Chapter 7

The Effect of Production Systems on Strawberry Quality

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Additional information is available at the end of the chapter

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Abstract

Strawberry with high polyphenols is receiving much more attentions recently. Production systems were reported positive effect on improving crop quality. A complete randomized design with two replicates was employed, and the strawberry selection 'SJ8976-1' was planted under three production systems: matted row system (MRS), plastic mulch (PM) and plastic mulch with row covers (PMRC). Total yield, average fruit weight, soluble solids content (SSC), titratable acidity (TA), firmness, fruit postharvest quality, total phenolic content (TPC), total antioxidant content (TAC), oxygen radical absorbance capacity (ORAC) and phenolic composition analysed by high-performance liquid chromatography (HPLC) were evaluated at different harvest times. The results showed that PMRC advanced fruit maturity and improved average fruit weight compared to MRS. SSC, TA and firmness of the strawberry fruits from PMRC were significantly increased at all harvests. Fruit weight loss, juice leakage and presences of grey mould were lower, and fruit glossiness was higher for those harvested under PMRC than those from MRS. TPC, TAC and ORAC of strawberry were significantly changed under different production systems. The phenolic compounds assessed in strawberry were grouped into six major categories, which were anthocyanins, kaempferol, flavonols, hydroxycinnamic acids, ellagic acid and benzoic acids.

Keywords: strawberry, fruit quality, production system, plastic mulch, phenolic content

1. Introduction

Phenolic compounds including signalling molecules, pigments and flavours represent a variety of functions in plant growth, development and defence [1]. Phenolic compounds and flavonoid compounds were synthesized through a vast range of secondary metabolites in plants. These phytochemicals are structurally diverse and act as bioactive compounds or plant antioxidants in medicine, food industry and human nutrition [2]. Fruits, such as strawberry, contain abundant

rich natural sources of phenolic compounds with high antioxidant capacities, which protect our bodies against free radicals and reactive oxygen species [3, 4]. The large amounts of phenolic compounds offered in strawberries have also been proved to make certain contributions in enhancing the quality of fresh fruits and extending shelf life by delaying senescence induced by oxidative degradation [5]. Therefore, due to the nutritional value and human health benefits in strawberry, the daily demand for strawberries was increasing as time went on. Research on the protective effects of plant-derived polyphenols has developed notably in recent years. In particular, their antioxidant properties have been the objective of extensive research [6–9].

Many factors including genotype, planting date, mulch type, temperature, fertilizer and production systems have been reported to affect strawberry yield and quality [10–12]. Among these factors, production systems play an important role in strawberry growth by enhancing berry size and marketable yield. Matted row system (MRS) is widely used in strawberry planting in north area in terms of lower cost and easy operation [13], but with the development of new technology, many disadvantages of MRS were reported such as poor picking efficiency, waste of fertilizer and high risk of fruits decay. Alternatively, plastic mulch (PM) and plastic mulch with row covers (PMRC) became the most recommended production systems in strawberry planting in recent years [14–16]. Fruit quality and phenolic content were improved under plastic mulch system and resulted in variety of benefits to the crop, including improved fruit cleanliness, prevention of bed erosion, extended harvest season, early ripening, increased yield, better weed control, ease of harvest and more efficient irrigation and fertilizer application [12, 17]. Furthermore, early fruit harvest under plastic culture especially with row covers provides higher income to growers in cool northern climate because of off-season fruit production. Research on bell pepper grown along the Mediterranean coast in raised soil beds (ridge) covered with plastic mulch showed that the use of impermeable plastic mulch in bell pepper cultivation affects water fluxes and may change crop water use and distribution compared to open-field conditions [18]. It also has been reported that the combination of hill plasticulture system and genotype leads a better result of higher flavonoid content and antioxidant capacity than the traditional cultivation system [19]. Plastic mulch affects the microclimate around the crop by modifying the radiation budget (absorptivity vs. reflectivity) of the mulch surface as well. Colour also affects the surface temperature of the mulch cover and consequently the underlying soil temperature [20].

Strawberries are of great nutrition amongst other fruits and have been found to contain 2- to 11-fold more antioxidant capacity than apples, peaches, pears, grapes, tomatoes, oranges or kiwifruit [21]. Therefore, to meet the everyday demands of strawberry with increasing antioxidant levels through breeding and/or cultivation systems is of great value in Canada. For the above reasons, a series of strawberry programs were set, and some cultivars were released by Agriculture and Agri-Food Canada (AAFC). 'SJ8976-1' is a new hardy strawberry selection with extra long storage life (*Fragaria* × *ananassa* Duch.) of the AAFC programme. The objective of the present study was to evaluate the effects of PM and PMRC, versus the conventional MRS, on total yield, yield per plant, average fruit weight, soluble solids content (SSC), titratable acidity (TA), firmness, fruit postharvest quality, total phenolic content (TPC), total antioxidant content (TAC), oxygen radical absorbance capacity (ORAC) and phenolic composition analysed by high-performance liquid chromatography (HPLC) in strawberry selection 'SJ8976-1', at different harvest times during the growing season.

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2. Materials and methods

2.1. Strawberry material

'SJ8976-1' is a new hardy strawberry selection with large fruit size, excellent flavour and long storage life (*Fragaria* × *ananassa* Duch.). The pale fruit colour of 'SJ8976-1' in combination with firmness, resistance to fruit rot and long shelf life makes it a good candidate for fresh market and transportation. The fruit colour of 'SJ8976-1' darkens during storage [22].

2.2. Experimental design

A complete randomized design with two replicates was used, and the strawberry selection 'SJ8976-1' was grown under three production systems: (1) matted row system (MRS), (2) plastic mulch (PM) and (3) plastic mulch with row covers (PMRC). Twenty-six plants of 'SJ8976-1' were planted in a double row 30 cm × 30 cm apart in 4 m long plots, supplied with drip irrigation down the centre of each row in 2008 at Agriculture and Agri-Food Canada, L'Acadie Experimental Farm (longitude: 73'35°W; latitude: 45'32°N), in L'Acadie, Quebec, Canada. For the PM and PMRC systems, runners were removed as the runners could not root and grow into a plantlet. But for the MRS, runners were kept and placed to complete the row as recommended by Ministere de l'Agriculture, des Pecheries et de l'Alimentation du Quebec (MAPAQ) [23]. White row cover over the bed was applied under PMRC and taken away until the fruits were formed. The mean temperature from strawberry flowering to harvest was 19.32°C in 2009 and 18.95°C in 2010, respectively. The total precipitation from strawberry flowering to harvest was 241.4 mm in 2009 and 238.7 mm in 2010, respectively.

