1   **Impact of salicylic acid, abscisic acid, and methyl jasmonate on postharvest quality and**

2   **bioactive compounds of cultivated strawberry fruit**

3

4   Mohamed M. El-Mogy[1,*], Marwa R. Ali[2], Omaima S. Darwish[1], and Hilary J. Rogers[3]

5   [1]Vegetable Crops Department, Faculty of Agriculture, Cairo University, Giza, Egypt

6   [2]Food Science Department, Faculty of Agriculture, Cairo University, Giza, Egypt

7   [3]School of Biosciences, Cardiff University, Sir Martin Evans Building, Museum Avenue,

8   Cardiff CF10 3AX, UK

9

10   *Mohamed El-Mogy (Corresponding author), email: elmogy@agr.cu.edu.eg; Tel

11   number: 002-01068027607, and ORCID number: 0000-0001-7598-7557

12

13   **Abstract**

14   **BACKGROUND:** Strawberry is one of the most highly consumed fruits worldwide.

15   However, it is highly perishable fruit postharvest.

16   **OBJECTIVE:** To assess the effect of dipping strawberry fruits after harvest in plant growth

17   regulators to maintain postharvest quality.

18   **METHODS:** Treatments tested were: 2 and 4 mM salicylic acid (SA), 0.25 and 0.50 mM

19   abscisic acid (ABA) and methyl jasmonate at 0.25 and 0.50 mM (MeJA). Bioactive

20   compounds and fungal growth were assessed over 12 days of storage at 4 °C.

21   **RESULTS:** Both concentrations of SA and MeJA significantly suppressed weight loss, decay

22   and respiration rate and 0.50 mM ABA also reduced decay. Both concentrations of SA

23   retarded color development, and total soluble solids content was enhanced by 0.50 mM ABA

24   and MeJA treatments. The most effective treatments for preserving firmness were 0.25 mM

25   MeJA and 4 mM SA. Reduction in loss of ascorbic acid and bioactive compounds during

storage was achieved using the highest concentrations of SA, ABA, and MeJA. Fungal growth was suppressed by all treatments but the best treatment was MeJA at both concentrations.

CONCLUSIONS: All three plant growth regulators reduce postharvest changes in strawberry but effects differ amongst the treatments.

Keywords: Fragaria ananassa, quality, postharvest storage, bioactive compounds.

1. Introduction

Strawberry fruit is considered one of the most popular horticultural crops world-wide and is a rich source of important minerals, vitamins (vitamin C), and phytochemicals (anthocyanins carotenoids and polyphenols), that play a significant role in human health [1]. However, strawberry, a non-climacteric fruit, is highly perishable with limited shelf-life due to its high water content, respiration rate, susceptibility to mechanical injury, and to microbial attack (especially by *Botrytis cinerea*) during storage [2]. Strawberry fruit deteriorates rapidly after harvest with loss of economic and nutritional value, and it needs to be harvested at a precise stage of maturity in order to obtain maximum postharvest quality. Hence, there is a demand not only from the producers but also from the consumers to extend shelf-life and reduce decay of strawberry fruit.

Recently, many postharvest techniques have been applied for reducing decay of strawberry fruit such as edible coating with *Aloe vera* and ascorbic acid [3], dipping in essential oils [4], melatonin treatment [5], controlled atmosphere storage [6], γ-irradiation [7], hot air and hot water dipping [2, 8], Nano-ZnO treatment [9], pulsed light [10], and ethylene action inhibitor (1-MCP) treatment [11]. However, some of these treatments are not realistic due to low customer acceptance or high treatment price. Therefore, it is important to develop novel effective methods to reduce senescence and enhance quality of strawberry fruit. One of the

postharvest treatments for reducing senescence of fruits is application of exogenous plant growth regulators. However, relatively few previous studies have compared the effects of different plant growth regulators on postharvest decay and quality of strawberry fruits.

Salicylic acid (SA) is a natural compound and is responsible for suppressing ethylene production and fungal growth such as that of *B. cinerea*. It was reported that SA concentrations of 1 and 2 mmol L^{-1} were the most effective for reducing ethylene production, microbial load and retaining overall quality of strawberry fruits [12]. Moreover, postharvest treatment with SA enhanced total antioxidant content in strawberry fruit [13]. It also reduced weight loss, decay and redness, maintained firmness, and increased hue angle [14].

Abscisic acid (ABA) is one of the most important plant hormones, acting as an inhibitor of growth and metabolism. Previous studies indicated that ABA plays an important role in fruit ripening and senescence not only in climacteric fruits such as tomatoes [15] but also in non-climacteric fruits such as strawberry [16]. Previous reports indicated also that ABA might increase postharvest quality of some fruits such as tomato by enhancing suberin accumulation [17], and increasing soluble sugar concentrations [18]. In strawberry postharvest treatment with 1, 10 or 100 mM ABA resulted in increased accumulation anthocyanin and softening mediated by an increase in PAL activity [19, 20, 21].

Methyl jasmonate (MeJA) is found naturally in higher plants and plays a key role in plant defense against pathogen infection. For example, application of exogenous MeJA reduced postharvest decay of peppers by enhancing tissue resistance to *Botrytis cinerea* [22] and reduced decay development in strawberry fruit [23, 24, 25]. Previous studies indicated that crop quality traits were also improved following exogenous MeJA treatment. For example, treatment of *Fragaria chiloensis* with MeJA also maintained fruit firmness and anthocyanin levels [23]. Indeed MeJA treatment was also shown to enhance strawberry aroma while retaining nutritionally important compounds [26].

76   To our knowledge, no previous studies have been performed, however, to compare the effects

77   of SA, ABA, and MeJA on storability, physico-chemical and sensory quality parameters of

78   strawberry fruits. Thus, the aim of the current study was to evaluate comparatively the effects

79   of postharvest treatment with SA, ABA, and MeJA on retarding senescence, reducing decay,

80   and improving quality traits of strawberry fruit during storage at 4 °C for 12 days.

81

82   **2. Materials and methods:**

83

84   *2.1. Plant materials and treatments*:

85

86   Strawberry (*Fragaria × ananassa*) cv. 'Festival' fruits were harvested at commercial ripeness

87   stage (¾ of fruit surface showing red colour) from the Faculty of Agriculture, Cairo

88   University experimental station and transported to the postharvest laboratory within 2 h. The

89   fruits were selected for uniformity of size and being free from any visual defects, and they

90   were randomly divided into seven groups (about 100 fruits per group). The strawberry fruit

91   groups were immersed in the following six solutions for 5 min at room temperature (20 °C).

92   The six solutions for treatments were prepared in distilled water as follows: SA-2 (2 mmol L^{-1}

93   salicylic acid), SA-4 (4 mmol L^{-1} salicylic acid), MeJA-0.25 (0.25 mmol L^{-1} methyl

94   jasmonate), MeJA-0.50 (0.50 mmol L^{-1} methyl jasmonate), ABA-0.25 (0.25 mmol L^{-1}

95   abscisic acid), and ABA-0.50 (0.50 mmol L^{-1} abscisic acid). The concentrations used were

96   selected based on preliminary experiment and previous work [SA (14), MeJA (23), and ABA

97   (16)]. The seventh group was the control (CON) and was dipped in distilled water. After

98   immersion, the fruit were recovered using autoclaved forceps and allowed to dry in a laminar

99   air flow hood at room temperature for 60 min. After drying, the fruit for each treatment were

100   packed in clamshells (each containing about 200 g of fruit) and stored at 4 °C and 90% RH

101 for 12 d. Clamshells for each treatment were divided into two groups. The first group was

102 stored continuously throughout the experimental storage period to determine weight loss and

103 decay. The second group was used to determine fruit quality parameters (firmness, total

104 soluble solids, respiration rate, and colour intensity), chemical parameters (pH, titratable

105 acidity, vitamin C, anthocyanin, total phenolic content and antioxidants capacity), and fungal

106 counts. All the measurements were performed at time intervals of 0, 4, 8 and 12 days after the

107 treatments and each treatment was replicated three times. All physical and chemical analyses

108 were performed on fresh fruits on the day of assay. The experiment was repeated twice.

