

Effect of mulching systems on fruit quality and phytochemical composition of newly developed strawberry lines

Li Fan^{1,2}, Valentine Roux³, Claudine Dubé², Denis Charlebois², Shutian Tao⁴, and Shahrokh Khanizadeh^{2*}

¹ College of Agronomy, Inner Mongolia Agricultural University, 010019, Hohhot, P. R. China

² Horticulture Research and Development Centre, Agriculture and Agri-Food Canada, 430 Gouin Blvd., St-Jean-sur-Richelieu, J3B 3E6, Quebec, Canada

³ ISARA-LYON, 23 rue Jean Baldassini, 69364, Lyon, France

⁴ College of Horticulture, Nanjing Agricultural University, 1 Weigang, Nanjing, 210095, P.R. China

e-mail: shahrokh.khanizadeh@agr.gc.ca

The effects of three mulching systems on total yield, average yield per plant, average fruit weight, soluble solids content (SSC), titratable acidity (TA), firmness and oxygen radical absorbance capacity (ORAC) of two newly developed lines ('Orléans' and 'Saint Pierre'), one advanced selection ('SJ8976-1') and two commonly used cultivars ('Jewel' and 'Kent') were evaluated. The studied mulching systems were: plastic mulch (PM), mulch with row cover (PMRC), and matted-row system (MRS). Results showed that plastic mulch with row cover (PMRC) generally increased yield per plant, average fruit weight, SSC, firmness and ORAC, but differences varied within harvest times. No significant differences in total yield and TA were observed under the selected mulching systems. Both PMRC and PM accelerated the harvest periods compared to MRS. 'Kent' and 'Jewel' had the highest total yield while 'SJ8976-1' and 'St-Pierre' had the highest average fruit weight. The highest SSC, TA and ORAC were found in 'Jewel'. There was no interaction between the mulching systems and genotypes, indicating that the effect of production system is independent of cultivars. PMRC seems to be a better growing system, improving fruit quality and increasing the nutritional value of all genotypes. By allowing off-season fruit production in cool climates, PMRC can be an alternative method to the costly high tunnels.

Key words: *Fragaria × ananassa* Duch., breeding, cultural practice, fruit quality, yield

Introduction

Now more than ever, consumers are looking for healthy food containing a large array of antioxidant compounds, including flavonoids and other phenolics. Such bioactive molecules offer some protection against free radicals and reactive oxygen species produced by our bodies. Recent studies have shown that phenolics are important components responsible for the antioxidant capacity (AC) observed in fruits and vegetables. Fruits, such as berries, are extremely rich natural sources of phenolic compounds with high antioxidant activity (Tsao et al. 2006, Henning et al. 2010).

Strawberry (*Fragaria × ananassa* Duch.) is an important fruit crop in North America. The increasing demand for strawberries, due not only to their flavour, but also to their nutritional value and human health benefits, has enhanced the economic importance of the industry (Tsao et al. 2006, Pinto et al. 2008, Seeram 2008, Henning et al. 2010). Strawberries contain large amounts of phenolic compounds, and it has also been shown that phenolic compounds play an important role in extending shelf life and enhancing the quality of fresh fruits by delaying senescence induced by oxidative degradation (Khanizadeh et al. 2009b).

These benefits have stimulated research on the phenolic composition and total antioxidant capacity of strawberry fruits. Therefore, increasing antioxidant levels through breeding and/or cultivation practices is an important option for supporting increased antioxidant intake.

Many factors have been shown to affect strawberry yield and quality, including genotype, planting date, temperature, fertilizer and mulching systems (Khanizadeh 1994, Kivijärvi et al. 2002, Anttonen et al. 2006). The matted row system (MRS) has long been the main system used in strawberry production in cold areas of North America, with the advantage of lower establishment costs (Hancock et al. 1997). However, in recent decades, plasticulture has drawn increased attention from growers and researchers as an effective way to offer the benefits of extended season, increased yield, better weed control, prevention of bed erosion, improved fruit cleanliness, ease of harvest and more efficient irrigation and fertilizer application (Scheel 1982, Himelrick et al. 1993, Moor et al. 2004). It has been reported that the use of row covers can modify the microclimate, help the establishment and development of strawberry runners, and accelerate early production while reducing disease incidence and increasing phenolic content of strawberries (Wang et al. 2002, Fan et al. 2011).

Despite the increasing use of plastic mulch (PM) and plastic mulch with row covers (PMRC) by growers as a replacement for MRS, little information is available on fruit quality, particularly oxygen radical absorbance capacity (ORAC), at different harvest times. The aim of this 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 and AC measured as ORAC, in selected strawberry fruits, at different harvest times during the growing season.