Optimum matured fruits were harvested from each plot 2–3 times per week from mid-June to mid-July of each year in 2009 and 2010 for a total of 10 harvests per season. The 10 harvests were finally pooled into three groups representing early, mid and late harvest. Total yield and average fruit weight were recorded at every harvest.

Thirty fruits at optimum maturity were harvested from each plot, rapidly put in cooler and then brought to the laboratory, where 15 of them were used to examine the shelf life and fruit quality and the remaining 15 fruits were immediately cut in halves and frozen in liquid nitrogen. Three 40-g subsamples of each treatment were stored at −80°C for chemical composition analysis [24].

2.3. Sample extraction procedures

Ten grams of fresh frozen fruits from different production systems was pestled for 2 min with 50 mL of 50% methanol at 25°C using a Polytron blender (Brinkmann Instruments, Westbury, NY, USA). The mixture was filtered firstly through Whatman no. 1 filter paper and then through a 0.45-μm Acrodisc syringe filters (Gelman Sciences, Ann Arbor, MI, USA). The filtrate was finally kept at −20°C, and the extracts resulting from this step were used in the TPC and TAC analysis [24].

2.4. Chemicals

The chemicals used for TPC, TAC, HPLC and ORAC are shown in **Table 1**.

Procedure	Chemicals	Company
TPC and TAC	Gallic acid, ferric chloride, sodium acetate, hydrochloric acid, sodium carbonate, 2,4,6-Tri(2-pyridyl)-1,3,5-triazine and the Folin-Ciocalteu reagent	Sigma Chemical Co. (St. Louis, MO, USA)
HPLC	gallic acid, p-Coumaric acid, m-Coumaric acid, o-Coumaric acid, kaempferol-3-glucoside, quercetin-3-glucoside, cyanidin-3-glucoside and pelargonidin-3-glucoside	Sigma Chemical Co. (Oakville, ON, Canada)
	Ellagic acid and pelargonidin-3-rutinoside	Apin Chemicals (Abingdon, UK)
ORAC	2,2-Azobis(2-methylpropionamidine) dihydrochloride (AAPH), fluorescein disodium and 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox)	Sigma Chemical Co. (Oakville, ON, Canada)

Table 1. The chemicals used for TPC, TAC, HPLC and ORAC.

2.5. Soluble solids content, titratable acidity and firmness

Five strawberries were selected randomly and blended thoroughly using a Supreme Juicerator (Acme Juicer Manufacturing Co., New Hartford, CT, USA), and the SSC of the juice was measured at room temperature with a refractometer (Abbe Mark II, Reichert-Jung, Depew, NY, USA) as described previously [25]. TA was measured by diluting 1 mL of strawberry juice with 9 mL of distilled water, adjusted to pH 8.1 using 0.1 N of NaOH (Accumet AB15 Basic pH metre; Fisher Scientific) as described previously [25]. Firmness was ranked from 1 (very soft) to 5 (very firm).

2.6. Fruit postharvest quality

Five fruits per replicate randomly selected from each plot were placed on Whatman no. 1 filter paper in open Petri dishes and left at room temperature (23°C) to evaluate postharvest deterioration. Fruit weight loss and juice leakage, fruit glossiness and the postharvest incidence of grey mould (*Botrytis cinerea* Pers.) were monitored daily until the fruits were considered non marketable. Fruit weight loss was calculated according to Wang et al. [26] using the following method:

$$\text{Weight loss} = \text{weight}_{\text{day } x} - \text{weight}_{\text{day } x+1}. \quad (1)$$

where $\text{weight}_{\text{day } x}$ is the total weight of the five tested berries in each Petri dish and $\text{weight}_{\text{day } x+1}$ is the total weight of the same five berries day after.

The fruit juice leakage was ranked from 1 ('no leak or juice loss') to 4 ('significant fruit leak or juice loss'), fruit glossiness was ranked from 1 ('dull') to 3 ('shiny'), and presences of grey mould were ranked from 1 ('no disease') to 5 ('the presence of mould') [24].

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2.7. Total phenolic content

The TPC was measured in accordance with the slightly modified Folin-Ciocalteu (FC) method [27]. In a 10-mL vial, a standard or sample extract (0.02 mL) and 0.1 mL of FC reagent were mixed with 1.58 mL of water for 3 min. After that, 0.3 mL of Na_2CO_3 (7.5%) was added, and the solution was allowed to stand for 30 min at 40°C. Absorption was measured at 765 nm with an Ultrospec 3100 pro UV/visible spectrophotometer (Fisher Scientific, Ottawa, ON, Canada). The result was expressed as gallic acid equivalent (GAE) in mg/g of fresh frozen weight using gallic acid as standard. The sample concentrations beyond 500 μg mL^{-1} were diluted before final analysis to suit the linear range of the standard curve.

2.8. Total antioxidant content

The TAC was determined by ferric reducing antioxidant power (FRAP) according to the method of Benzie and Strain [28]. Briefly, the FRAP reagent was freshly prepared by mixing 300 mM acetate buffer (pH 3.6), 10 mM TPTZ in 40 mM HCl and 20 mM $FeCl_3 \bullet 6H_2O$ at the ratio of 10:1:1 (v/v/v). Then add 2.4 mL FRAP reagent and 80 μl of diluted sample, and the plate was incubated at 37°C for 4 min. The absorbance readings were taken at 593 nm using Agilent 8453 spectrophotometer (Agilent Technologies, Waldbronn, Germany). The TAC value was calculated on the basis of $Fe_2SO_4 \cdot 7H_2O$ and expressed as micromoles of $Fe_2SO_4 \cdot 7H_2O$ equivalent per gram of fresh frozen weight.