109

110 *2.2. Chemicals*

111

112 Salicylic acid, methyl jasmonate, abscisic acid, ethyl alcohol, ACS spectrophotometric grade,

113 95.0%, methyl alcohol, gallic acid and Folin & Ciocalteu's phenol reagent were purchased

114 from Sigma-Aldrich (USA). Potato dextrose Agar**,** sodium carbonate, potassium acetate and

115 hydrochloric acid were purchased from Al Gomhoria CO, Cairo, Egypt.

116

117 *2.3. Weight loss*

118

119 Weight loss percentage was determined by weighing strawberry fruits using digital scales on

120 each sampling day during storage and calculated using the following equation:

121 Weight loss (%) = (Initial weight - Final weight/ Initial weight) $\times$ 100.

122

123

124

125 *2.4. Decay percentages*

5

126

127 The decay percentage was determined at each sampling point and calculated according to the

128 following equation:

129 Decay percentage (%) = (Number of decayed fruits / Total number of fruits) × 100.

130

131 *2.5. Firmness (N)*

132

133 Ten random strawberry fruits from each treatment were used for determining firmness at two

134 points. The two points tested were located in the central zone on opposite sides of fruits.

135 Firmness was measured using a FT011 penetrometer (Wagner Instruments, Italy) and values

136 are presented as Newtons (N).

137

138 *2.6. Soluble solids* content *(SSC)*

139

140 Five strawberry fruits were selected for measuring SSC from each treatment (with three

141 replicates). The fruits were mixed in a blender for 2 mins and SSC was determined using a

142 digital refractometer (model PR101, Co. Ltd., Japan) at room temperature (25°C). Readings

143 were taken as % of total soluble solids in the fruit. The same juice was used for determining

144 titratable acidity and pH.

145

146 2.7. *Titratable acidity (TA) and pH*

147

148 TA of strawberry juice was measured using a digital burette and determined by titrating 5 g

149 (diluted with 50 mL distilled water) of strawberry juice sample with 0.1 mol L^{-1} sodium

150 hydroxide to an end point of pH 8.1 and expressed as percent of citric acid in the fruit juice.

151 The pH of the juice was determined using a pH-meter (EuTech, Instruments, pH 510,

152 Singapore).

153

154 *2.8. Skin fruit colour*

155

156 Skin colour of strawberry fruit was measured with a Minolta colorimeter (Model CR-400,

157 KonicaMinolta, INC, Tokyo, Japan) on five fruit per replicate. *L**, *a**, *b**, chroma (*C**) and

158 hue angle (*h°*) were determined. Each measurement was taken at three locations for each

159 individual fruit. A standard white calibration plate was used to calibrate the colorimeter.

160

161 *2.9. Respiration rate*

162

163 Five separate single fruits were placed in separate gas-tight jars (200 ml) at 5°C for 2 h. After

164 2 h, 1 mL of air sample was removed from the headspace and was analyzed using an O_2/CO_2

165 gas analyzer (model 902D, MA, USA). Respiration rate was expressed as mmol CO_2

166 $kg^{-1}FWh^{-1}$.

167

168 *2.10. Ascorbic acid and total anthocyanin content*

169

170 Ascorbic acid (AA) content was determined using a titrimetric method with 2, 6-

171 dichlorophenol indophenol [27]. The results of AA content are expressed as mg/100 g fresh

172 weight.

173 Five strawberry fruits were selected randomly from each replicate and homogenized in a

174 laboratory blender (Heidalph DGH Rundfunk- Fernsehen, Typ-DR 22054, Germany) at high

175 speed to determine anthocyanin and total phenolic compounds. Anthocyanin content was

176 determined using the pH-differential method described by Tonu et al. [28]. Briefly, 4 g of

177 strawberry puree was extracted with 40 ml of solvent, ethanol: 0.1 M HCl (85:15%, V:V).

178 The mixture was centrifuged at $6.000 \times g$ for 20 min and then the supernatant was filtered

179 using Whatman No.1 filter paper; the supernatant was collected and used for anthocyanin

180 determination. Extractions were done in triplicate. Extracts (3 ml) were diluted in 5 ml of two

181 different buffers; pH = 1.0 and pH = 4.5. After 30 minutes of incubation at room temperature,

182 absorption (A) was measured at 510 nm and at 700 nm. The absorbance values of the diluted

183 samples (A) were calculated as follows:

184 $A = (A_{510} - A_{700}) \, pH_{1.0} - (A_{510} - A_{700}) \, pH_{4.5}$

185 Total anthocyanin content was calculated as follows:

186 $TAC = A \times MW \times df \times 1000/(\varepsilon \times \lambda \times m)$

187 Total anthocyanin content was calculated as mg cyanidin-3-glucoside equivalent per kg dry

188 extract (mg C3GE/kg) by using (A) the difference of absorbance between pH 1 and pH 4.5

189 solutions, a dilution factor (df), conversion factor to kg (1000), a molar absorptivity (ε) of

190 $24,825 \, M^{-1} \, cm^{-1}$ (at 510 nm), a molecular weight (MW) of 484.82, cuvette optical path length

191 (λ)(1 cm), and weight of the sample (m)(g).

192

193 *2.11. Total phenolic content*

194

195 The total phenolic content (TPC) was determined according to Aaby et al. [29] using Folin-

196 Ciocalteau reagent with gallic acid as standard. Aliquots of strawberry puree were centrifuged

197 at $8000 \times g$ for 20 min at room temperature. The resulting homogenate was filtered through

198 filter paper to obtain a clear juice. One mL of collected clear juice was mixed with 5 mL of a

199 1/10 dilution of Folin-Ciocalteau reagent and 4 mL sodium bicarbonate (7.5% w/v), and the

200 mixture was diluted to 100 mL with distilled water. The solution was kept in the dark at room

temperature for 2 h; the absorbance was then measured at 765 nm with a spectrophotometer (model UV-2401 PC, Shimadzu, Milano, Italia). TPC was expressed as gallic acid equivalents in mg per 100 g fresh weight (mg GAE/100 g FW) using a gallic acid standard curve.

2.12. Antioxidant capacity

The effect of different treatments on strawberry fruit antioxidant capacity was determined according to the method of Yen and Chen [30]. Strawberry samples (10 g) were homogenized in 200 mL of distilled water, and then filtered using Whatman No.1 filter paper and 5 mL of filtrate was diluted into 25 mL of distilled water. Strawberry extract (1 mL) was added to 3 mL of methanol and 1 mL of 2,2-diphenyl-1-picrylhydrazyl (DPPH) (0.012 g DPPH in 100 mL^{-1} of methanol). The mixture was shaken in the dark at room temperature for 10 min. The absorbance was measured at 517 nm. The antioxidant capacity was expressed as % of inhibition according to the formula:

Inhibition (%) = ($A_{control}$ - A_{sample}/$A_{control}$) × 100

where *A* control and *A* sample are the absorbance of the control and sample, respectively [31].

2.13. Microbiological evaluation

Fruit samples (10 g) were crushed and diluted (1:10 w/v) in 0.1% buffered peptone water, homogenized by hand massaging for 5 min and serially diluted with buffered peptone water. The homogenate (0.1 ml) was plated on potato dextrose agar in duplicate. Fungal counts (log CFU/g) were determined after incubation at 25-28 °C for 5 days [32].

2.14. Statistical analysis

225 The whole experiment was repeated twice and the data were pooled. Data were subjected to

226 analysis of variance (ANOVA) with SPSS software. Sources of variation were storage period

227 (days) and treatments. A Duncan test at $p < 0.05$ was used to compare means among

228 treatments.

229

230 **3. Results**

231

232 *3.1. Weight loss, respiration rate, and decay were reduced by postharvest treatments*

233

234 The effect of dipping strawberry cv. 'Festival' fruit in different concentrations of SA, ABA,

235 and MeJA on weight loss, respiration rate, and decay percentage during 12 days of storage at

236 4°C is shown in Fig. 1. Weight loss n increased during the storage period following all

237 treatments (Fig. 1A). After 8 days of storage, all treatments significantly ($p < 0.05$) reduced

238 weight loss compared to the control except the two concentrations of ABA. However, at the

239 end of the storage period (12 days), only treatment with 0.25 mM MeJA significantly reduced

240 weight loss compared to the control.

