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Effect of Organic and Conventional Systems on Fruit Storage of Strawberry (*Fragaria* × *Ananassa* Duch) Grown under Greenhouse Conditions

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Abstract: A plastichouse experiment was carried out during the 2004/2005 season at Abu-Ghannam's farm in Kreimeh in the northern Jordan Valley, to compare the effect of four fermented organic matter doses (1.5, 3.0, 4.5 and 6.0 kg m^{-2}) with that of the conventional fertilizer and control treatments on strawberry cultivar Honor growth. Strawberries were used to study some postharvest parameters related to length of storage and fruit quality using two storage methods; normal cold storage (air storage) and Modified Atmosphere storage (MA). For this purpose, fruits were harvested in February, March and April and stored at 0°C and about 90-95% RH. A Randomized Complete Block Design (RCBD), with two factor factorial (6 treatments and 2 storage conditions) and three replicates (harvest dates), was used. At the end of the storage experiment the highest anthocyanin content was obtained under air storage conditions. Among the different treatments 4.5 kg OM m^{-2} treatment gave the highest anthocyanin content, while 1.5 kg OM m^{-2} treatment gave the lowest content. The interaction between the control and MA storage resulted in the lowest weight loss, while the highest weight loss was obtained by the interaction between conventional and air storage. MA storage prolonged berries storage life; the longest storage period was recorded for the 6 kg OM m^{-2} treatment and the lowest was recorded for the control treatment. Number of rotted fruits was highest in the MA compared to air storage. No effect of the treatments or interaction between the treatments was observed in respect to fruit rot incidence.

Key words: Strawberry, *Fragaria* × *ananassa*, fruit quality, air storage, MA storage postharvest, organic, conventional

INTRODUCTION

Shelf life is the maximum periods after harvest with nearly 100% of the stored fruits are still marketable and it is cultivar dependent (Pelayo *et al*., 2003). Fruit shelf life during storage is an important feature from a producer's and a distributor's point of view, allowing the determination of risks arising from the loss of commercial value of fresh fruit in trade turnover (Radajewska and Borowiak, 2002). Strawberry is one of the most delicate and highly perishable fruits, being susceptible to mechanical injury, physiological deterioration, water loss, decay and has very short storage ability and postharvest shelf-life. Fruit quality characteristics are primarily influenced by preharvest crop

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management; the quality of the harvested produce can be at best maintained, but not improved after harvest (Perez *et al*., 1997; Manleitner *et al*., 2002; Ames *et al*., 2003). The berries are very fragile and susceptible to mechanical injury, their skin results in rapid loss of water in low humidity environments and strawberries have one of the highest respiration rates of all fresh commodities (Mitcham, 1996). Organically grown strawberries were firmer and more resistant to deterioration than the conventionally grown fruits, so postharvest losses of conventionally grown fruits were significantly higher than those of organically grown fruits (Cayuela *et al*., 1997).

Minimum maturity indices of strawberry included 2/3-3/4 fruit surface showing pink or red color, at this stage the berries are firmer than fully ripe fruits (Mitcham, 1996; Kader, 1999; Haffner, 2002). Strawberry can be stored at 0°C and 90 to 95% relative humidity (Mitcham, 1996; Krivorot and Dris, 2002) for up to 5-7 days if precooled after harvest (Rivera and Tong, 2004). Even under low temperature and high humidity conditions, storage life is usually only about 7 days (Perez *et al*., 1997), or 7-10 days according to the cultivar used, but storage period could be extended to 13-15 days if fruits are packaged in polyethylene (PE) bags (Krivorot and Dris, 2002).

Packaging material affects the quality and shelf life; packing in polyethylene bags decreased respiration, maintained quality, prolonged the shelf life (Krivorot and Dris, 2002). In addition packaging protects against mechanical damage and prevents moisture loss (Perez *et al*., 1997). However, non-perforated films significantly increased shelf life, improved fruit firmness and reduced weight loss and rot. Respiration rate and ethylene production increased under air storage conditions at 5°C as found by Pelayo *et al*. (2003). Morris *et al*. (1985) reported that as postharvest holding time and temperature increased the quality of strawberries decreased.