2.9. Oxygen radical absorbance capacity (ORAC) assay

For the ORAC assay, 5 g of fresh frozen fruit from different production systems was completely pestled in 15 mL of 50% acetone using a Polytron blender (Brinkmann Instruments, Westbury, NY, USA). The mixture was centrifuged at 10,000 rpm for 10 min, and the supernatant was kept in a 1.5-mL vial at −20°C.

The ORAC assay measures the capacity of the antioxidant to prevent the oxidization of a free radical (peroxyl) in biological systems. The assay was performed as described previously [29] with a Synergy™ Multi-Mode Microplate Reader (Bio-Tek Instruments, Inc., Winooski, VT, USA).

2.10. HPLC analysis

Three grams of fresh frozen strawberry from different production systems was mixed with 15 mL acetone and homogenized using a Polytron® homogenizer (Brinkmann Instruments, Inc., Westbury, NY, USA) for 1 min. The extracts were then filtrated through no. 1 Whatman filter paper and concentrated under vacuum in a water bath at 35°C with a Heidolph Laborota 4000 rotary evaporator (Elk Grove village, IL, USA). The concentrated sample was dissolved in 15 mL of acidified water (3 g/100g formic acid) and then passed through a C18 Sep-Pak cartridge (Waters Ltd., Mississauga, ON, Canada), which was previously activated with methanol followed by water, and then 3 g/100 g aqueous formic acid. The anthocyanins and other phenolics were then recovered with 3 mL of acidified methanol containing 3 g/100 g formic acid. The methanol extract was passed through a 0.45-μm Acrodisc syringe filter (Sigma Chemical Co., Oakville, ON, Canada), and 10 μL of each sample was injected for the HPLC analysis. All standards except for anthocyanins were dissolved in methanol. Anthocyanins were dissolved in 1 g/100g HCl in methanol [30].

The individual phenolic compounds of berries were analysed by HPLC, using a Varian (Varian Inc., Palo Alto, CA, USA) HPLC system. A photodiode array detector (Model 335) and a quaternary pump (Model 240) were equipped in the HPLC system. Samples were injected at 40°C, and the separation was performed with a reverse phase 4.6-mm Polaris C18-A column coupled with a 4.6-mm MetaGuard Polaris C18-A guard column (Varian Inc., Palo Alto, CA, USA). The mobile phase was acidified water containing 2.5 g/100g formic acid (A) and acidified methanol containing 2.5 g/100 g formic acid (B). The flow rate was 1.0 ml/min, with a gradient profile consisting of B with the following proportions (v/v) of A: 0–15 min, 15–30% B; 15–20 min, 30% B; 20–25 min, 30–80% B; 25–42 min, 80% B; 42–42.5 min, 80–100% B; 42.5–50.25 min, 100% B; and 50.25–51.25 min, 0% B. The detector was simultaneously monitoring the different groups of phenolics at 254, 280, 320, 350 and 510 nm. Equilibration time between samples was 15 min. Data were collected and analysed by Varian Workstation Star version 6.41. Total phenolic compounds were divided into six groups and quantified as described in our previous work [30].

2.11. Statistical methods

Statistical analysis was performed using SAS software [31]. Data were analysed using GLM procedure, and the least significant difference (LSD) test was used for mean separation at 5% level when it was significant. The arcsine transformation was used for rank data before data analysis, and the results were presented as a rank for simplicity when the outcomes of transformed and non-transformed data were the same. The data from 2009 to 2010 were pooled together after analysing each year separately and testing the homogeneity of the experimental error.

3. Results and discussion

3.1. Effect of production systems on yield

Yield is an important characteristic that farmers considered a lot in strawberry production. Compared to the MRS, PMRC accelerated strawberry fruit production by 8 and 10 days in 2009 and 2010, respectively, followed by PM when fruits were harvested 4 and 5 days before MRS in 2009 and 2010, respectively, similar to those observed by Jin et al. [32]. Soria et al. [33] also reported that based on two consecutive cropping seasons data, plastic tunnels improved early marketable yield, total marketable yield and first-class fruits of strawberry. The increased yield and fruit size might be due to the increase in soil temperature for PM and PMRC. The early ripening of the fruits under PM and PMRC systems will probably generate a better income due to off-season production. Total yields of PM and PMRC were significantly lower than that of MRS, but the yield per plant of PMRC was significantly higher than PM and MRS (**Table 2**). Fruits harvested from PMRC and PM were significantly larger than those harvested from MRS (**Table 2**). This might be because of less competition between the plants since all the runners were removed under PM and PMRC but kept under MRS [24].

3.2. Effect of production systems on SSC, TA and firmness

SSC, TA and firmness dramatically affect strawberry fruit quality. The production systems had a significant effect on the SSC, TA and firmness of the strawberry fruits and the SSC increased, while TA and firmness decreased all through the harvest season (**Table 3**). PMRC significantly

increased the SSC, TA and firmness of the strawberry fruits at all harvests compared to PM and MRS (**Table 3**). Meanwhile PM significantly enhanced SSC and TA of strawberry fruit but had no effect of firmness of strawberry fruit compared to MRS (**Table 3**). Strawberry planted under PMRC produce higher-quality fruits than those without row covers, possibly because the microclimate under the covers was modified and the soil temperature was elevated which maybe result in better root establishment and advanced growth stages [20].

	Total yield (g m^{-2})	Yield $plant^{-1}$ (g $plant^{-1}$)	Average fruit weight (g)
Production systems			
Matted row system	1299.14a	54.22c	9.89b
Plastic mulch	891.63b	89.16b	12.21a
Plastic mulch with row covers	982.99b	132.69a	13.23a
$LSD_{0.05}$	113.30	24.07	1.26

$LSD_{0.05}$: least significant difference at the 0.05 level.
Different lower-case letters in the same column indicate statistically significant differences between different treatments ($p < 0.05$).

Table 2. Total yield, yield per plant and average fruit weight of strawberry selection 'SJ8976-1' grown under three production systems.