241 The 2 and 4 mM SA treated fruits showed significant ($p < 0.05$) reduction of respiration rate

242 at all storage period time points compared to the control fruits (Fig. 1B). After 4 and 8 days of

243 storage, there were no differences in respiration rate between fruit treated with 0.25 and 0.50

244 mM ABA and the control. However, after 12 days of storage, treatment of strawberry fruit

245 with 0.50 mM ABA resulted in greater respiration rate than the control or the other

246 treatments. MeJA at 0.50 mM significantly reduced respiration rate at all storage period time

247 points.

248 No decay was observed on the surface of strawberry fruit after 4 days of storage after any of

249 the treatments, however, strawberry fruit treated with 2 and 4 mM SA showed greater

10

250   resistance against decay when compared with the control and the other treatments after both 8

251   and 12 days of storage (Fig. 1C). Treatment with the higher concentration of SA resulted in

252   less surface decay than the lower concentration after 8 days of storage, however, the

253   difference between two concentrations of SA was not significant after 12 days of storage.

254   Treatment with ABA showed the same trend of results as SA but after 12 days, treatment with

255   0.25 mM ABA was not effective at reducing decay compared to the control. Treatments with

256   MeJA (0.25 and 0.50 mM) significantly delayed the development of decay compared to

257   control fruits throughout the storage periods. However, no significant difference was observed

258   in decay between 0.25 and 0.50 mM MeJA treated fruit.

259

260   *3.2. Changes in colour*

261

262   The effect of dipping strawberry cv. 'Festival' fruit in different concentrations of SA, ABA,

263   and MeJA on L*, a*, and ascorbic acid content during 12 days of storage at 4°C is shown in

264   Fig. 2. The L* value is an indicator for brightness of the fruit surface: high values indicate

265   less pigment accumulation and less ripening while the lower values indicate more intense

266   colour and more ripening. Results shown in Supplementary Table (1) indicate that L* values

267   of fruit surfaces generally decreased during storage. After 4 days of storage, the L* values of

268   fruit subjected to all treatments were significantly higher (lighter colour) than those of the

269   control except for the 0.25 mM MeJA treatment. After 8 days only the SA treated fruit and

270   after 12 days the SA treated and the 0.25 mM JA treated fruit, had higher L* values than the

271   control. ($p < 0.05$).

272   A positive (+) a* value is an indicator for redness while, negative (-) values are a sign of

273   greenness. Thus a positive a* value is correlated with anthocyanin concentration in strawberry

274   fruits [17]. Here, a* values increased with storage duration from 4 to 8 days following all

11

275   treatments (Supplementary Table 1). Both SA treatments resulted in significantly lower a*

276   values than the control at all time points (Fig. 2B). There were no differences in a* values

277   between the two concentrations of ABA or the lower concentration of MeJA treatment and

278   the control after 8 storage. However, no differences were recorded between control and either

279   concentration of ABA and MeJA after 12 days of storage.

280

281   *3.3. Strawberry fruit quality is affected by treatments*

282

283   Firmness, SSC, pH, and titrable acidity (TA) were determined as indicators of strawberry fruit

284   ripening and quality as well as their metabolic activity (Table 1). SSC was significantly ($p <$

285   0.05) influenced by treatments. SSC at harvest was 10.87±0.13 Brix, and decreased

286   significantly after 4 d of storage in both control and most treated fruits (Supplementary Table

287   1). Treatment with both ABA concentrations reduced SSC loss compared to the control while

288   the other treatments had no effect after 4 days of storage. After 8 and 12 d of storage, both

289   treatments with ABA (0.25 and 0.50 mM) and MeJA (0.25 and 0.50 mM) showed

290   significantly higher SSC values compared to control.

291   Fruit firmness was 4.71±0.03 N at harvest time and decreased during storage after all

292   treatments (Supplementary Table 1). No significant difference was observed between treated

293   fruit and the control after 4 days of storage (Table 1). After 8 and 12 days of storage, fruit

294   firmness was found significantly ($p <$ 0.05) higher in all treated fruits when compared with

295   control. Among all treatments, MeJA at 0.25 mM and SA at 4 mM showed highest fruit

296   firmness at both time points during the storage period.

297   In the controls, pH rose from dya0 to day 8 and then fell back, while TA contents rose from

298   day 0 to day 8 and thereafter remained constant (Supplementary Table 1). However,

12

299 postharvest treatments with SA, ABA, and MeJA had no clear effect on either character

300 during storage.

301

302 *3.4. Effect of treatments on bioactive compounds and antioxidant* capacity

303

304 *3.4.1. Changes in ascorbic acid*

305 Ascorbic acid decreased with increasing storage time (Fig. 2C). No significant difference was

306 observed in AA amongst all treated fruit and the control after 4 days of storage. However after

307 8 and 12 days of refrigerated storage, treatment of fruit with 4 mM SA, 0.50 mM ABA, and

308 0.25 mM MeJA significantly reduced ($p < 0.05$) the loss of AA compared to the control.

309 Neither the lower concentration of SA or ABA was able to reduce AA loss after 8 or 12 days

310 of storage. Both concentrations of MeJA also reduced loss of AA after 12 days and when used

311 at 0.25 mM a loss reduction was also seen after 8 days of storage.

312

313 *3.4.2. Changes in antioxidant* capacity

314

315 Antioxidant capacity was 78.32±2.27 % at the beginning of the storage period and decreased

316 with increasing storage periods at 4°C in all treated fruits (Supplementary Table 1). However,

317 all treated strawberry fruit retained more antioxidant capacity compared to the control

318 treatment at each time point (Fig. 3A). Furthermore, strawberries treated with the higher

319 concentration of SA, ABA, and MeJA showed higher values of antioxidant capacity at each

320 time point compared to the lower concentrations, although the difference was not significant

321 for ABA at day 8 of storage.

322

323 *3.4.3. Changes in TPC*

13

324

A slight increase in TPC was observed after 4 days of storage at 4°C in strawberry fruits with

most of the plant hormone treatments, which ranged from (211- 224) mg GAE/100g FW,

compared to the untreated control (206 GAE/100g FW) (Fig. 3B). After 4 days of storage,

there was a decrease in TPC in all treated fruit and control (Supplementary Table 1).

However, the fruit treated with the higher concentrations of all three hormones retained

significantly higher TPC after both 8 and 12 days of storage compared to the control.

3.4.3. Changes in total anthocyanin content

Total anthocyanin content was significantly affected by treatment with SA, ABA, and MeJA

(Fig. 3C). Anthocyanin content increased slightly between 4 and 8 days of storage following

treatment with the lower concentrations of SA, ABA, and MeJA, but by day 12, it had

decreased (Supplementary Table 1). However, anthocyanin content of all treated fruits was

significantly greater at 8 and 12 days of storage compared to the control. Strawberries treated

with the lower concentration of ABA showed the highest anthocyanin content at the end of

storage period followed by the strawberries treated with 2 mM SA and 4 mM SA.

3.5. Fungal count (log CFU/g) was affected by postharvest treatments

The effect of dipping strawberry cv. 'Festival' fruit in different concentrations of SA, ABA,

and MeJA on fungal counts (log CFU/g) during storage for 12 days at 4°C is presented in

Table 2. The principal decay fungi detected were *Botrytis cinerea* and *Rhizopus stolonifer*. No

fungal growth was detected from fruit treated with SA (4 mM), ABA (0.50 mM), and MeJA

(0.25 and 0.50 mM) at day 0. At all storage time points (4, 8 and 12 days) fungal growth in all

14

349 treated fruits was either absent or significantly lower than in the control ($p > 0.05$). After 8

350 days of storage, fruit treated with the higher concentration of SA and both concentrations of

351 MeJA recorded significantly lower fungal counts than the other treatments or control and

352 ranged from 2.5 – 2.6 log CFU/g. At the end of the storage period, the control sample reached

353 4.2 log CFU/g followed by the SA and ABA treated fruit (3.9 log CFU/g). The most effective

354 treatments for controlling fungal growth were the two concentrations of MeJA without any

355 significant difference between them.