Anthocyanin synthesis continued in harvested fruit, particularly those stored in air, even at low storage temperature; after 2 weeks of storage, anthocyanin was increased by 18% (Holcroft and Kader, 1999). Fruit harvested at 50% red became fully red during storage and the anthocyanin concentration increased by 140, 50 and 30% in fruit harvested at 50% red, red and red + 24 h, respectively. But in another experiment conducted Manleitner *et al*. (2002) an opposite trend was found; they did not see any significant difference between different storage methods when referring to anthocyanin content, which was 40.7 mg/100 g before storage, 39 mg/100 g after storage in open containers and 39.4 mg/100 g after storage in covered containers with non-perforated films.

Rivera and Tong (2004) found that strawberry fruits may lose some color, shrivel and lose flavor, after few days of storage and berry shelf life can be extended by packing berries in containers coated with heat-shrink polyethylene film. Average weight loss in open trays was higher than packaged strawberries; Manleitner *et al*. (2002) found that average weight loss in open trays was 7.1% (1.78%/day), while in trays covered with perforated film weight loss was 1.33% (0.33%/day).

The major postharvest disease of strawberries is gray mold or ash mold rot, caused by the fungus *Botrytis cinerea* (Rivera and Tong, 2004), which is one of the most common and serious fruit rot diseases, found on both green and ripe strawberries (Ames *et al*., 2003; Kadir, 2003). It causes major losses which are associated with bruising and soft or leaky berries (Mitcham, 1996; Kivijarvi *et al*., 2002). Infections first occur on fruit tissue under the calyx, fruit infections appear as soft and light brown areas that increase rapidly under cool temperatures, wet conditions and high relative humidity (Sikora, 1996).

In Jordan, no research has been done regarding postharvest behaviour of organically produced strawberry fruits, in spite of good sources of organic matter especially animal manure and plant residues, which are available at very low costs.

This experiment aimed to compare between the effect of MA and air storage conditions on strawberry fruit quality grown using organic and conventional production systems.

MATERIALS AND METHODS

This study was conducted during the 2004/2005 season, in a plastichouse (9×56.5 m) in the northern Jordan Valley. The organic matter for this experiment was prepared, according to Preusch *et al*. (2004) recommendations. Soil solarization was applied to the soil of the experimental site from the 1st of August to the 15th of October, according to procedures outlined by Abu-Blan and Abu-Gharbieh (1994).

Field Treatments

The width of the plastichouse was divided into nine equal sections (1 m each), while the length was divided into four equal sections (each 14 m long), so each experimental unit (bed) represented 1×14 m (width by length) while the remaining 0.5 m from the length was left at the entrance of the plastichouse. The conventional planting was done according to the system applied in the farm where the experiment was conducted, which included the use of pesticides and inorganic fertilizers. However, in organic culture treatments, all types of chemicals (pesticides and inorganic fertilizers) were excluded and the rates of 1.5, 3, 4.5 and 6 kg fermented compost/m^2 were spread and incorporated into the beds. In addition to the conventional treatment and the four organic treatments a control treatment (no organic and no inorganic fertilizers and pesticides) was included in the study.

A Randomized Complete Block Design (RCBD), with four replicates per treatment was used. All data obtained were statistically analyzed by variance, according to the procedure outlined by Steel and Torrie (1980). The differences between means of the different treatments were compared by the Least Significant Difference (LSD) test using SAS and differences with probability value at $p = 0.05$ were considered significant.

Storage Treatments

In this experiment; strawberry fruits were stored at 0°C and about 90-95% RH, under two storage conditions; Modified Atmosphere Packaging (MAP) or normal cold storage conditions. It included 12 treatments as indicated in Table 1. Berries produced in the first experiment, were used in the storage experiment. At the assigned date fruits were harvested and placed in a shady cool place until being directly transferred to the cold room at the University of Jordan campus. Fruits were cleaned from soil by hand and mixed. Only non diseased fruits with suitable degree of ripeness and lack of any apparent damage and with clear red color were used for this experiment which was repeated at three harvesting dates (February, March and April, 2005). Each storage time; triplicate jars were used for each replicate and then average readings were considered.