Material and methods

Field experiment design

A complete randomized design with two replicates was used and twenty-six plants per replicate of four strawberry cultivars ('Jewel', 'Kent', 'Orléans', 'St-Pierre') and one selection ('SJ8976-1') were grown under three mulching systems: matted row system (MRS), plastic mulch (PM) and plastic mulch with row cover (PMRC). The experiment was set up at the L'Acadie Experimental Farm (longitude: 73.35° W; latitude: 45.32° N), in L'Acadie, Quebec, Canada in 2009 and the strawberries were planted in a double row 30 × 30 cm apart in 18-m long plots and supplied with drip irrigation down the centre of each row. Runners were removed from the plants cultivated under PM and PMRC, but were kept and placed in the MRS as recommended by the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) (Evans et al. 1988). For PMRC, white floating cover was applied over the bed on every October and removed when there were about 10% flowers on the plants. The strawberry plants were under routine management and normal plant protection. The mean temperature and total precipitation from flowering to harvest were 19.65 °C and 268.7 mm during 2010 and 2011. All the parameters were measured in 2010 and 2011.

Fruits were harvested from each plot at fully red stage, 2–3 times per week, from June to mid-July, for a total of 13 harvests. These harvests were finally divided into three periods, as early, mid and late harvests. Total yield and average fruit weight of each genotype were recorded at every harvest. Thirty fruits at fully red stage were randomly selected from each plot, immediately cut into small pieces and frozen in liquid nitrogen. Three 40 g subsamples of each cultivar and growing technique were stored at –80 °C for SSC, TA and ORAC determination.

SSC, TA and firmness

The juice of 15 g of fresh-frozen fruit of each strawberry genotype was obtained using a Supreme Juicerator (Acme Juicer Manufacturing Co., New Hartford, CT, USA), and the SSC of the juice was determined at 20 °C using a hand-held refractometer (Sper Scientific Ltd., Scottsdale, AZ, USA). TA was measured by diluting 1 mL of strawberry juice with 9 mL of distilled water, titrated to pH 8.1 (Accumet AB15 Basic pH meter; Fisher Scientific) using NaOH 0.1 N. TA was expressed as the % citric acid based on the volume of sodium hydroxide added during the titration, as described previously (Khanizadeh et al. 2009a). Firmness was ranked from 1 (very soft) to 5 (very firm).

ORAC

For the ORAC assay, 5 g of frozen fruit of each strawberry genotype were ground in 15 ml of 50% acetone using a Polytron blender (Brinkmann Instruments, Westbury, NY, USA). The mixture was centrifuged at 10000 rpm for 10 min and the supernatant was transferred to a 1.5-ml vial and stored at -20 °C before being analyzed. Extracts resulting from this procedure were used for ORAC.

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 with a Synergy™ 2 Multi-Mode Microplate Reader (Bio-Tek Instruments, Inc., Winooski, VT, USA). 2,2'-Azobis(2-methylpropionamide) dihydrochloride (AAPH), fluorescein disodium and 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) were purchased from Sigma Chemical Co. (Oakville, ON, Canada). Trolox, a hydrosoluble vitamin E analogue, was used as standard. AAPH, used as a peroxyl radical generator, reacts with a fluorescent probe (fluorescein) to form a non-fluorescent reaction product; residual fluorescence is quantified with a fluorometer. Briefly, 150 µl of sodium fluorescein solution (4×10^{-6} mM) was added to the wells of a 96-well microplate. Thereafter, 25 µl of 75 mM phosphate buffer (pH 7.4) was added to the blank wells, 25 µl of the Trolox dilutions to the standards and 25 µl of the properly diluted sample to the samples. The plate was then incubated for 30 minutes at 37 °C. Reactions were initiated by the addition of 25 µl of AAPH solution (153 mM) using the microplate reader's injector (Huang et al. 2002). The fluorescence was then monitored kinetically, with data taken every minute by the Gen5™ Data Analysis Software (Bio-Tek, Winooski, VT, USA). Results of the ORAC assay were calculated with a linear standard curve obtained with the Trolox standards and were expressed as µM Trolox equivalent (TE) per gram fresh-frozen weight.

Statistical analysis

Statistical analysis was performed using SAS software (SAS 1989). Data were analyzed using GLM procedure and the least significant difference (LSD) test was used for mean separation at the 5% level when the F value was significant. The angular or inverse sine transformation was used for rank data (firmness) 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 (Steel and Torrie 1980). The data from 2010 and 2011 were pooled together after analyzing each year separately and testing the homogeneity of the experimental error.

Results and discussion

There was no interaction between the mulching systems and genotypes, indicating that their effect was independent of each other. All genotypes responded similarly to the different mulching systems and performed better under PMRC than under the two other mulching systems.

