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THE IMPACT OF OPEN-FIELD AND PROTECTED CULTIVATION ON BIOCHEMICAL CHARACTERISTICS OF BANANAS (*Musa* spp. AAA)

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ABSTRACT

Bananas have been grown in both open-field and protected cultivation in the subtropics. There are a very limited number of publications focusing on the impact of cultivation systems on the physico-chemical characteristics of bananas. For this reason, we assessed these fruit characteristics including sugars, malic acid, L-ascorbic acid, macro and micro nutrients well as fat and fatty acids of green and ripe bananas (*Musa* spp. AAA) in both cultivation systems. Experimental results have showed that many parameters affected the fruit ripening stage more than the cultivation system. Sucrose was the most abundant sugar followed by fructose and glucose in both the unripe and the ripe fruit stages. Sugar content, malic acid and L-ascorbic acid were higher in the ripe stage compared to the green stage. The cultivation system affected only glucose content, however, malic acid and L-ascorbic acid were not affected by the cultivation system. The most abundant macro and micro elements found were potassium and iron respectively. Cultivation system affected only potassium, zinc and manganese contents. Nitrogen and phosphorous, were found to be higher in the ripe stage. However, calcium, zinc, manganese and cupper were higher in the unripe stage. The fatty acid showed low value in the unripe stage for both cultivation systems. The concentration of MUFAs were found to be higher in the unripe stage for open-field condition while SFAs and PUFAs percentage were found to be higher in both cultivation systems. Experimental results clearly showed that physico-chemical characteristics of bananas were mainly affected by the ripening stage while the cultivation systems only affected a few characteristics.

Key words: *Musa Cavendishii*, sugars, acids, mineral content, HPLC, fatty acids

INTRODUCTION

Bananas are one of the most important fruits due to their high nutritive value, taste and aroma. It is the fourth largest food crop after rice, wheat and maize and have been grown in every humid tropical region as well as in subtropical conditions [Ariaset al. 2003]. Open-field cultivation is the common production system in the tropics, however, bananas are also grown in some subtropical countries such as Egypt, South Africa, Spain, Australia, Turkey and Israel in both open-fields and in protected systems. In Turkey, bananas are one of the most economically grown tropical crop especially in the Mediterranean coastal regions. The production areas increased recently due to the high profit and the low labour cost. Protected cultivation is more popular due to the high yield and better fruit quality.

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Bananas are the most preferred fruit by consumers due to health benefits compounds. The Dietary Guidelines Advisory Committee recommends the dietary intake of vitamins A, C, and E, Ca, Mg, K, and fiber [USDA and HHS 2005]. Most of these can be provided by the consumption of fruit and vegetables. According to the USDA and HHS [2010], consumption of fruit and vegetables contribute to the uptake of folate, magnesium, potassium, dietary fiber, and vitamins A, C, and K. Thus, reducing the risk of chronic diseases and certain types of cancer. Ripe banana fruits contain 75.7% water, 22.2% carbohydrates, 1.1% proteins, 0.2% lipids and 0.8% ash [Robinson 1996].

Fatty acids (FA) and lipids are important structural and metabolic constituents of plant/fruit cells. They are essential components of membranes and are important for the compartmental and orderly function of most physical and chemical reactions taking place in a functional fruit cell [Saquet et al. 2000]. FA and lipids often serve as precursors of important regulatory and aroma volatile substances (jasmonates, phosphoinositides). Free FA or those liberated by lipase activity and further metabolized by b-oxidative enzymes and/or lipoxygenase, are generally regarded as being the main precursors of ester, alcohol and aldehyde volatiles produced by fruits during development and maturation [Fellmanet al. 2000].

Bananas are climacteric fruits and during fruit ripening, the peel color converts from green to yellow, starch converts to sugars, the flavour develops and the pulp softens. The first observable sign of ripening is a color change from green to yellow [Meng et al. 1997]. The banana fruits are usually sold on the market when they are at the sixth stage of ripening. Once ripening has started, fruit ripens quickly and sweetens as the result of starch-reserve degradation and subsequent conversion to soluble sugars mainly sucrose, glucose and fructose [Cordenunsi and Lajolo 1995]. The cultivation systems play an important role in banana fruit quality. Most of the fruit quality parameters have been studied in the Cavendish banana group, however, no comparative study has been published regarding fruit quality characteristics of Dwarf Cavendish bananas grown under open-field and protected cultivation systems. As far as we know, there are only a few published studies on the chemical composition of Dwarf Cavendish bananas grown in open-field and protected cultivation in the two stages of ripening.