	Early harvest			Mid harvest			Late harvest		
	SSC (°Brix)	TA (%)	Firmness	SSC (°Brix)	TA (%)	Firmness	SSC (°Brix)	TA (%)	Firmness
Production systems									
Matted row system	6.9b	0.75b	3.2b	7.1c	0.68b	2.4b	7.6b	0.63b	1.4b
Plastic mulch	7.8a	0.94a	3.2b	7.8b	0.88a	2.3b	8.4a	0.76a	1.5b
Plastic mulch with row covers	8.1a	0.87a	3.6a	8.7a	0.84a	2.8a	8.8a	0.78a	2.2a
$LSD_{0.05}$	0.6	0.08	0.3	0.5	0.08	0.2	0.5	0.09	0.3

$LSD_{0.05}$: least significant difference at the 0.05 level.
Different lower-case letters in the same column indicate statistically significant differences between different treatments ($p < 0.05$).

Table 3. Early-, mid- and late-harvest soluble solids content (SSC), titratable acidity (TA) and firmness of strawberry selection 'SJ8976-1' grown under three production systems.

3.3. Effect of production systems on shelf life

Photographs of disease development and fruit juice leakage of strawberry selection 'SJ8976-1' used for shelf life, juice leakage and presences of grey mould classification are presented in **Figure 1**. 'SJ8976-1' has a special longer shelf life (about 9 days) after storage at room temperature than the commercial strawberry varieties. Production systems significantly affected strawberry

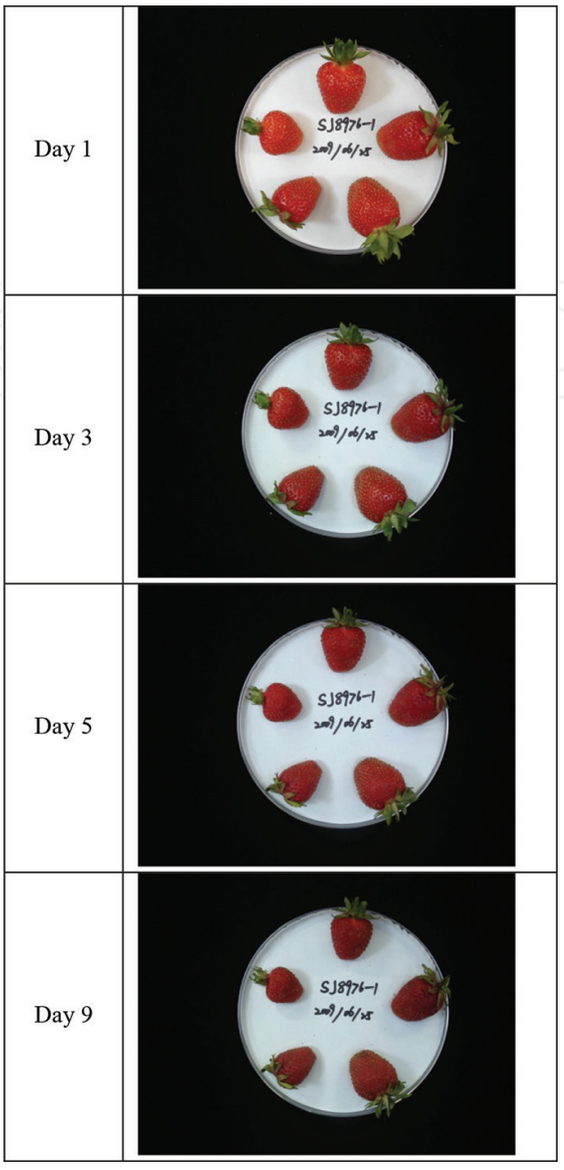

Figure 1. Photographs of disease development and fruit juice leakage of strawberry selection 'SJ8976-1' used for shelf life, juice leakage and presences of grey mould classification.

shelf life, including fruit weight loss, juice leakage, glossiness and presences of grey mould during storage (**Figure 2**). Fruit weight loss, juice leakage and presences of grey mould after storage were lower, and fruit glossiness was higher for those fruits harvested from PMRC than those from the MRS. Significant lower fruit weight loss was observed for PMRC and PM compared to the MRS, and the results were more pronounced after day 7 (**Figure 2A**). It was interesting to note that PMRC had significant lower juice leakage than the MRS, but the differences between PMRC and PM and PM and MRS were not significant until day 11 (**Figure 2B**). The fruits from PMRC kept their glossiness longer during storage at room temperature than MRS and PM. The remarkable difference among different production systems was obtained at 7 days after harvest (**Figure 2C**). Similar finding was reported in Finland that plastic production systems promoted better shelf life [11]. No significant differences were observed between the production systems on the first 5 days of harvest for presences of grey mould, but significantly less grey mould

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were observed on fruits harvested from PMRC than those harvested from MRS and PM from day 7 to the end of the test when all fruits were ranked as non-marketable (**Figure 2D**). Lower grey mould incidence on fruit harvested from PMRC might be due to the higher TPC and TAC content of the fruits as suggested previous [25, 34] or the protection that fruits received from the row cover against pathogen and rainfall as suggested by Freeman and Gnayem [16].