Effect of mulching systems

The mulching systems had no significant effect on total yield, but they did have a significant effect on yield per plant and average fruit weight (Table 1). PMRC gave the highest yield per plant and highest average fruit weight, followed by PM, while MRS gave the least yield per plant and the lowest average fruit weight. Plants grown under PMRC and PM produced earlier fruits than under MRS. PMRC and PM resulted in harvests 8 to 13 days and 4 to 10 days earlier than MRS, respectively (data not shown). Our results are similar to those of Berglund et al. (2006), who reported that better establishment of strawberry plants gives higher yields and earlier harvests when grown under PM. It has also been reported by Soria et al. (2009) that early marketable yield, total marketable yield and first class fruits arose under plastic tunnels throughout two consecutive cropping seasons. Earlier harvests and higher marketable yields could lead to higher profitability for strawberry growers, especially in northern climates.

Table 1. Total yield, yield per plant and average fruit weight of selected strawberry genotypes grown under three mulching systems.

	Total yield (g m ⁻²)	Yield plant ⁻¹ (g plant ⁻¹)	Average fruit weight (g)
Mulching system			
Matted-row system	1508.25a	72.6c	8.9c
Plastic mulch	1335.78a	133.6b	10.4b
Plastic mulch with covers	1319.8a	187.0a	12.0a
LSD _{0.05}	183.61	22.0	0.7
Genotype			
Jewel	1615.4a	146.4ab	10.1b
Kent	1738.9a	173.9a	8.8c
Orléans	1195.7bc	117.2cd	10.0b
St-Pierre	1331.5b	125.8bc	11.6a
SJ8976-1	1057.9c	92.0d	11.8a
LSD _{0.05}	237.0	28.37	0.9
Growing technique	NS	***	***
Genotype	***	***	***
Growing technique x genotype	NS	NS	NS

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 or between different cultivars ($p < 0.05$).

*, **, *** and NS indicate significant difference at 0.05, 0.01, 0.001 and not significant, respectively.

The mulching systems had a significant effect on the SSC of the strawberry fruits and the differences became larger for late harvests. However, the different mulching systems had no significant effect on TA throughout the three harvest times (Table 2). PMRC significantly increased the SSC and firmness of the strawberry fruits at all harvests (Table 2). Our data showed that plants grown under PMRC produce fruits of better quality than those without row covers, probably because of the modified microclimate under the covers. The elevated soil temperature under row covers might affect the establishment and growth of strawberry plants and promote their growth stages.

ORAC is considered one of the few methods that combined both the inhibition percentage and inhibition time of the antioxidant activity of reactive species into a single measurement (Cao et al. 1995). It has been extensively applied for the assessment of free radical scavenging capacity of human plasma, proteins, DNA, pure antioxidant compounds and antioxidant plant/food extracts (Dávalos et al. 2004). In this study, AC quantified by ORAC was significantly enhanced under PMRC at all harvests (Table 2). The content in phenolic compounds, which are important contributors to AC, depends on various environmental factors, including mulching systems (Wang et al. 2002, Moor et al. 2005, Jin et al. 2011), thus suggesting that PM and PMRC increased strawberry phenolic content when compared to MRS.

Our results showed that PMRC, a combination of plastic mulch and row cover, seems to be the best of the three systems tested. The improvement of yield per plant, average fruit weight, SSC, firmness and ORAC under PMRC might be related to the elevated soil temperature and to the quality of radiation under the cover. Similar results were obtained by Wang et al. (2002), Poling (1993), Aflatuni et al. (1997), Sharma et al. (2008) and Ibarra et al. (2001). Sharma et al. (2008) reported that row covers and mulching, individually or in combination, significantly improved plant physiology, growth, and berry yield attributes and reduced the incidence of albinism of strawberry. They concluded that berry weight and yield were the highest in plants grown under row covers and black polyethylene mulch. Similar results on muskmelon, reported by Ibarra et al. (2001), showed that plants grown under PMRC had higher plant biomass, specific leaf area, relative growth rate and net assimilation rate compared to the control plants. Furthermore, they reported that an earlier harvest, with increased total yield, was achieved for those plants grown under row covers compared to non-covered plants. In our previous study, PMRC was also assessed as the best mulching system compared to PM and MRS on strawberry growing. PMRC generally enhanced the phenolic content and total antioxidant capacity of 'Orléans' strawberry compared to MRS and PM (Fan et al. 2012).