MATERIAL AND METHODS

Sample preparation. The experiments were conducted during the two-ratoon crops (2009–2011) in Alanya province, Antalya Turkey, in both open-field and in protected cultivation using Dwarf Cavendish plants. Drip irrigation system was used and fertigation was applied as recommended by Lahav and Turner [1983]. After the harvest, maturation was achieved by application of ethylene (1000 ppm) at +18°C and 85–90% relative humidity. Color index was assessed according to the CSIRO banana ripening guide [CSIRO 1972]. Banana fruits reached the peel color stage 6 after 6 days of ethylene treatment. Unripe (1 : green stage) and ripe stage (6 : eating stage) of bananas were homogenized using a fruit blender. For each sample, approximately 500 g of banana pulp was weighed and all analyses were carried out in triplicates using the same homogenate.

HPLC analysis of sugars, malic acid and L-ascorbic acid. One gram of sample was powdered with liquid nitrogen in a mortar to obtain a homogenized material. Extraction was done according to the Miron and Schaffer [1991]. Sugars were identified and quantified by HPLC/RID10A (Agilent 1100 series). A reverse-phase Nucleosil NH_2 analytical column (150 mm × 4.6 mm internal diameter, 5 um) was used at room temperature with a flow rate of 1 mL min^{-1}. Elution was isocratic with a mixture of acetonitrile : water (7.5 : 2.5, v/v).

Organic acid analyses were done according to Bozan et al. [1997] using HPLC (VWD Agilent 1100 series) equipment. A reverse-phase Ultrasphere ODS analytical column (250 mm × 4.6 mm *i.d.*, 5 um) was used for separation of the organic acids and detection was carried out at a wavelength of 210 nm for malic acid and 242 nm for L-ascorbic acid detection. Elution was isocratic with 0.5% aqueous *meta*-phosphoric acid.

Macro and micro nutrient element analysis. Fruit pulps were dried for one day at room temperature and then dried at 65°C for 48 h. Total nitrogen was measured using Kjeldahl distillation unit [Jones 1991] then nitrogen concentration (%) was calculated. The other elements (phosphorus, potassium, calcium, iron, magnesium, manganese, zinc, copper) were assessed using the same samples. A 0.5 g sample was dried at 500°C and 5 ml HCl (20%) was added. The volume was made up with distilled water to

50 ml. Other compounds were assessed using atomic absorption. Macronutrients values were measured by g/kg and micronutrients as mg/kg [Chapman and Pratt 1961]. The phosphorus content of the samples was assessed using $SnCl_2$ blue color method using a spectrometer [Kacar 1972].

GC analysis of fatty acids. The lipid extraction from unripe and ripe banana fruit pulp was carried out according to Bligh and Dyer [1959]. The fatty acids were analyzed by GC Clarus 500 (Perkin Elmer, USA) equipped with a flame ionization detector and a fused silica capillary SGE column (30 m × 0.32 mm × 0.25 μm). The GC oven temperature was 140°C, for 5 min, and was raised to 200°C at a rate of 4°C/min and to 220°C at a rate of 1°C/min. The injection and the detector temperatures were 220°C and 280°C, respectively and the split ratio was 1 : 100. Fatty acids were identified and quantified by comparing the retention times of FAME mix (including 37 standards, Supelco).

Statistical analysis

The experiment was laid out in a completely randomized factorial design with three replicates per treatment (10 fruits for each replicate). Data was analyzed by analysis of variance (ANOVA) using the SAS software. Significance between means was tested by LSD and a multiple range test at a probability of 0.05. Triplicate GC analyses were performed, and the results were expressed by the percentage of GC area as a mean value ± standard deviation.