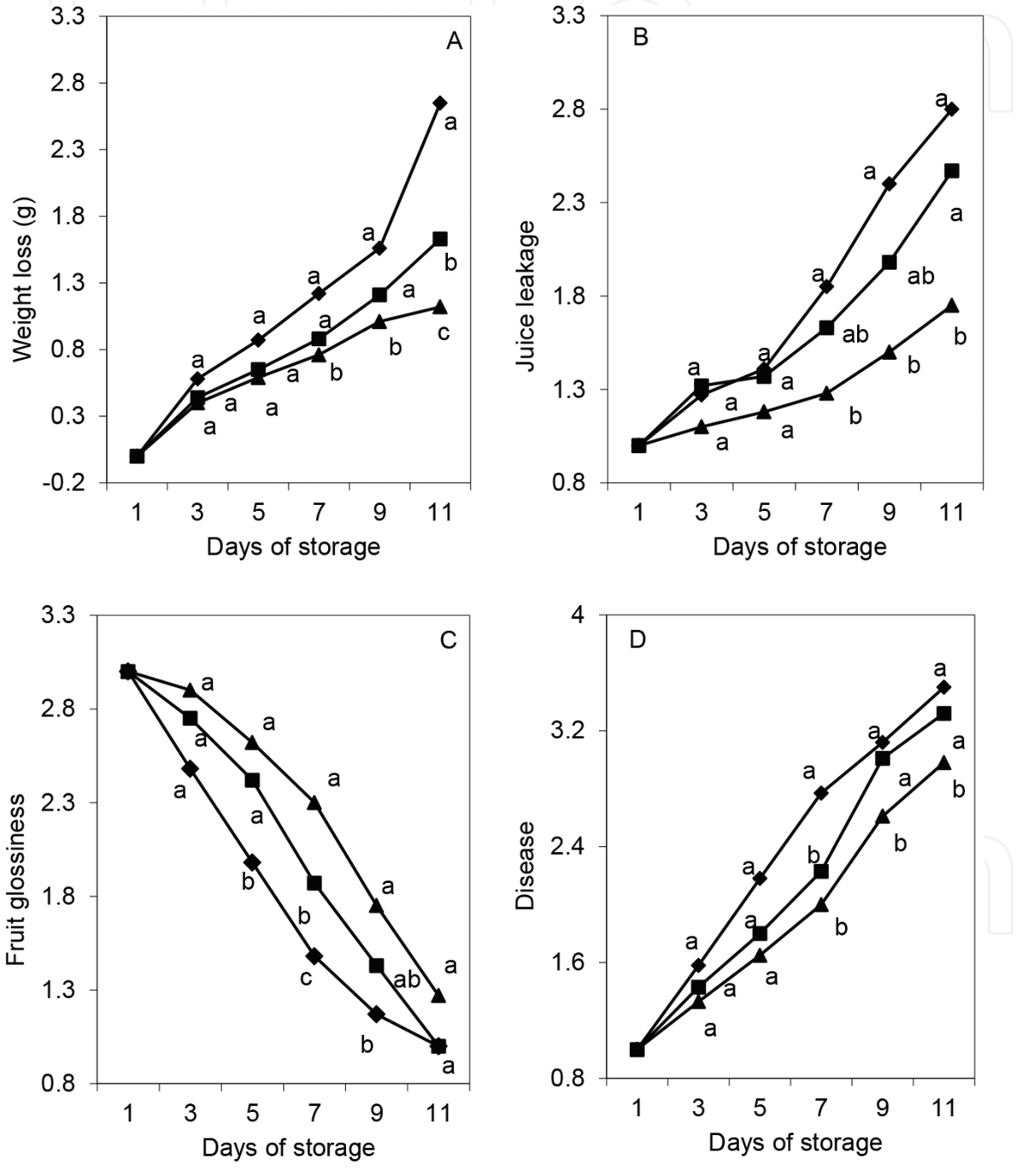

Figure 2. Early-, mid- and late-harvest fruit weight loss (A), fruit juice leakage (B), fruit glossiness (C) and incidence of grey mould (D) on strawberry selection 'SJ8976-1' during 11 days of storage at room temperature (23°C) grown under three production systems. Means with the same letter within the same day were not significantly different at 0.05 level. ◆, Matted row system; ■, plastic mulch; and ▲, plastic mulch with row covers.

3.4. Effect of production systems on antioxidant capacity

Production systems significantly changed the TPC, TAC and ORAC, but the effects varied during the different harvests (**Table 4**). PMRC promoted TPC, TAC and ORAC of strawberry fruits compared to MRS throughout the harvest season. At early harvest, TPC, TAC and ORAC were significantly higher for PMRC than MRS, but the differences of TPC and TAC between PM and MRS were not significant (**Table 4**). At mid harvest, TPC, TAC and ORAC reached the peak, and PM showed a significant change of TPC and ORAC compared to MRS. PM showed a significant change of TAC compared to MRS until the late harvest (**Table 4**). The increase of TPC and TAC might be attributed to the changes of microenvironment temperature, moisture, various enzyme activities and rhizospheric microflora of soil under the PMRC compared to the MRS which promoted the growth stages similar to the finding of Wang et al. [19] who reported that fruits from hill plasticulture had higher flavonoid contents and TAC than the MRS. The fruits harvested from PMRC not only showed the higher TPC and TAC but also the better shelf life than those from MRS in our study. The relation between antioxidant activity and fruit shelf life could be explained by our previous research that some of the antioxidants may reduce the incidence of postharvest diseases during storage and be responsible for postharvest quality [34]. Similar results were found by Wang and Millner [35] which indicated that cultural systems affected ORAC values, flavonoids and anthocyanins of 'Allstar' and 'Chandler' strawberries. ORAC is another new method of measuring antioxidant

	Early harvest			**Mid harvest**			**Late harvest**		
	TPC (μg GAE g^{-1})	**TAC (μmol g^{-1})**	**ORAC (μmol TE g^{-1})**	**TPC (μg GAE g^{-1})**	**TAC (μmol g^{-1})**	**ORAC (μmol TE g^{-1})**	**TPC (μg GAE g^{-1})**	**TAC (μmol g^{-1})**	**ORAC (μmol TE g^{-1})**
Production systems									
Matted row system	1437.9b	14.5b	20.6c	1522.8c	15.0b	22.4c	1355.8b	14.1c	21.5c
Plastic mulch	1521.1ab	14.7b	22.4b	1698.0b	16.4ab	24.1b	1603.3a	15.5b	22.4b
Plastic mulch with row covers	1610.2a	16.1a	24.3a	1867.4a	17.8a	25.2a	1631.4a	16.8a	23.6a
$LSD_{0.05}$	155.8	1.2	0.9	140.4	1.5	0.9	168.6	1.0	0.8

TPC and TAC were performed in triplicate for each of three replicates in 2009 and 2010.

TPC is expressed as micrograms of gallic acid equivalent (GAE) per gramme of fresh frozen weight; TAC is expressed as micromoles of $Fe_2SO_4 \cdot 7H_2O$ equivalent per gramme of fresh frozen weight.

LSD ($p < 0.05$): least significant difference at the 0.05 level.

Different lower-case letters in the same column indicate statistically significant differences between different treatments ($p < 0.05$).