356

357 **4. Discussion**

358 *4.1. Weight loss, respiration rate, and colour changes*

359

360 Our results showed that the most effective treatments for reduction of weight loss were SA

361 and MeJA. Application of SA has been found to reduce water loss during refrigerated storage

362 of various crops including strawberry [14]. The positive effects of SA for reducing weight

363 loss are related to its overall effects in maintaining fruit quality [13, 14]. This in turn is likely

364 due to the effect of SA treatments in reducing respiration rate and ethylene production

365 [12,13]. In this study respiration rate was significantly reduced by the SA treatments.

366 The effect of MeJA in reducing weight loss is likely related to its effect in reducing loss of

367 firmness (Table 1). This in turn may be due to effects on total antioxidants [33] that result in

368 increasing lignin content as observed in previous work on *Fragaria chiloensis* fruit [23].

369 Treatment with 0.50 mM MeJA also significantly reduced the respiration rate during storage

370 of the strawberry fruit, presumably related to the maintenance of firmness and fruit quality.

371 This is in agreement with previous work [34] showing that whereas in unripe fruit MeJA

372 increased respiration, at later stages of ripening MeJA treatment had the opposite effect. The

373 increased of respiration rate induced by 0.5 mM ABA could be due to enhanced ethylene

15

374   production elicited by ABA treatment which was previously reported in strawberry cv.

375   'Everest' [20].

376   Here treatment with 4 mM SA resulted in a shinier/lighter skin colour (higher L* values)

377   compared to the control throughout storage at 4 $^{\circ}$C. Effects of post-harvest treatments on

378   strawberry colour appear to vary [14]. For example, 2 mM SA treatment of *F. ananassa* cv

379   'Camarosa' fruit did not affect lightness (L*) [14]. The difference to the results presented here

380   may be due to the cultivar, or the different SA concentration used. In other fruit, lower

381   moisture loss leads to higher brightness (higher L* values) [35]. This would fit here with the

382   reduction in weight loss, but would need further verification. No difference was observed in

383   L* with ABA treatment at later storage time points. In previous work exogenous application

384   of 0.1 mM ABA to strawberry fruit, accelerated colour development by increasing

385   anthocyanin content and phenylalanine ammonia-lyase (PAL) activity [21]. The difference

386   with our results could be explained by the difference in the fruit maturity stage used, or the

387   method of ABA application, which in the case of Chen et al. [21] was via the peduncle.

388   In this study, the lowest a* values were obtained by both SA treatments during all storage

389   periods. This could be due to the reduction in weight loss (Fig 1.A) and respiration rate (Fig

390   1.B) leading to a delay in the accumulation of anthocyanin. Again this contrasts with results

391   reported by Shafiee et al. [14], who did not find any changes in a* values when strawberry cv.

392   'Camarosa' fruit were dipped in SA. The different cultivar used in this study could again

393   explain the differences with our results. Compared to the control, treatment with ABA had no

394   significant effect on a* value. However, Li et al. [19] reported a significant increase in a*

395   value of strawberry fruits using a 1 mM ABA treatment compared to controls. The difference

396   with our results could be due to the use of a higher concentration of ABA (1 mM) compared

397   to our study (0.50 mM).

398

4.2. SSC, Firmness, pH, and TA

SA treatment did not significantly affect SSC content, in agreement with Shafiee et al. [14]. However, in our study, ABA treatments did significantly increase SSC content. This is in agreement with previous work [19] where ABA treatment also increased colour formation, and anthocyanin accumulation while decreasing firmness. This combined effect was ascribed to an overall acceleration of ripening. Here firmness was actually increased by ABA treatment. The difference to the previous study may relate to the stage of maturity used for the studies: in this study fruit were treated at commercial ripeness while in the previous study the fruit were at the large green stage of maturity.

Firmness is a key factor for strawberry fruit quality. In this study, compared with controls, strawberry fruit treated with 4 mM SA showed higher firmness (Table 1), in agreement with a previous report showing that strawberry cv. 'Camarosa' fruits treated with SA had higher firmness than controls [14]. This result might be related to the effects of SA in reducing the activity of the main cell wall degrading enzymes (pectin methylesterase, cellulase, polygalacturonase) and reducing the activity of enzymes such as lipoxygenase which leads to higher firmness of fruits [13]. Here MeJA also increased firmness, in agreement with a previous study that tested pre-harvest applications of MeJA on postharvest qualities of *F. chiloensis*. In contrast Concha et al [36] found that application of MeJA decreased firmness, however in their study fruit were treated at a less mature stage which may account for the difference.

Our results show that SA treatment resulted in a higher TA than the control after 8 and 12 days of storage. This result does not agree with Shafiee et al. [14] or Ayub et al [37] who found that postharvest treatment with SA did not significantly affect TA, however these studies different in the treatment combinations used [14] and length of treatment [37] making

17

424   a full comparison difficult. Our results do however support the hypothesis that SA conserves

425   acidity in fruits via a reduction in respiration rate [13, 37].

426

427   *4.3. Ascorbic acid, Total Phenolics, anthocyanin and antioxidant* capacity

428   The positive effect of SA in reducing loss of AA is in agreement with previous studies [13,

429   33] and is likely due to its stimulation of the biosynthesis of ROS scavenging enzymes [13].

430   Treatment with 0.50 mM ABA also significantly increased AA retention. This result is in

431   agreement with Li et al. [19] who found an increase in antioxidant capacity in the first few

432   days post-harvest but not at later time points. On the other hand, Ayub et al. [37] did not find

433   any changes in AA related to ABA treatment. This could be due to the method of ABA

434   application, which was performed by injecting 100µL of 1 mM ABA diluted in 2% ethanol

435   solution into the fruit receptacles. In our study, MeJA also reduced AA loss in strawberry

436   fruits after longer term storage. This is in agreement with, Lolaei et al. [38] who reported a

437   significant increase in AA by treating strawberry cvs. 'Selva' and 'Queen Elisa' fruits with

438   0.50 and 1 mM MeJA.

439   The antioxidant capacity of all treated fruits was already higher than the control after only 4

440   days of storage. Moreover effects were most pronounced with the highest concentration of

441   each of the growth regulators. This contrasts with the ascorbic acid levels which were not

442   affected by the treatments at day 4 and suggests that the antioxidant effects of the treatments

443   were not mediated by changes in ascorbic acid. Phenolics are an important class of

444   antioxidant compounds in berries [9, 29]. In accordance with Ayala-Zavala et al., [40] MeJA

445   significantly increased retention of TPC at all time points.

446   The pattern of the effects of treatments on TPC do follow quite closely the pattern of

447   antioxidant capacity changes, although at day 4 the effects of all the treatments on antioxidant

448   capacity seemed to be more pronounced compared to the trend of TPC change, suggesting

449 that other antioxidant pathways may also be stimulated by the treatments. The retention of

450 TPC by treatments with high concentrations of SA and MeJA are consistent with previous

451 studies indicating that both growth regulators enhance the efficiency of antioxidant systems in

452 plants [40, 13].

453 Anthocyanin is one of the major compounds present in strawberries. In our study we observed

454 few differences in total anthocyanin content after 4 days of storage with the treatments tested.

455 However, at later time points all the treatments significantly improved anthocyanin retention.

456 This result is in agreement with the study by Ayala-Zavala et al., [40], where strawberries

457 treated with MeJA showed the highest values of anthocyanin after 12 days of storage at

458 7.5°C. Moreover, Yueming and Daryl [41] reported that treatment with ABA stimulated

459 accumulation of anthocyanin and increased ethylene production, and suggested that this may

460 be due to the effects of ABA in enhancing PAL activity.