RESULTS AND DISCUSSION

The content of fructose, glucose, sucrose and total sugar at two ripening stages of bananas from open field and protected cultivation systems are presented in Table 1. The sugar composition and amount varied significantly between the unripe and the ripe stages, however, only the glucose content was affected by the cultivation system. Sucrose had the highest amount followed by fructose and glucose. During the ripening process, all the sugars as well as sugar content had increased. The cultivation system did not affect the fructose, sucrose and total sugar content statistically. According to the cultivation system, the fructose, sucrose and total sugar content of bananas varied between 2.29–2.30%, 5.65–5.68% and 10.14–10.18% respectively. However, only the glucose content was affected by the cultivation system and glucose was found to be higher (2.22%) in open field conditions. Torija et al. [1998], reported that during the ripening of bananas, soluble sugars increased (as starch is converted to soluble solids) and sucrose comprised more than 70% of the total sugars in fully ripe bananas [Torija et al. 1998]. Banana ripening is characterized by a number of biochemical and physiological changes, including changes in peel color and increase of sugars and organic acids. It is well accepted that fruits having above 12% Brix are considered more attractive to consumers [McGlone and Kawano 1998]. Torija et al. [1998], quantified (by HPLC) 2.03 g sucrose, 0.89 g glucose and 0.72 g fructose per 100 g of ripe banana fruit. Arcila et al. [2002a], evaluated many physical and chemical characteristics in the 'Dominico-Harton' (*Musa* AAB Simmonds) banana cultivar at various locations in Colombia during the ripening stage. Similar to previous reports, the authors reported that the starch content sharply decreased during the ripening stage. Chemical composition of banana pulp (the external, medium and central parts) was studied by Forster et al. [2003]. The highest values were detected in the central part of the pulp. Similar to our results, monosaccharides (glucose 1.82% and fructose 1.64%) were lower than sucrose (12.65%). Carvalho et al. [2011], reported the physical and physico-chemical properties of three banana cultivars of the subgroup 'Maçã' at various maturation stages. They found that as the ripening progressed, acidity, soluble solids and sugars were increased. Yei et al. [2012], reported that sucrose, fructose and glucose were the main sugars at the ripe stage of bananas.

The malic acid and L-ascorbic acid content of the unripe and the ripe stages of banana pulp under open field and protected cultivation systems are given in Table 2. Malic and L-ascorbic acid contents were affected in the fruit ripening stage, however, the cultivation system only effected malic acid. The content of both acids was higher in the ripe stage compared to the unripe stage. The average content of malic acid increased between 0.15 to 0.70% and L-ascorbic acid 3.17 to 10.95 mg/100 g fruit weight (FW). The amount of malic acid varied 0.41–0.44 and L-ascorbic acid 7.09–7.03 for both cultivation systems. Liverani and

Table 1. Fructose, glucose, sucrose and total sugar content (%) in the unripe and the ripe stages of bananas under open-field and protected cultivation

Specification		Ripening stages		Cultivation system mean
		unripe	ripe	
fructose				
Cultivation system	open-field	1.60 B	2.97 A	2.29
	protected cultivation	1.59 B	3.01 A	2.30
Ripening stages mean		1.60 b	2.99 a	
$LSD_{\%5}$ ripening stages: 0.1132 $LSD_{\%5}$ cultivation system: NS $LSD_{\%5}$ ripening stages × cultivation system: 0.1601				
glucose				
Cultivation system	open-Field	1.52 C	2.91 A	2.22 a
	protected cultivation	1.63 C	2.50 B	2.05 b
Ripening stages mean		1.56 b	2.71 a	–
$LSD_{\%5}$ ripening stages: 0.0839 $LSD_{\%5}$ cultivation system: 0.0839 $LSD_{\%5}$ ripening stages × cultivation system: 0.1186				
sucrose				
Cultivation system	open-field	4.77 B	6.53 A	5.65
	protected cultivation	4.65 B	6.70 A	5.68
Ripening stages mean		4.71 b	6.62 a	–
$LSD_{\%5}$ ripening stages: 0.4020 $LSD_{\%5}$ cultivation system: NS $LSD_{\%5}$ ripening stages × cultivation system: 0.5685				
total sugars				
Cultivation system	open-field	7.87 B	12.41 A	10.14
	protected cultivation	7.86 B	12.50 A	10.18
Ripening stages mean		7.87 b	12.46 a	–
$LSD_{\%5}$ ripening stages: 0.1775 $LSD_{\%5}$ cultivation system: NS $LSD_{\%5}$ ripening stages × cultivation system: 0.2510				

Ripening stages × cultivation system means with the same capital letters is not significantly different ($P < 0.05$).
Ripening stages means with the same letter are not significantly different ($P < 0.05$).
NS: not significant.
Cultivation system means with the same letter are not significantly different ($P < 0.05$).