Effect of genotypes

Strawberry fruits are regarded as having considerable health benefits, primarily because of the antioxidant content, which can protect the human body against cellular oxidation reactions (Seeram 2008, Henning et al. 2010, Schrage et al. 2010). Genetic background significantly influences the agronomic characteristics, fruit quality and phytochemical activity of strawberries. 'Jewel' and 'Kent' had the highest total yield and yield per plant, followed by 'St-Pierre' and 'Orléans', while 'SJ8976-1' had the lowest total yield and yield per plant. In contrast, the largest average fruit weights were obtained in 'SJ8976-1' and 'St-Pierre' vs. 'Kent', which had the smallest average fruit weight (Table 1).

Genotype is the most important factor in determining fruit quality in strawberry, such as SSC and TA. Significant differences were observed in SSC and TA of tested genotypes at mid harvest (Table 2). 'Jewel' had the highest SSC and TA, while 'Kent' had the lowest SSC. There were significant genotypic differences for firmness at early harvest, but the differences vanished at mid and late harvests (Table 2). 'St-Pierre' was significantly firmer compared to all the other genotypes.

Table 2. Early-, mid- and late-harvest soluble solids content (SSC), titratable acidity (TA), firmness and oxygen radical absorbance capacity (ORAC) of selected strawberry genotypes grown under three mulching systems.

	Early harvest				Mid harvest				Late harvest			
	SSC (°Brix)	TA (%)	Firmness	ORAC (μmol TE g ⁻¹)	SSC (°Brix)	TA (%)	Firmness	ORAC (μmol TE g ⁻¹)	SSC (°Brix)	TA (%)	Firmness	ORAC (μmol TE g ⁻¹)
Mulching system												
Matted row system	7.2a	0.96a	3.3b	22.3c	7.4b	0.92a	2.4b	22.5c	6.4c	0.83a	1.4b	22.9b
Plastic mulch	8.0b	0.94a	3.2b	23.7b	7.7b	0.95a	2.3b	25.4b	7.5b	0.94a	1.4b	23.4b
Plastic mulch with covers	7.8ab	0.89a	3.6a	25.5a	8.3a	0.96a	2.7a	27.0a	7.9a	0.87a	2.0a	24.7a
LSD0.05	0.6	0.10	0.3	0.9	0.5	0.08	0.2	0.9	0.3	0.09	0.3	0.8
Genotype												
Jewel	8.1a	1.13a	3.4ab	25.1a	8.2a	1.10a	2.5a	26.4a	7.9a	1.04a	1.6a	25.2a
Kent	7.2a	0.87b	3.3b	24.0a	7.4b	0.87b	2.3a	25.2b	6.9cd	0.82b	1.3a	23.4bc
Orléans	8.0a	0.83b	3.2b	24.8a	8.1a	0.86b	2.3a	26.2ab	7.5b	0.83b	1.6a	24.2b
St-Pierre	7.5a	0.94b	3.7a	22.8b	7.5b	0.86b	2.7a	23.8c	6.6d	0.89b	1.8a	23.1c
SJ8976-1	7.6a	0.86b	3.3b	22.4b	7.7ab	1.03a	2.5a	23.2c	7.3bc	0.82b	1.7a	22.5c
LSD0.05	0.8	0.14	0.3	1.2	0.6	0.10	0.3	1.2	0.4	0.12	0.4	1.0
Mulching system	*	NS	**	***	**	NS	**	***	***	NS	***	***
Genotype	NS	**	*	***	*	***	NS	***	***	**	NS	***
Mulching system x genotype	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

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 or between different cultivars ($p < 0.05$). *, **, *** and NS indicate significant difference at 0.05, 0.01, 0.001 and not significant, respectively.

At early harvest, 'Jewel', 'Kent' and 'Orléans' showed higher AC than 'St-Pierre' and 'SJ8976-1'. 'Jewel' was the only cultivar that maintained its highest AC.

The significant genotypic differences in agronomic characteristics, fruit quality profile and AC reported here are consistent with previous reports on strawberry and raspberry (Anttonen et al. 2006, Khanizadeh et al. 2009a, Wang et al. 2010, Yu et al. 2010). From our results, 'Kent' and 'Jewel' produced higher yield while 'St-Pierre' and 'SJ8976-1' had the largest fruit size. 'Jewel', 'Kent' and 'Orléans' had similar ORAC values consistently throughout the season.

Conclusions

The results presented in this paper indicate that the content of phytochemical compounds, as well as fruit quality characteristics, improved under PMRC. PMRC not only accelerates earlier harvest, which results in higher income because of off-season production and larger fruit size, but also improves fruit quality and nutritional value. PMRC is a good alternative to MRS and can probably be used as an alternative method to high tunnels or mini tunnels, which are expensive.

Acknowledgements

The authors would like to acknowledge the support received from the Office of International Cooperation and Exchange, the China Scholarship Council and the International Scientific Cooperation Bureau of Agriculture and Agri-Food Canada.

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