461 The antioxidant capacity of anthocyanins may be one of their most significant biological

462 properties [42], however in our study the pattern of effects of the treatments on anthocyanin

463 content did not match antioxidant activity closely, indicating that other antioxidants are also

464 affected by the treatments

465

466 *4.5. Decay and fungal count (log CFU/g)*

467 Results presented here show that treatment of fruits with SA, ABA, or MeJA reduced decay

468 development during storage at 4°C. Plants use several mechanisms to protect themselves from

469 pathogenic attack; one of them is accumulation of SA [13, 43]. *Botrytis cinerea* and *Rhizopus*

470 *stolonifer* were the main decay fungi detected in our study. Our results are in agreement with

471 those previously reported [12] showing that postharvest treatment with SA reduced fungal

472 decay of strawberry cv. 'Selva' fruits caused by *Botrytis cinerea*. The role of SA in

473 controlling postharvest spoilage is likely due to its role in increasing hydrogen peroxide

19

474 (H_2O_2) in plants which acts as a signal molecule to activate plant resistance systems against

475 pathogen attack [13]. To our knowledge, no previous work has studied the effect of

476 exogenous ABA postharvest treatment on the decay development of strawberry fruit. Our

477 results indicate that 0.50 mM ABA retards decay during cold storage. This result could be due

478 to induced activity of defence enzymes by the ABA such as phenylalanine ammonia-lyase

479 (PAL) [20]. Our results also showed that MeJA at the two tested concentrations could delay

480 the development of decay in strawberry fruits, in agreement with previous studies [24, 25,

481 44]. The action of MeJA here is likely due to its activation of defence pathways [45].

482

483 **5. Conclusions**

484

485 In summary, a comparison of our results with the literature clearly indicates the need for

486 comparative studies using fruit of the same maturity and equivalent application methods. Our

487 results confirm and expand on previous studies showing that application of SA, ABA and

488 MeJA are potentially useful postharvest treatments to enhance strawberry shelf life. However,

489 the direct comparison of their effects provided in this study, indicates subtly different

490 responses that are worthy of further investigation to understand underlying mechanisms and

491 potential synergies.

492

493 **Conflict of interest**

494 The authors have declared no conflict of interest.

495

496 **References**

497 [1]   Dragišić Maksimović J, Poledica M, Mutavdžić D, Mojović M, Radivojević D,
498   Milivojević D. Variation in nutritional quality and chemical composition of
499   fresh strawberry fruit: combined effect of cultivar and storage. Plant Foods for
500   Human Nutrition. 2015; 70: 77-84. DOI: 10.1007/s11130-014-0464-3.

20

[2]   Wei Y, Wei Y, Xu F, Shao X. The combined effects of tea tree oil and hot air treatment on the quality and sensory characteristics and decay of strawberry. Postharvest Biology and Technology. 2018; 136: 139–144. DOI: 10.1016/j.postharvbio.2017.11.008.

[3]   Sogvar OB, Saba MK, Emamifar A. *Aloe vera* and ascorbic acid coatings maintain postharvest quality and reduce microbial load of strawberry fruit. Postharvest Biology and Technology. 2016 (a); 114: 29-35. DOI: 10.1016/j.postharvbio.2015.11.019.

[4]   El-Mogy MM, Alsanius BW. Cassia oil for controlling plant and human pathogens on fresh strawberries. Food Control. 2012; 28: 157-162. DOI: org/10.1016/j.foodcont.2012.04.036

[5]   Liu C, Zheng H, Sheng K, Liu W, Zheng L. Effects of melatonin treatment on the postharvest quality of strawberry fruit. Postharvest Biology and Technology. 2018; 139: 47-55. DOI: 10.1016/j.postharvbio.2018.01.016.

[6]   Alamar MC, Collings E, Cools K, Terry LA. Impact of controlled atmosphere scheduling on strawberry and imported avocado fruit. Postharvest Biology and Technology. 2017; 134: 76–86. DOI: 10.1016/j.postharvbio.2017.08.003

[7]   Maraei RW, Elsawy KM. Chemical quality and nutrient composition of strawberry fruits treated by γ-irradiation. Journal of Radiation Research and Applied Sciences. 2017; 10 (1): 80-87. DOI:org/10.1016/j.jrras.2016.12.004

[8]   Caleb OJ, Wegner G, Rolleczek C, Herppich WP, Geyer M, Mahajan PV. Hot water dipping: Impact on postharvest quality, individual sugars, and bioactive compounds during storage of 'Sonata' strawberry. Scientia Horticulturae. 2016; 210 (10): 150-157. DOI: 10.1016/j.scienta.2016.07.021.

[9]   Sogvar OB, Saba MK, Emamifar A, Hallaj R. Influence of nano-ZnO on microbial growth, bioactive content and postharvest quality of strawberries during storage. Innovative Food Science & Emerging Technologies. 2016 (b); 35: 168-176. DOI: 10.1016/j.ifset.2016.05.005.

[10] Duarte-Molina F, Gómez PL, Castro MA, Alzamora SM. Storage quality of strawberry fruit treated by pulsed light: Fungal decay, water loss and mechanical properties. Innovative Food Science & Emerging Technologies. 2016; 34: 267-274. DOI: 10.1016/j.ifset.2016.01.019.

[11] Li L, Lichter A, Chalupowicz D, Gamrasni D, Goldberg T, Nerya O, Ben-Arie R, et al. Effects of the ethylene-action inhibitor 1-methylcyclopropene on postharvest quality of non-climacteric fruit crops. Postharvest Biology and Technology. 2016; 111: 322–329. DOI: 10.1016/j.postharvbio.2015.09.031

[12] Babalar M, Asghari M, Talaei A, Khosroshahi A. Effect of pre- and postharvest salicylic acid treatment on ethylene production, fungal decay and overall quality of Selva strawberry fruit. Food Chemistry. 2007; 105: 449–453. DOI: 10.1016/j.foodchem.2007.03.021.

[13] Asghari M, Aghdam MS. Impact of salicylic acid on post-harvest physiology of horticultural crops. Trends in Food Science and Technology. 2010; 21: 502–509. DOI: 10.1016/j.tifs.2010.07.009.

[14] Shafiee M, Taghavi TS, Babalar M. Addition of salicylic acid to nutrient solution combined with postharvest treatments (hot water, salicylic acid, and calcium dipping) improved postharvest fruit quality of strawberry. Scientia Horticulturae. 2010; 124: 40–45. DOI : 10.1016/j.scienta.2009.12.004

[15] Zhang M, Yuan B, Leng P. The role of ABA in triggering ethylene biosynthesis and ripening of tomato fruit. Journal of Experimental Botany. 2009; 60:1579–1588. DOI: 10.1093/jxb/erp026.

[16]   Chen J, Mao L, Lu W, Ying T, Luo Z. Transcriptome profiling of postharvest strawberry fruit in response to exogenous auxin and abscisic acid. Planta. 2016(a); 243: 183–197. DOI:10.1007/s00425-015-2402-5

[17]   Tao XY, Mao LC, Li JY, Chen JX, Lu WJ, Huang, S. Abscisic acid mediates wound-healing in harvested tomato fruit. Postharvest Biology and Technology. 2016; 118: 128–133. DOI: 10.1016/j.postharvbio.2016.04.002.

[18]   Barickman TC, Kopsell DA, Sams CE. Abscisic acid improves tomato fruit quality by increasing soluble sugar concentrations. Journal of Plant Nutrition. 2017; 40 (7): 964–973. DOI.org/10.1080/01904167.2016.1231812.

[19]   Li D, Zisheng L, Mou W, Wang Y, Ying T, Mao L. ABA and UV-C effects on quality, antioxidant capacity and anthocyanin contents of strawberry fruit (*Fragaria ananassa* Duch.). Postharvest Biology and Technology. 2014; 90: 56–62. DOI: 10.1016/j.postharvbio.2013.12.006.

[20]   Jiang Y, Joyce DC. ABA effects on ethylene production, PAL activity, anthocyanin and phenolic contents of strawberry fruit. Plant Growth Regulation. 2003; 39: 171–174. DOI: 10.1023/A:1022539901044 ·

[21]   Chen J, Mao L, Mi H, Lu W, Ying T, Luo Z. Involvement of abscisic acid in postharvest water-deficit stress associated with the accumulation of anthocyanins in strawberry fruit. Postharvest Biology and Technology. 2016(b); 111: 99–105. DOI:org/10.1016/j.postharvbio.2015.08.003

[22]   Tzortzakisa N, Chrysargyrisa A, Sivakumarb D, Loulakakisc K. Vapour or dipping applications of methyl jasmonate, vinegar and sage oil for pepper fruit sanitation towards grey mould. Postharvest Biology and Technology. 2016; 118: 120–127. DOI: doi.org/10.1016/j.postharvbio.2016.04.004.