Table 2. Malic acid and L-ascorbic acid content (%) in the unripe and the ripe stages of bananas under open-field and protection cultivation systems

Specification		Ripening stages		Cultivation system mean
		unripe	ripe	
malic acid (%)				
Cultivation system	open-field	0.14 C	0.68 B	0.41 b
	protected cultivation	0.16 C	0.72 A	0.44 a
Ripening stages mean		0.15 b	0.70 a	–
$LSD_{\%5}$ ripening stages: 0.0196 $LSD_{\%5}$ cultivation system: 0.0196 $LSD_{\%5}$ ripening stages × cultivation system: 0.0278				
L-ascorbic acid (mg/100 g)				
Cultivation system	open-field	2.82 D	11.36 A	7.09
	protected cultivation	3.52 C	10.54 B	7.03
Ripening stages mean		3.17 b	10.95 a	–
$LSD_{\%5}$ ripening stages: 0.1472 $LSD_{\%5}$ cultivation system: NS $LSD_{\%5}$ ripening stages × cultivation system: 0.2082				

Explanations as in Table 1.

Cangini [1991] showed that there is an accumulation of malic acid in the fruit during growth and ripening. The malic acid concentration has been reported to increase three to seven fold during ripening [Wyman and Palmer 1964]. Stover and Simmonds [1987], reported that malic acid increased during the ripening. Wenkam [1990], reported that L-ascorbic acid values were 5.1 mg/100 g of fresh weight in Williams and 14.6 mg/100 g in Dwarf Brazilian bananas. Similar reports by Mustaffa et al. [1998], showed that L-ascorbic acid increased during the ripening progress. Arcila et al. [2002b], reported that the fruit characteristics of 'Dominico Harton' (*Musa* AAB Simmonds) plantain banana variety did not vary in various locations. Similar results reported by Forster et al. [2003] showed that no statistical differences were detected in L-ascorbic acid content of banana pulp under open-field and protected cultivation. Hernandez et al. [2006] reported as 7.15 mg/100 g ascorbic acid using HPLC technique in the ripe stages of bananas. Forster et. al. [2003] reported that an average AA as 11.5 ±3.3 mg/100 g in cv. Grand Enana, while Cano et al. [1997] found higher amounts: 33.2 ±0.6 mg/100 g. On the other hand, Leong and Shui [2002], found the AA content to be 2.1 ±0.8 mg/100 g in ripe bananas. In this study, the average content of vitamin C was 3.17 mg/100 g in unripe fruit while 10.95 mg/100 g in ripe fruit. Our results for Cavendish bananas (obtained by HPLC),

Table 3. Macro element levels (g/kg) in the unripe and the ripe stages of bananas under different cultivation systems

Specification		Ripening stages		Cultivation system mean
		unripe	ripe	
nitrogen				
Cultivation system	open-field	4.35 B	5.63 A	4.99
	protected cultivation	4.47 B	5.70 A	5.09
Ripening stages mean		4.41 b	5.67 a	–
$LSD_{\%5}$ ripening stages: 0.1813 $LSD_{\%5}$ cultivation system: NS $LSD_{\%5}$ ripening stages × cultivation system: 0.2564				
phosphorus				
Cultivation system	open-field	1.22 A	1.15 B	1.19
	protected cultivation	1.17 AB	1.17 AB	1.17
Ripening stages mean		1.20	1.16	–
$LSD_{\%5}$ ripening stages: NS $LSD_{\%5}$ cultivation system: NS $LSD_{\%5}$ ripening stages × cultivation system: 0.0666				
potassium				
Cultivation system	open-field	11.77 B	12.75 A	12.26 b
	protected cultivation	12.90 A	12.72 A	12.81 a
Ripening stages mean		12.34 b	12.74 a	–
$LSD_{\%5}$ ripening stages: 0.2914 $LSD_{\%5}$ cultivation system: 0.2914 $LSD_{\%5}$ ripening stages × cultivation system: 0.4122				
calcium				
Cultivation system	open-field	0.25	0.22	0.24
	protected cultivation	0.37	0.23	0.30
Ripening stages mean		0.31	0.23	–
$LSD_{\%5}$ ripening stages: NS $LSD_{\%5}$ cultivation system: NS $LSD_{\%5}$ ripening stages × cultivation system: NS				
magnesium				
Cultivation system	open-field	1.42 A	1.38 AB	1.40
	protected cultivation	1.40 AB	1.35 B	1.38
Ripening stages mean		1.41	1.37	–
$LSD_{\%5}$ ripening stages: NS $LSD_{\%5}$ cultivation system: NS $LSD_{\%5}$ ripening stages × cultivation system: 0.0608				