After that 420-470 g strawberry fruits were placed in a plastic jar (500 g capacity) and stored uncovered (air storage) or covered with shrink wrap (MAP). The shrink wrap (manufactured in Al-Nur

Table 1: Storage experiment treatments

Treatments	Replications
*MA packaging conventional fruits	3
Air storage conventional fruits	3
MA packaging (control)	3
Air storage (control)	3
MA packaging 1.5 kg OM m^{-2}	3
Air storage 1.5 kg OM m^{-2}	3
MA packaging 3.0 kg OM m^{-2}	3
Air storage 3.0 kg OM m^{-2}	3
MA packaging 4.5 kg OM m^{-2}	3
Air storage 4.5 kg OM m^{-2}	3
MA packaging 6.0 kg OM m^{-2}	3
Air storage 6.0 kg OM m^{-2}	3

*MA: Modified Atmosphere

Jordanian company for plastic industry, Amman-Jordan) is made from LLD-polyethylene resin, approved as pollution-free by FDA of US, it does not generate any harmful monomer or poisonous gas even at high temperature and it's heat resistance temperature is 120°C, while it's cold resistance temperature is -60°C.

During storage air temperature and relative humidity were recorded by Hygrothermograph (TR di Turoni and C. Snc Hygrothermograph, Italy), humidity in the cold room was controlled by Humidifier (Ultrasonic Humidifier Cole-Parmer Inst. Co., Order No. U-37700-85, USA).

Parameters Measured

Each fruit jar was removed from the cold room, when fruits in it started showing any wilting or any rot incidence, at each storage average readings were recorded for the three jars per treatment.

Fruit Keeping Quality

Anthocyanin

Before and at the end of each storage date; 3 to 4 fruits per plastic jar and replicate were used for anthocyanin determination. Strawberry fruit color was expressed as mg anthocyanin per 100 g fruit fresh weight, anthocyanin content was estimated by pH-Differential Spectrophotometer method, absorbance was taken by Spectrophotometer (Varian, Cary 100 Conc, CaryWin soft ware, Australia). For anthocyanin estimation; fruits were grinded and homogenized through pestle and mortar. Then a 10 g sample was placed in a plastic bottle, 100 mL of 1: 99 V/V (HCl: methanol) added to it and shacked for half an hour, then filtrated through filter paper, two samples 5 mL each were placed in two volumetric flasks (25 mL) and the volume for each flask, was completed with a different pH buffer (pH 1 for sample 1 and pH 4.5 for sample 2). The absorbance was measured for each of the samples at the wavelengths 510 and 700 nm. After that, the following equation was applied:

$$\text{Absorbance} = (A_{510\,nm}\ \text{pH}\ 1 - A_{700\,nm}\ \text{pH}\ 1) - (A_{510\,nm}\ \text{pH}\ 4.5 - A_{700\,nm}\ \text{pH}\ 4.5)$$

Then total anthocyanins (% W/W) in the samples were calculated according to the following equation: $\% W/W = A/^{a}L \times MW \times DF \times V/Wt \times 100$.

Where:

- A = Absorbance.
- ϵ = Pelargonidin 3-Glucoside (PGD 3-GLU) coefficient = 22400.
- L = Cell path length (usually 1 cm)
- MW = Anthocyanin molecular weight = 433.2
- DF = Dilution factor.
- V = Final volume (mL).
- Wt = Sample weight (mg).

Then the obtained values (g/100 g) were converted into mg anthocyanin/100 g fruit fresh weight by multiplying with 1000. Finally the results were expressed as milligrams of pelagonidin-3-glucoside per 100 g fruit fresh weight. According to the procedures used by Cheng and Breen (1991); Garzon and Wrolstand (2002); NSF International (2004).

Rot Incidence

Directly after the end of storage; the number of spoiled fruits in each plastic jar was recorded.

Storage Period

Maximum storage period was estimated by counting the number of days from the first day of storage until the end of the storage period, while the fruits are still marketable.