[23]   Saavedra GM, Figueroa NE, Poblete LA, Cherian S, Figueroa CR. Effects of preharvest applications of methyl jasmonate and chitosan on postharvest decay, quality and chemical attributes of *Fragaria chiloensis* fruit. Food Chemistry. 2016; 190: 448–453. DOI: 10.1016/j.foodchem.2015.05.107.

[24]   Saavedra GM, Sanfuentes E, Figueroa PM, Figueroa CR. Independent preharvest applications of methyl jasmonate and chitosan elicit differential upregulation of defense-related genes with reduced incidence of gray mold decay during postharvest storage of *fragaria chiloensis* fruit. Int. J. Mol. Sci. 2017; 18(7):1420. Doi:10.3390/ijms18071420.

[25]   Zhang FS, Wang XQ, Ma SJ, Cao SF, Li N, Wang XX, Zheng YH. Effects of methyl jasmonate on postharvest decay in strawberry fruit and the possible mechanisms involved. Acta Hortic. 2006; 712: 693-698

[26]   Moreno Fde L, Blanch GP, Flores G, del Castillo ML. Impact of postharvest methyl jasmonate treatment on the volatile composition and flavonol content of strawberries. Journal of the science of food and agriculture. 2010; 90: 989-994.

[27]   Association of Official Analytical Chemistry. (AOAC). Official Methods of Analysis of AOAC international. 2000; 17th ed. Gaithersburg, MD, USA.

[28]   Tonu T, Ulvi M, Lech S. Strawberry anthocyanin determination by pH differential spectroscopic method- how to get true results? Acta Scientiarum Polonorum, Hortorum Cultus. 2014; 13(3) : 35-47.

[29]   Aaby K, Skrede G, Wrolstad RE. Phenolic composition and antioxidant activities in flesh and achenes of strawberries (*Fragraria ananassa*). Journal of Agricultural and Food Chemistry. 2005; 3:4032-4040. DOI: 10.1021/jf048001o

598 [30]   Yen GC, Chen HY. Antioxidant activity of various tea extracts in relation to their
599   antimutagenicity. Journal of Agriculture and Food Chemistry. 1995; 43: 27-32. DOI:
600   10.1021/jf00049a007.
601 [31]   Rababah TM, Al-Mahasneh MA, Kilani I, Yang W, Alhamad MN, Ereifej K, et al.
602   Effect of jam processing and storage on total phenolics, antioxidant activity, and
603   anthocyanins of different fruits. Journal of the Science of Food and Agriculture. 2010;
604   91: 1096–1102. DOI:10.1002/jsfa.4289.
605 [32]   Naresh S, Byungjin M, Eunice AB. Microbial Decontamination of Fresh Produce
606   (Strawberry) Using Washing Solutions. Journal of Food Research. 2015; 4 (3): 128-
607   137. DOI:org/10.5539/jfr.v4n3p128
608 [33] Asghari M, Hasanlooe AR. Interaction effects of salicylic acid and methyl jasmonate on
609   total antioxidant content, catalase and peroxidase enzymes activity in "Sabrosa"
610   strawberry fruit during storage. Scientia Horticulturae. 2015; 197: 490-495.
611   doi.org/10.1016/j.scienta.2015.10.009.
612 [34]   Pérez AG, Sanz C, Olías R, Olías JM. Effect of Methyl Jasmonate on in Vitro
613   Strawberry Ripening. Journal of Agricultural and Food Chemistry. 1997; 45 (10):
614   3733-3737. DOI: 10.1021/jf9703563.
615 [35]   Delwiche M, Baumgardner RA. Ground color as a peach maturity index. Journal of the
616   American Society for Horticultural Science. 1983; 110: 53–57.
617 [36]   Concha CM, Figueroa NE, Poblete LA, Onate FA, Schwab W, Figueroa CR. Methyl
618   jasmonate treatment induces changes in fruit ripening by modifying the expression of
619   several ripening genes in *Fragaria chiloensis* fruit. Plant physiology and biochemistry.
620   2013; 70: 433-44. doi: 10.1016/j.plaphy.2013.06.008.
621 [37]   Ayub RA, Bosetto L, Galvão CW, Etto RM, Inaba J, Lopes PZ. Abscisic acid
622   involvement on expression of related gene andphytochemicals during ripening in
623   strawberry fruit *Fragaria × ananassa* cv. Camino Real. Scientia Horticulturae. 2016;
624   203: 178–184. DOI: 10.1016/j.scienta.2016.03.026.
625 [38]   Lolaei A, Zamani S, Ahmadian E, Mobasheri S. Effect of methyl jasmonate on the
626   composition of yield and growth of strawberry (Selva and Queen Elisa). International
627   Journal of Agriculture Crop Science. 2013; 5: 200–206.
628 [39]   Kahkonen MP, Hopia AI, Vuorela HJ, Rauha JP, Pihlaja K, Kujala TS, Heinonen M.
629   Antioxidant activity of plant extracts containing phenolic compounds. J Agric Food
630   Chem 1999; 47 (10): 3954-62.
631 [40]   Ayala-Zavala JF, Wang SY, Wang CY, Gonzalez-Aguilar GA. Methyl jasmonate in
632   conjunction with ethanol treatment increases antioxidant capacity, volatile compounds
633   and postharvest life of strawberry fruit. European Food Research and Technology.
634   2005; 221(6): 731–738. DOI: 10.1016/j.lwt.2004.03.002.
635 [41]   Yueming J, Daryl C. ABA effects on ethylene production, PAL activity, anthocyanin
636   and phenolic contents of strawberry fruit. Plant Growth Reg. 2003; 39: 171– 174.
637 [42] Wang H, Cao G, Prior RL. Total antioxidant capacity of fruits. Journal of Agricultural
638   and Food Chemistry. 1996; 44: 701-705. DOI: 10.1021/jf950579y
639
640 [43] Barman K, Sharma S, Kumari P, Siddiqui MW. Salicylic Acid. Postharvest Management
641   Approaches for Maintaining Quality of Fresh Produce (pp.51-68). 2016; Wyndmoor ,
642   PA, Springer Nature.
643 [44]   Moline HE, Buta JG, Saftner RA, Maas JL. Comparison of three volatile natural
644   products for the reduction of postharvest decay in strawberries. Advances in
645   Strawberry Research.1997; 16: 43–48.
646 [45]   Dar TA, Uddin M, Khan MMA, Hakeem KR, Jaleel H. Jasmonates counter plant
647   stress: A Review. Environmental and Experimental Botany. 2015; 115: 49-57.

Tables

Table 1: Effect of salicylic acid (2 and 4 mM), abscisic acid (0.25 and 0.50 mM), and methyl jasmonate (0.25 and 0.50 mM) on TSS, firmness, pH, and acidity of strawberry fruits stored for 12 d at 4 °C. Data are mean of three replicates ± standard errors. Different letters indicate significant differences amongst treatments at each time point (Duncan test, $p < 0.05\%$).

Time	Treatment	SSC	Firmness	pH	TA
(day)	(mM)	Brix	N		% citric acid
0		10.87±0.63	4.71±0.03	3.54±0.06	0.98±0.06
4	2 SA	9.23±0.88 bc	4.11±0.05 a	3.62±0.03 bc	0.92±0.01 ab
4	4 SA	9.23±0.06 bc	4.16±0.03 a	3.57±0.01 c	0.97±0.01 a
4	0.25 ABA	9.76±0.16 ab	4.03±0.37 a	3.57±0.02 c	0.91±0.00 ab
4	0.50 ABA	10.43±0.23 a	4.13±0.08 a	3.66±0.00 b	0.89±0.01 b
4	0.25 MeJA	8.63±0.12 c	4.20±0.05 a	3.62±0.01 bc	0.95±0.01 ab
4	0.50 MeJA	9.46±0.08 bc	4.16±0.12 a	3.74±0.01 a	0.93±0.01 ab
4	Control	8.63±0.63 c	4.13±0.14 a	3.64±0.02 b	0.89±0.03 b
8	2 SA	9.46±0.09 bc	3.66±0.03 bc	3.69±0.00 ab	0.92±0.01 ab
8	4 SA	9.46±0.17 bc	3.78±0.04 ab	3.58±0.01 c	0.96±0.01 a
8	0.25 ABA	9.61±0.19 b	3.50±0.06 c	3.67±0.03 ab	0.91±0.03 bc
8	0.50 ABA	10.56±0.19 a	3.60±0.06 bc	3.69±0.00 ab	0.87±0.01 cd
8	0.25 MeJA	9.96±0.30 ab	3.90±0.10 a	3.65±0.03 b	0.90±0.00 bc
8	0.50 MeJA	10.03±0.49 ab	3.70±0.06 b	3.72±0.01 a	0.88±0.01 cd
8	Control	8.68±0.09 c	3.28±0.04 d	3.71±0.02 a	0.84±0.01 d
12	2 SA	9.80±0.06 cd	3.50±0.16 bc	3.57±0.01 a	0.89±0.02 a
12	4 SA	9.70±0.10 cd	3.70±0.06 a	3.50±0.01 a	0.89±0.01 a
12	0.25 ABA	10.11±0.07 bc	3.34±0.03 d	3.60±0.07 a	0.86±0.01 ab
12	0.50 ABA	11.23±0.35 a	3.43±0.03 cd	3.56±0.03 a	0.87±0.00 ab
12	0.25 MeJA	10.76±0.46 ab	3.60±0.06 ab	3.59±0.07 a	0.89±0.03 a
12	0.50 MeJA	10.18±0.09 bc	3.48±0.04 bcd	3.64±0.05 a	0.88±0.01 ab
12	Control	9.16±0.44 d	3.13±0.03 e	3.50±0.01 a	0.84±0.00 b

