Ezzat, A.**, Szabó, Z., Nyéki, J., Holb, I.J.: Preliminary results on salicylic acid treatment on brown rot caused by *Monilinia laxa* on Jumbo Cot fruit, *Prunus armeniaca* L.
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5. Amira, S.M., Nagwa, M.M.E., **Ezzat, A.**: Some microbial treatments against the tomato leaf miner; *Tuta absoluta* (Merick) under natural field conditions.
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6. **Ezzat, A.**, Nyéki, J., Soltész, M., Amriskó, L., Balázs, G., Mikita, T., Szabó, Z.: Storability of some apricot varieties as affected by storage period.
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8. Szabó, Z., Szani, Z., Kiss, G., **Ezzat, A.**, Veres, E., Takács-Hajós, M., Szalay, L., Soltész, M., Nyéki, J.: Changes of the apricot variety choice in Hungary.
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9. **Ezzat, A.**, Nyéki, J., Veres, E., Soltész, M., Szabó, Z.: P-5 differences in blooming time of some apricot varieties in Hungary.
In: 2nd Global congress on plant reproductive biology. 50,
10. **Ezzat, A.**: Physiological and pomological evaluation of apricot cultivars.
In: 2nd international scientific workshop of Egyptian PhD students and their academic supervisors. 5,

The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of Web of Science, Scopus and Journal Citation Report (Impact Factor) databases.

11 December, 2014