Average Daily Weight Loss

It was estimated for each plastic jar, by dividing average weight loss during the storage period, through the number of days in storage.

Experimental Design and Statistical Analysis

A Randomized Completely Block Design (RCRD), with two factor factorial (6 field treatments and 2 storage conditions) and three replications (three storage dates) was used. All data obtained were statistically analyzed by variance according to the procedure outlined by Steel and Torrie (1980), the differences between means of the different treatments were compared by Least Significant Difference (LSD) test using SAS. Then interactions between treatments were separated by software MSstat. Statistical differences with probability values at p = 0.05 were considered significant.

RESULTS AND DISCUSSION

Anthocyanin Content

There were significant differences in anthocyanin content of strawberries between MA and air storage. Maximum anthocyanin content (52.31 mg/100 g f. wt) was found in the air storage treatment, while the lowest anthocyanin content (42.86 mg/100g f. wt) was obtained by the MA storage treatment (Table 2). This means that air storage enhanced anthocyanin synthesis during storage compared to MA storage, also anthocyanin content could be due to the relatively high moisture loss from the air stored fruits compared to the MA stored fruits which were protected against moisture loss (Perez *et al*., 1997), thus resulting in concentrated anthocyanin content (which was measured on fruit fresh weight basis) of the air stored fruits (Table 2). In addition, oxygen (O_2) availability in air storage could enhance anthocyanin production, while shortage of O_2 under MA conditions is supposed to limit anthocyanin production.

Results of fruit anthocyanin content tested immediately at the beginning of the storage experiment (Table 3), showed that the 6 kg OM m^{-2} treatment gave the highest content (40.69 mg/100 g f. wt.), while the control treatment gave the lowest content (35.1 mg/100 g f. wt.). Comparing these results with results obtained at the end of storage; indicate an increase in anthocyanin content after storage in MA and in air storage. The percent of anthocyanin increase ranged from 15.97-24.12%. These results are in agreement with those obtained by Forney *et al*. (1998) and Pelayo *et al*. (2003) who found an increase in anthocyanin concentration during strawberry storage, due to continuous synthesis of this pigment especially in air storage. On the other hand results of the treatments with the storage type interactions did not show any significant effect on the fruit anthocyanin content, nevertheless the highest anthocyanin content (57.5 mg/100 g f. wt.) obtained by the 4.5 kg OM m^{-2} treatment under air storage conditions and the lowest (41.19 mg/100 g f. wt.) obtained by the 1.5 kg OM m^{-2} treatment under MA storage conditions (Table 5). These results indicate that anthocyanin synthesis during storage significantly affected by the field treatments and storage type treatments.

Weight Loss

The highest average daily weight loss (1.69%) was obtained in the air storage, while the lowest weight loss (0.10%) was obtained in the modified atmosphere storage (Table 2). Similar results

Table 2: Effects of storage method (MA or air), on anthocyanin content, weight loss, length of storage and number of rotted fruits of plastichouse grown strawberries irrespective of the treatments

Storage type	Anthocyanin content (mg/100 g f.wt.)	Weight loss (%)	Length of storage (Days)	No. of rotted fruits
*MA packaging	42.86b**	0.10b	16.46a	3.850a
Air storage	52.31a	1.69a	8.61b	0.037b

*MA: Modified Atmosphere; ** Means within each column having different letter(s) are significantly different according to LSD at 5% level

Table 3: Effect of organic matter on fruit anthocyanin content at the beginning and at the end of storage and percent of anthocyanin change of plastichouse grown strawberries

Treatments	At the beginning of storage (mg anthocyanin/100 g f. wt.)	At the end of storage (mg anthocyanin/100 g f. wt)	Anthocyanin change (%)
Conventional	38.10	46.65bc**	+ 18.32
Control	35.10	45.45c	+ 22.78
1.5 kg OM* m^{-2}	37.81	45.00c	+ 15.97
3.0 kg OM m^{-2}	39.42	48.48ab	+ 18.68
4.5 kg OM m^{-2}	38.76	51.08a	+ 24.12
6.0 kg OM m^{-2}	40.69	48.83ab	+ 16.67