Table 2: Effect of salicylic acid (2 and 4 mM), abscisic acid (0.25 and 0.50 mM), and methyl jasmonate (0.25 and 0.50 mM) on mold and yeast (log CFU/g) of strawberry fruits stored for 12 d at 4 °C. Data are mean of 3 replicates ± stander errors. Different letters indicate significant differences (Duncan test, P<0.05%).

Treatments	Storage period (Days)			
	0	4	8	12
2 SA	2.60± 0.05 b	2.6 ± 0.05 c	3.70 ± 0.06 b	3.93 ± 0.03 b
4 SA	ND*	ND	2.53 ± 0.03 d	3.86 ± 0.03 b
0.25 ABA	2.53 ± 0.03 b	2.7 ± 0.03 b	3.53 ± 0.03 c	3.86 ± 0.03 b
0.50 ABA	ND	2.6 ± 0.05 c	3.53 ± 0.03 c	3.86 ± 0.03 b
0.25 MeJA	ND	ND	2.43 ± 0.03 d	3.63 ± 0.03 c
0.50 MeJA	ND	ND	2.53 ± 0.03 d	3.66 ± 0.03 c
Control	2.9 ± 0.03 a	3.1 ± 0.05 a	4.00 ± 0.06 a	4.23 ± 0.03 a

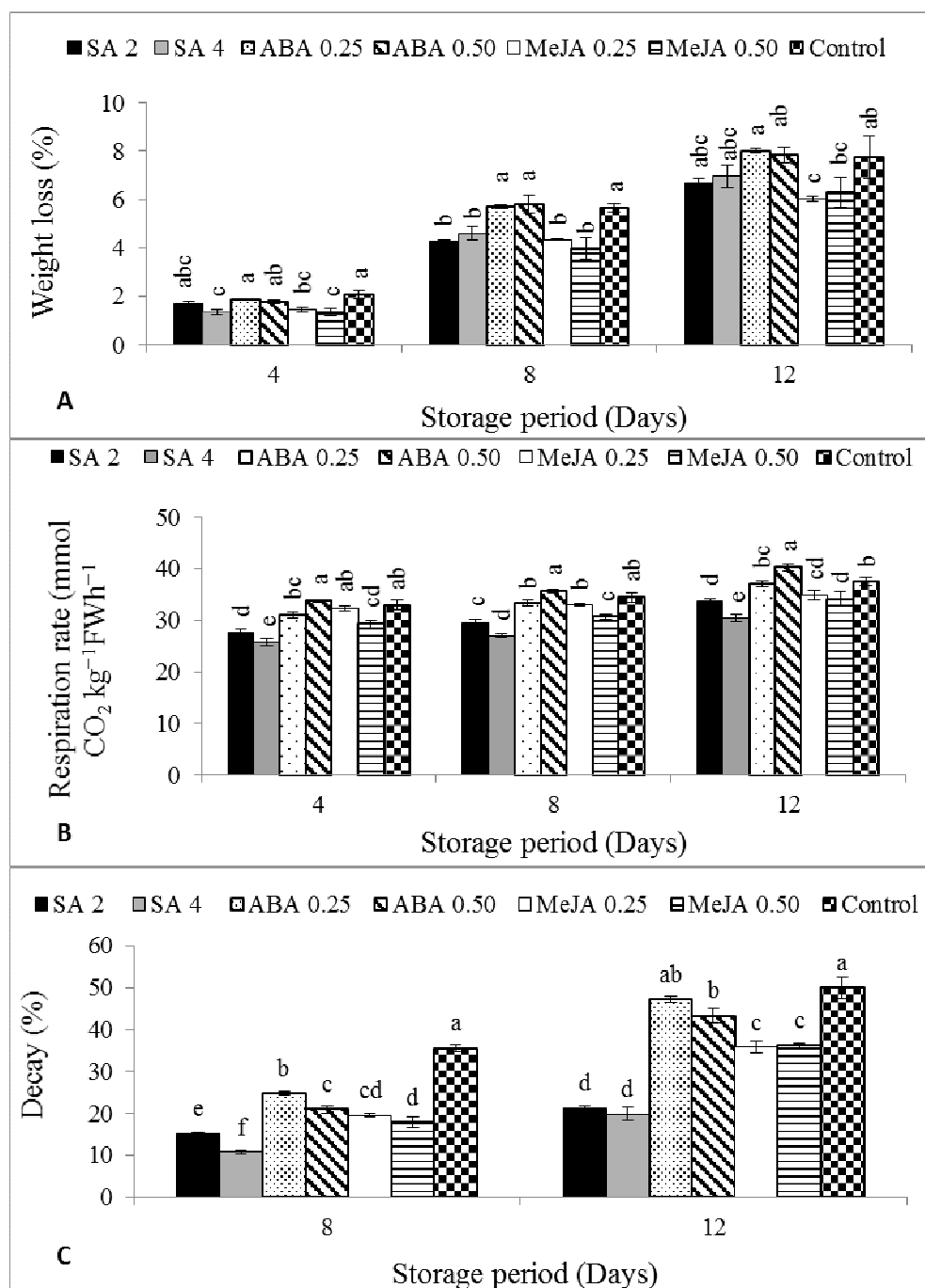***ND : mean (not detected) there is no fungal growth found.**