Table 4. Early-, mid- and late-harvest total phenolic content (TPC), total antioxidant capacity (TAC) and oxygen radical absorbance capacity (ORAC) of strawberry selection 'SJ8976-1' grown under three production systems.

capacities *in vitro*. Higher ORAC value indicates higher capacity to scavenge oxygen radicals. In other words, fruit harvested from PMRC showed higher ORAC value, which means PMRC enhanced the nutritional value of strawberry fruit.

3.5. Effect of production systems on phenolic composition

Phenolic compounds, found in numerous fruits, vegetables and beverages, were not only providing supplemental functions in a plant's life cycle but also offering health benefits to humankind. They have been viewed as potential sources of dietary constituents to prevent the majority of diet-related diseases such as high cholesterol, high blood pressure and obesity. In our study, the main phenolic compounds identified by HPLC analysis in strawberry selection 'SJ8976-1' were grouped into six major categories: anthocyanins, hydroxycinnamic acids, kaempferol, flavonols, ellagic acid and benzoic acids. Among the six categories, anthocyanins accounted for 53.5% of the total phenolics and turned out to be the most predominant phenolic compounds. The physiological function of anthocyanin is responsible for the red colour of the strawberry skin and flesh. The second most abundant category was hydroxycinnamic acids, which accounted for 24.5% of the total phenolics, while kaempferol accounted for only 2.2% which was the lowest percentage of the total phenolics (**Table 5**).

In general, the strawberry fruits harvested from PMRC represented significantly higher amount of total phenolics than those from MRS and PM at all the three harvests based on the sum of the six categories of phenolic compounds (**Table 5**). In detail, significantly higher ellagic acid was assessed in the fruits from PMRC and PM than those from MRS. PMRC significantly enhanced total benzoic acids in strawberry fruit compared to MRS and PM during the early harvest, but the differences were no longer significant at mid and late harvests. Fruits harvested under PMRC showed significantly higher total hydroxycinnamic acids than MRS and PM in early harvest, and from mid to late harvest, the accumulation of hydroxycinnamic acids maximized in a peak. Those fruits from PMRC had no significantly higher amount of flavonols than those from MRS and PM at beginning, but the amount of flavonols grew quickly and achieved the peak by end of mid harvest under all three production systems; at late harvest fruit from PMRC and PM presented significantly higher total flavonols than MRS. Moreover, during all the harvests, significantly higher total anthocyanins accumulated under PMRC than the strawberry from MRS.

The modified phenolic compositions of strawberry under row covers may be primarily attributed to the elevated temperature, transmitted light spectrum and soil acidity inside the covers. Similar findings were observed in tobacco that the interaction of variety and cultural practices had significant effect on total polyphenols, rutin and chlorogenic acid in tobacco leaves [36]. Sharma et al. [37] also informed that mulching itself or combined with row covers had significant influence on plant physiology characteristics and berry yield of strawberry.

The subgroups of anthocyanins and hydroxycinnamic acids detected in strawberry selection 'SJ8976-1' were cyanidin-3-glucoside, pelargonidin-3-glucoside, pelargonidin-3-rutinoside and m-Coumaric acid, o-Coumaric acid and p-Coumaric acid, respectively. m-Coumaric acid, varied from 38.8 to 96.0 μg/g, was the major representative of the hydroxycinnamic acids.

Treatment	Ellagic acid (254 nm)	Total benzoic acids (280 nm)	Total hydroxycinnamic acids (280 nm)	Total kaempferol (280 nm)	Total flavonols (350 nm)	Total anthocyanins (510 nm)	Total phenolics—sum of 6 groups
Early harvest							
Matted row system	11.9b	18.9b	41.7b	4.2b	5.3a	97.8b	179.8b
Plastic mulch	19.3a	22.3b	52.4b	4.9b	7.2a	120.7ab	226.7ab
Plastic mulch with row cover	21.2a	28.7a	68.8a	5.8a	8.9a	144.6a	278.0a
$LSD_{0.05}$	3.8	4.5	11.9	0.8	3.9	28.0	55.3
Mid harvest							
Matted row system	15.3b	19.6b	48.8b	6.0b	11.1c	110.5b	211.3c
Plastic mulch	18.8a	23.2ab	60.8b	7.5a	22.2b	147.2a	279.7b
Plastic mulch with row cover	19.6a	24.8a	80.3a	8.2a	28.9a	168.9a	330.7a
$LSD_{0.05}$	2.7	5.1	15.8	0.8	5.9	30.1	50.3
Late harvest							
Matted row system	13.6b	20.6a	60.3b	4.4b	8.3b	144.2b	251.4b
Plastic mulch	15.4b	22.6a	81.2b	5.8a	17.4a	175.6ab	318.1ab
Plastic mulch with row cover	19.0a	24.2a	108.5a	6.2a	18.7a	206.3a	382.9a
$LSD_{0.05}$	3.2	3.7	20.6	1.0	4.7	33.5	65.2
% Total	6.3	8.3	24.5	2.2	5.2	53.5	100.0

Anthocyanins were quantified using cyanidin-3-glucoside (C3G), pelargonidin-3-glucoside (P3G) and pelargonidin-3-rutinoside (P3R); hydroxycinnamic acids were quantified using *p*-Coumaric acid (pC), *m*-Coumaric acid (mC) and *o*-Coumaric acid (oC); kaempferol was quantified using kaempferol-3-glucoside (K3G); flavonols were quantified using quercetin-3-galactoside; benzoic acids were quantified using gallic acid, and the authentic standard was used for ellagic acid.

LSD ($p < 0.05$): least significant difference at the 0.05 level.

Different lower-case letters in the same column indicate statistically significant differences between different treatments ($p < 0.05$).

Table 5. Early-, mid- and late-harvest phenolic composition (μg g^{-1} fresh frozen weight) of strawberry selection 'SJ8976-1' grown under three production systems.

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In contrast, o-Coumaric acid varied from 0.5 to 4.0 μg/g from early to late harvest accounted for the lowest portion of hydroxycinnamic acids. Moreover, the content of p-Coumaric acid, m-Coumaric acid and o-Coumaric acid was significantly promoted by PMRC at all stages (**Table 6**). Pelargonidin-3-glucoside was the dominant anthocyanin measured in strawberry selection 'SJ8976-1', while cyanidin-3-glucoside and pelargonidin-3-rutinoside were found in smaller amounts. PMRC significantly promoted the contents of pelargonidin-3-glucoside and cyanidin-3-glucoside compared to MRC, while the production systems only had the significant effect on pelargonidin-3-rutinoside at the late harvest (**Table 6**).