* OM: Organic Matter; ** Means within each column having different letter(s) are significantly different according to LSD at 5% level; + Means the percent of increase in anthocyanin content

Table 4: Effect of organic matter on fruit weight loss, length of storage and number of rotted fruits of plastichouse grown strawberries

Treatments	Weight loss (%)	Length of storage (days)	No. of rotted fruits
Conventional	1.08a	12.22ab	1.94a
Control	0.96ab	11.78b	2.39a
1.5 kg OM* m^{-2}	0.82c	12.44ab	1.89a
3.0 kg OM m^{-2}	0.80c	13.06a	1.50a
4.5 kg OM m^{-2}	0.89bc	12.78a	1.78a
6.0 kg OM m^{-2}	0.84bc	12.94a	2.17a

* OM: Organic Matter; ** Means within each column having different letter(s) are significantly different according to LSD at 5% level

Table 5: Interaction of field treatments (organic matter or chemical fertilizer) with storage type (MA or air) on fruit anthocyanin content, weight loss, length of storage and number of rotted fruits of plastichouse grown strawberries

Field treatments	Storage type	Anthocyanin content (mg/100 g f.wt.)	Weight loss (%)	Length of storage (days)	No. of rotted fruits
Conventional	MA*	42.29e**	0.12b	16.22ab	3.78ab
	Air storage	51.01b	2.05a	8.22de	0.11c
Control	MA	41.90e	0.09b	15.67b	4.78a
	Air storage	49.01bc	1.84a	7.89e	0.00c
1.5 kg OM* m^{-2}	MA	41.19e	0.12b	16.22ab	3.78ab
	Air storage	48.81bcd	1.52a	8.67cde	0.00c
3.0 kg OM m^{-2}	MA	43.85cde	0.10b	16.78a	3.00b
	Air storage	53.11ab	1.52a	9.33c	0.00c
4.5 kg OM m^{-2}	MA	44.65cde	0.11b	16.89a	3.44ab
	Air storage	57.50a	1.66a	8.67cde	0.11c
6.0 kg OM m^{-2}	MA	43.26de	0.10b	17.00a	4.33ab
	Air storage	54.40ab	1.59a	8.89cd	0.000c

+ OM: Organic Matter; * MA: Modified Atmosphere; ** Means within each column having different letter(s) are significantly different according to LSD at 5% level

were obtained by Krivorot and Dris (2002) who found that weight loss of non-packaged berries was 2.0-4.0% per day, which was higher than that of packaged fruits and packaging in polyethylene bags resulted in only 0.05-0.63% weight loss per day, due to increased transpiration. In addition packaging protected strawberries against mechanical damage and prevented moisture loss (Perez *et al*., 1997) and reduced weight losses (Manleitner *et al*., 2002).

On the other hand, the highest average daily weight loss (1.08%) was obtained by the conventional treatment without a significant difference from the control treatment, while the lowest weight loss (0.8%) was obtained by the 3 kg OM m^{-2} treatment (Table 4). All organic matter treatments had a significantly lower average daily weight loss compared to the conventional treatment. The control treatment had an intermediate weight loss when compared to the conventionally and organically produced fruits (Table 4). According to Cayuela *et al*. (1997) organically produced strawberries were firmer and more resistant to deterioration than conventionally grown fruits. Therefore, losses of conventionally grown fruits were significantly higher than those of organically grown fruits.

Table 5, showed that the highest average daily weight loss (2.05%) was obtained by the conventional treatment under air storage conditions, without being significantly different from fruits under air storage conditions of all other treatments. The lowest weight loss (0.09%) was obtained by fruits from the control treatment which were kept under MA conditions, without being significantly different from other fruits stored under MA conditions, irrespective of their origin. The high weight losses in the conventional treatment stored under air storage type could be due to two main reasons: 1. Fruit stored under air storage conditions had always higher weight losses compared to MA stored fruits. 2. The large fruit size of the conventionally produced fruits compared to the organically produced fruits or the control, caused higher moisture losses and more fruit respiration. On the other hand the low weight losses of the MA stored control fruits could be due to low moisture losses and low respiration rate under MA conditions, in addition to the small fruit surface area compared to fruit of other production systems.