Figures

Figure 1: Effect of salicylic acid (SA) (2 and 4 mM), abscisic acid (ABA) (0.25 and 0.50 mM), and methyl jasmonate (MeJA) (0.25 and 0.50 mM) on (A) weight loss (%), (B) respiration rate (mmol CO_2 $kg^{-1}FWh^{-1}$), and (C) decay % of strawberry fruits stored for 12 d at 4 °C. Respiration rate at start of the storage was 24.75 ± 0.32 mmol CO_2 $kg^{-1}FWh^{-1}$. No decay was observed at 4 d from start of the storage, hus, panel (C) shows just 8 and 12 d. Data are mean of three replicates. Different letters for every storage point indicate significant differences (Duncan test, $p < 0.05$).
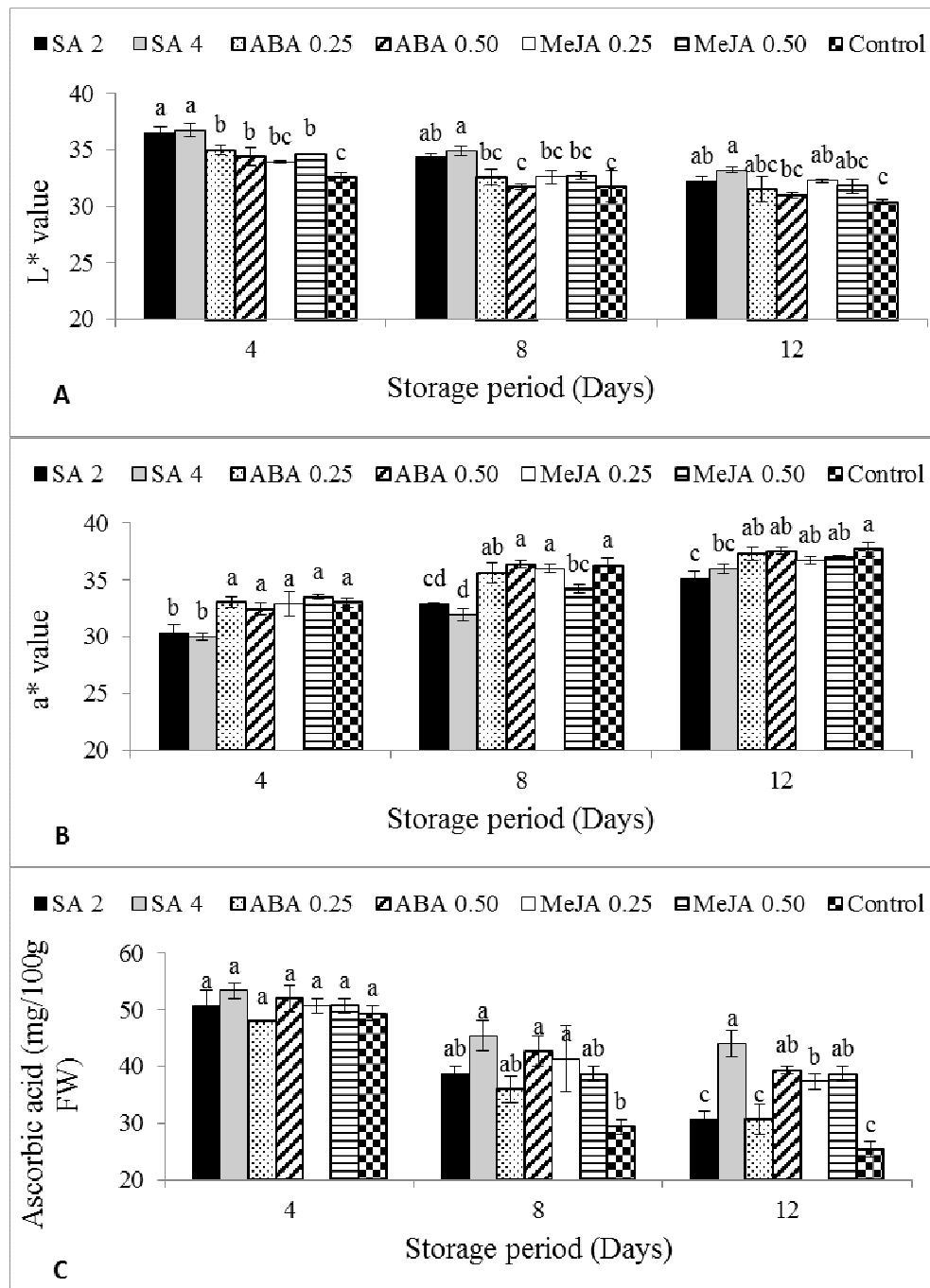
Figure 2: Effect of salsylic acid (2 and 4 mM), abscisic acid (0.25 and 0.50 mM), and methyl jasmonate (0.25 and 0.50 mM) on (A) *L** value, (B) *a** vlaue, and (C) ascorbic acid (mg/100g FW) of strawberry fruits stored for 12 d at 4 °C. *L** value, *a** value, and ascorbic acid value at start of the storage were 34.52±0.23, 33.60± 0.20, and 54.66±1.33 (mg/100g FW), respectively. Data are mean of 3 replicates. Different letters for every storage point indicate significant differences (Duncan test, P<0.05%).
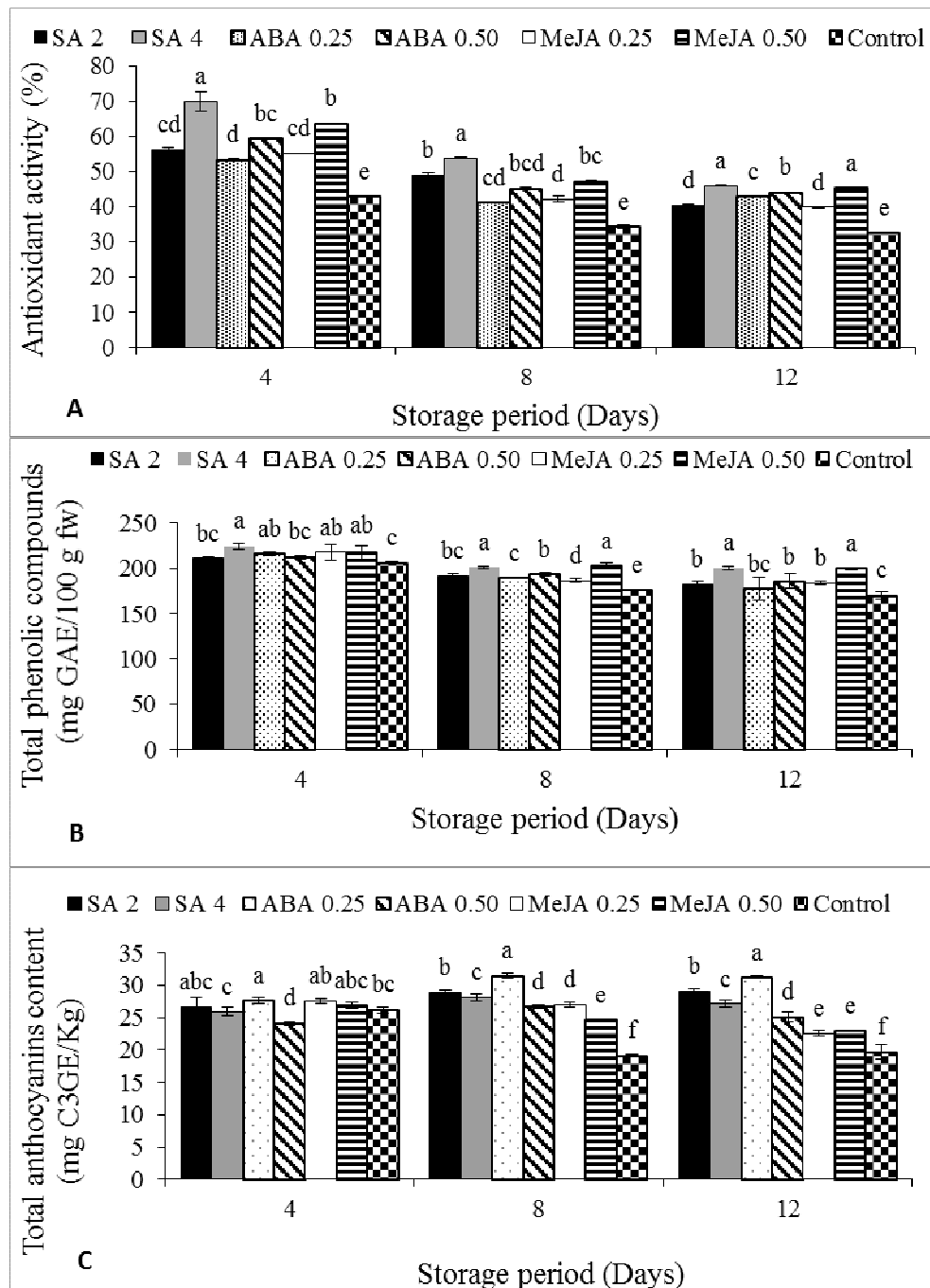
Figure 3: Effect of salicylic acid (2 and 4 mM), abscisic acid (0.25 and 0.50 mM), and methyl jasmonate (0.25 and 0.50 mM) on (A) antioxidant activity %, (B) total phenolic compunds (mg GAE/100 g fw), and (C) total anthocyanin content (mg C3GE/Kg) of strawberry fruits stored for 12 d at 4 °C. Antioxidant activity, total phenolic compunds, and total anthocyanin content at start of the storage were 78.32±2.27 %, 210.33±2.72 (mg GAE/100 g fw), and 26.22±0.91 (mg C3GE/Kg), respectively. Data are means of three replicates. Different letters indicate significant differences within each time point (Duncan test, P<0.05%).