Treatment	Hydroxycinnamic acids (280 nm)			Anthocyanins (510 nm)		
	pC	mC	oC	C3G	P3G	P3R
Early harvest						
Matted row system	2.4b	38.8b	0.5b	6.8b	89.3b	1.7a
Plastic mulch	3.0b	48.6b	0.8b	8.1b	110.4ab	2.2a
Plastic mulch with row cover	4.6a	62.8a	1.4a	11.8a	130.5a	2.3a
$LSD_{0.05}$	0.8	10.5	0.4	2.8	25.3	0.7
Mid harvest						
Matted row system	2.1b	46.1b	0.6b	8.9b	99.0b	2.6a
Plastic mulch	2.3b	57.6b	0.9b	14.3a	130.5a	2.4a
Plastic mulch with row cover	3.9a	74.7a	1.7a	16.8a	149.3a	2.8a
$LSD_{0.05}$	1.0	13.4	0.5	3.3	28.0	0.5
Late harvest						
Matted row system	3.3b	55.9c	1.1b	12.8b	128.6c	2.8b
Plastic mulch	3.8b	75.9b	1.5b	16.6a	155.7b	3.3ab
Plastic mulch with row cover	8.5a	96.0a	4.0a	18.1a	184.6a	3.6a
$LSD_{0.05}$	1.5	14.8	1.2	2.2	21.4	0.7

Anthocyanins were quantified using cyanidin-3-glucoside (C3G), pelargonidin-3-glucoside (P3G) and pelargonidin-3-rutinoside (P3R); hydroxycinnamic acids were quantified using *p*-Coumaric acid (pC), *m*-Coumaric acid (mC) and *o*-Coumaric acid (oC); kaempferol was quantified using kaempferol-3-glucoside (K3G); flavonols were quantified using quercetin-3-galactoside; benzoic acids were quantified using gallic acid, and the authentic standard was used for ellagic acid.

LSD ($p < 0.05$): least significant difference at the 0.05 level.

Different lower-case letters in the same column indicate statistically significant differences between different treatments ($p < 0.05$).

Table 6. Early-, mid- and late-harvest phenolic composition (μg g^{-1} fresh frozen weight) of strawberry selection 'SJ8976-1' grown under three production systems.

These results are congruent with the findings of other researchers who indicated that significantly higher amounts of cyanidin-3-glycoside and pelargonidin-3-glycoside were assessed in strawberry fruits from hill plasticulture in comparison to MRS [19]. The consecutive experiment by Wang et al. also indicated that pelargonidin was the predominant anthocyanin in strawberry fruits [26]. Furthermore, the increased antioxidant capacity and phenolic compositions in berries may offer higher nutritional values to humankind [4, 30].

4. Conclusion

In summary, PMRC advanced fruit maturity and improved average fruit weight compared to MRS. SSC, TA and firmness of the strawberry fruits from PMRC were significantly increased at all harvests. Fruit weight loss, juice leakage and presences of grey mould were lower, and fruit glossiness was higher for those harvested under PMRC than those from MRS. TPC, TAC as well as ORAC of strawberry were significantly changed under different production systems. The phenolic compounds assessed in strawberry were grouped into six major categories, which were anthocyanins, kaempferol, flavonols, hydroxycinnamic acids, ellagic acid and benzoic acids.

Our results can provide useful insight to growers in north cooler climate because PMRC not only accelerates strawberry fruit ripening but also ameliorates fruit quality by improving nutritional value. PMRC could be a recommended alternative of MRS.

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References

[1] Vermerris W, Nicholson R. Phenolic compound biochemistry. 1st ed. West Lafayette: Springer; 2008.

[2] Cesar G. Fraga, editor. Plant phenolics and human health: biochemistry, nutrition and pharmacology. 1st ed. New Jersey: John Wiley & Sons; 2009.

[3] Tsao R, Khanizadeh S, Dale A. Designer fruits and vegetables with enriched phytochemicals for human health. Canadian Journal of Plant Science. 2006. 86(3): 773-786.

[4] Henning S M, Seeram N P, Zhang Y, Li L, Gao K, Lee R P, Wang D C, Zerlin A, Karp H, Thames G, Kotlerman J, Li Z Heber D. Strawberry consumption is associated with increased antioxidant capacity in serum. Journal of Medicinal Food. 2010. 13(1): 116-122.

[5] Khanizadeh S, Tsao R, Rekika D, Yang R, Charles M T, Rupasinghe H P V. Advances in fruit breeding in eastern Canada—role of phytochemicals in designing specialty fruits. Acta Horticulturae. 2009. 814: 205-208.

[6] Crespo P, Giné Bordonaba J, Terry L A Carlen C. Characterisation of major taste and health-related compounds of four strawberry genotypes grown at different Swiss production sites. Food Chemistry. 2010. 122(1): 16-24.

[7] Cheplick S, Kwon Y I, Bhowmik P, Shetty K. Phenolic-linked variation in strawberry cultivars for potential dietary management of hyperglycemia and related complications of hypertension. Bioresource Technology. 2010. 101(1): 404-413.

[8] Cejudo Bastante M J, Durán Guerrero E, Castro Mejías R, Natera Marín R, Rodríguez Dodero M C, Barroso C G. Study of the polyphenolic composition and antioxidant activity of new sherry vinegar-derived products by maceration with fruits. Journal of Agricultural and Food Chemistry. 2010. 58(22): 11814-11820.

[9] Basu A, Rhone M, Lyons T J. Berries: emerging impact on cardiovascular health. Nutrition Reviews. 2010. 68(3): 168-177.

[10] Khanizadeh S. Breeding strawberries for Eastern Central Canada. Euphytica. 1994. 77(1–2): 45-49.

[11] Kivijärvi P, Parikka P, Tuovinen T. The effect of different mulches on yield, fruit quality and strawberry mite in organically grown strawberry. in Organic production of fruit and berries. 2002, The Danish Institute of Agricultural Sciences, Department of Horticulture: Årslev, Denmark.