Storage Duration

In the case of number of days in storage, there were significant differences between the two types of storage (MA and air storage); the longest storage period (16.46 days) was obtained by MA storage, while the shortest storage period (8.61 days) was obtained by air storage (Table 2). As a result, it appears that MA increased the storage period of strawberries from 8 to about 17 days. These results are in line with findings of Krivorot and Dris (2002), who found that storage life, is usually about 7-10 days according to the cultivar used, but it could be extended to 13-15 days if fruits are packaged in polyethylene (PE) bags. Furthermore the present results are within the range obtained by different researchers; for example, Perez *et al*. (1997) reported the storage life of strawberry fruits to be about 7 days, while Krivorot and Dris (2002) found it to be between 7-10 days in air storage and 13-15 days for packaged fruits. MA storage reduced weight loss (Manleitner *et al*., 2002) decreased respiration and maintained quality of strawberries (Krivorot and Dris, 2002). On the other hand, the increase in respiration under air storage conditions resulted in reduced storage capability of strawberries (Pelayo *et al*., 2003). On the other hand the control treatment lasted in storage for a significantly shorter period when compared to all other treatments except the 1.5 kg OM m^{-2} and the conventional treatments (Table 4). There were no significant differences in the interaction of the treatments and storage type in respect to the number of days in storage (Table 5). The longest storage (17 days) was obtained by the 6 kg OM m^{-2} treatment under MA storage type. While the shortest storage period ($\approx$ 8 days) was obtained by the control treatment under air storage condition, which could be due to the air storage conditions that did not maintain fruit quality. In addition these results indicate that length of storage was only significantly affected by the both treatment and storage type, while the interaction between both didn't affect the length of strawberry fruit storage.

Number of rotted fruits

In the case of number of rotted fruits the significantly highest number of fruits affected by rot (3.85 fruits/container) was found in the MA storage, while the lowest number of rotted fruits (0.04 fruits/container) was found under air storage conditions (Table 2). These results disagree with those obtained by Krivorot and Dris (2002) who found that fruit decay was significantly reduced by non-perforated films. The relatively high number of rotted fruits under MA conditions could be due to the extended storage life by MA and to the high relative humidity inside the containers, such conditions are known to stimulate fungi growth. On the other hand the highest number of rotted fruits (2.39 fruits/container) was observed in the control treatment and the lowest (1.5 fruits/container) in the 3 kg OM m^{-2} (Table 4). No significant differences in the number of rotted fruits, were observed as a result of the interaction between storage type and treatment (Table 5), but the highest number of rotted fruits (4.78 fruits/container) was obtained by the control treatment under MA conditions and the lowest (0.0 fruits/container) was obtained by control, 1.5, 3 and 6 kg OM m^{-2} treatments under air storage conditions. So it seems that only the storage condition type had a significant effect on the number of rotted fruits, while other treatments (treatments or the interaction between the treatments and storage type) had no significant effect on the number of the rotted fruits.

CONCLUSIONS

Anthocyanin synthesis was increased during storage; air storage gave the highest content, while modified atmosphere storage gave the lowest anthocyanin content. On the other hand the 4.5 kg OM m^{-2} treatment gave the highest fruit anthocyanin content during storage, while 1.5 kg OM m^{-2} treatment gave the lowest content. Organic matter treatments had significantly lower weight loss compared to the conventional treatment and modified atmosphere storage reduced weight loss compared to air storage. The interaction between the control and modified atmosphere storage produced the lowest weight loss, while the highest weight loss was obtained by the interaction between the conventional production and air storage. Modified atmosphere storage prolonged berries storage life, compared to air storage and the 6 kg OM m^{-2} treatment resulted in the longest storage period. Number of rotted fruits was highest in modified atmosphere storage compared to air storage. Further work should systematically investigate modified atmosphere packaging materials, with defined gas permeability to CO_2, O_2 and water vapor to guarantee optimal microclimate conditions within the fruit tray during strawberry storage and handling.

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