[12] Anttonen M J, Hoppula K I, Nestby R, Verheul M J, Karjalainen R O. Influence of fertilization, mulch color, early forcing, fruit order, planting date, shading, growing environment, and genotype on the contents of selected phenolics in strawberry (*Fragaria* × *ananassa* Duch.) fruits. Journal of Agricultural and Food Chemistry. 2006. 54(7): 2614-2620.

[13] Hancock J F, Goulart B L, Luby J J Pritts M P. The strawberry matted row: Practical cropping system of dated anachronism? Advances in Strawberry Research. 1997. 16: 1-4.

[14] Scheel D C. The effect of clear polyethylene winter mulch on the growth and yield of strawberries. Advances in Strawberry Production. 1982. 1: 29-30.

[15] Black B L, Enns J M, Hokanson S C. Advancing the matted-row strawberry production system. in Proc. 5th North American Strawberry Conference. 2002. Alexandria, VA, USA.

[16] Freeman S, Gnayem N. Use of plasticulture for strawberry plant production. Small Fruits Review. 2005. 4(1): 21-32.

[17] Neuweiler R, Bertschinger L, Stamp P, Feil B. The impact of ground cover management on soil nitrogen levels, parameters of vegetative crop development, yield and fruit quality of strawberries. European Journal of Horticultural Science. 2003. 68(4): 183-191.

[18] Allen R G, Pereira L S, Raes D, Smith M. Crop evapotranspiration-guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. FAO, Rome. 1998. 300(9): D05109.

[19] Wang S Y, Zheng W, Galletta G J. Cultural system affects fruit quality and antioxidant capacity in strawberries. Journal of Agricultural and Food Chemistry. 2002. 50(22): 6534-6542.

[20] Filipović V, Romić D, Romić M, Borošić J, Filipović L, Mallmann F J K, Robinson D A. Plastic mulch and nitrogen fertigation in growing vegetables modify soil temperature, water and nitrate dynamics: experimental results and a modeling study. Agricultural Water Management. 2016. 176: 100-110.

[21] Scalzo J, Politi A, Pellegrini N, Mezzetti B, Battino M. Plant genotype affects total antioxidant capacity and phenolic contents in fruit. Nutrition. 2005. 21(2): 207-213.

[22] Khanizadeh S, Buszard D. SJ89264-6 and SJ8976-1 two strawberry selections with long storage life. in III International Strawberry Symposium 439. 1996.

[23] Evans W D, Dale A, Hunter C. The strawberry in Ontario. 1st ed. Ottawa: Queen's Printer for Ontario; 1988.

[24] Fan L, Yu C, Fang C, Zhang M, Ranieri M, Dubé C, Khanizadeh S. The effect of three production systems on the postharvest quality and phytochemical composition of Orléans strawberry. Canadian Journal of Plant Science. 2011. 91(2): 403-409.

[25] Khanizadeh S, Tao S, Zhang S, Tsao R, Rekika D, Yang R, Charles M T, Gauthier L Gosselin A. Profile of antioxidant activities of selected strawberry genotypes. Acta Horticulturae. 2009. 814: 551-556.

[26] Wang Q, Tury E, Rekika D, Thérèse Charles M, Tsao R, Hao Y J, Dubé C, Khanizadeh S. Agronomic characteristics and chemical composition of newly developed day-neutral strawberry lines by Agriculture and Agri-Food Canada. International Journal of Food Properties. 2010. 13(6): 1234-1243.

[27] Slinkard K, Singleton V L. Total phenol analysis: automation and comparison with manual methods. American Journal of Enology and Viticulture. 1977. 28: 49-55.

[28] Benzie I F F, Strain J J. The ferric reducing ability of plasma (FRAP) as a measure of 'antioxidant power': The FRAP assay. Analytical Biochemistry. 1996. 239(1): 70-76.

[29] Fan L, Roux V, Dubé C, Charlebois D, Tao S, Khanizadeh S. Effect of mulching systems on fruit quality and phytochemical composition of newly developed strawberry lines. Agricultural and Food Science. 2012. 21(2): 132-140.

[30] Fan L, Dubé C, Fang C, Roussel D, Charles M T, Desjardins Y, Khanizadeh S. Effect of production systems on phenolic composition and oxygen radical absorbance capacity of 'Orléans' strawberry. LWT—Food Science and Technology. 2012. 45(2): 241-245.

[31] SAS Institute. SAS User's Guide, v6. Cary, NC, USA SAS Institute; 1989.

[32] Jin P, Wang S Y, Wang C Y, Zheng Y. Effect of cultural system and storage temperature on antioxidant capacity and phenolic compounds in strawberries. Food Chemistry. 2011. 124(1): 262-270.

[33] Soria C, López-Aranda J M, Medina J J, Miranda L, Domínguez F J. Evaluation of strawberry production and fruit firmness under small and large plastic tunnels in annual crop system. Acta Horticulturae. 2009. 842: 119-124.

[34] Tao S, Zhang S, Tsao R, Charles M T, Yang R, Khanizadeh S. *In vitro* antifungal activity and mode of action of selected polyphenolic antioxidants on *Botrytis cinerea.* Archives of Phytopathology and Plant Protection. 2010. 43(16): 1564-1578.

[35] Wang S Y Millner P. Effect of different cultural systems on antioxidant capacity, phenolic content, and fruit quality of strawberries (*Fragaria* × *aranassa* Duch.). Journal of Agricultural and Food Chemistry. 2009. 57(20): 9651-9657.

[36] Yanfang D, Tiezhao Y, Yapei L, Zhixiao Y, Gang X, Xiaoquan Z, Xuhui L. Effects of ecology and variety and their interactions on polyphenols compounds in flue-cured tobacco. Chinese Tobacco Science. 2013. 34(1): 17-21.

[37] Sharma R R, Singh R, Singh D, Gupta R K. Influence of row covers and mulching interaction on leaf physiology, fruit yield and albinism incidence in 'Sweet Charlie' strawberry (*Fragaria* × *ananassa* Duch.). Fruits. 2008. 63(2): 103-110.

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