Explanations as in Table 1.

Table 4. Micro element levels (mg/kg) at different ripening stages of bananas under different cultivation system

Specification		Ripening stages		Cultivation system mean
		unripe	ripe	
iron				
Cultivation system	open-field	25.18	27.55	26.37
	protected cultivation	26.25	27.85	27.05
Ripening stages mean		25.72	27.70	–
$LSD_{\%5}$ ripening stages: 0.1132 $LSD_{\%5}$ cultivation system: NS $LSD_{\%5}$ ripening stages × cultivation system: 0.1601				
zinc				
Cultivation system	open-field	6.05 B	4.28 C	5.17 b
	protected cultivation	6.64 A	6.26 AB	6.45 a
Ripening stages mean		6.35 a	5.27 b	–
$LSD_{\%5}$ ripening stages: 0.3937 $LSD_{\%5}$ cultivation system: 0.3937 $LSD_{\%5}$ ripening stages × cultivation system: 0.5567				
manganese				
Cultivation system	open-field	7.85 A	6.34 B	7.10 a
	protected cultivation	5.08 C	5.03 C	5.06 b
Ripening stages mean		6.47 a	5.69 b	–
$LSD_{\%5}$ ripening stages: 0.2285 $LSD_{\%5}$ cultivation system: 0.2285 $LSD_{\%5}$ ripening stages × cultivation system: 0.3232				
copper				
Cultivation system	open-field	5.99 AB	5.81 B	5.90
	protected cultivation	6.71 A	6.27 AB	6.49
Ripening stages mean		6.35	6.04	–
$LSD_{\%5}$ ripening stages: NS $LSD_{\%5}$ cultivation system: NS $LSD_{\%5}$ ripening stages × cultivation system: 0.8896				

Exlanation as in Table 1.

Table 5. Fat and fatty acid content (%) of unripe and ripe bananas under protected and open field conditions

Fatty acids	Fat	Cultivation systems			
		open-field		protected	
		unripe	ripen	unripe	ripe
Average		0.07 ±0.01	0.11 ±0.02	0.08 ±0.02	0.11 ±0.01
Myristic acid	C14:0	1.11 ±0.03	n.d.	2.07 ±0.06	0.46 ±0.00
Palmitic acid	C16:0	28.5 ±0.11	32.03 ±0.12	28.04 ±0.67	34.59 ±0.40
Heptadecanoic acid	C17:0	0.12 ±0.01	0.31 ±0.00	n.d.	n.d.
Stearic acid	C18:0	2.58 ±0.01	1.74 ±0.04	2.33 ±1.03	1.18 ±0.00
Arachidic acid	C20:0	0.07 ±0.00	1.23 ±0.02	0.63 ±0. 52	0.31 ±0.01
Behenic acid	C22:0	n.d.	0.78 ±0.03	n.d.	1.71 ±0.04
∑SFA		30.83	36.28	33.07	36.23
Palmitoleic acid	C16:1	4.50 ±0.05	2.07 ±0.01	4.22 ±0,04	3.79 ±0.00
Oleic acid	C18:1n9	7.97 ±0.07	6.51 ±0.06	5.11 ±0.3	4.56 ±0,11
∑MUFA		12.47	8.51	9.40	7.50
Linolenic acid	C18:2n6	26.15 ±0.47	18.90 ±0.04	28.87 ±2.99	24.97 ±0.34
α-Linoleic acid	C18:3n3	15.54 ±0.87	23.98 ±0.03	13.20 ±2.78	28.46 ±0.30
cis-5.8.11.14.17-Eicosapentaeonic acid	C20:5n3	0.12 ±0.01	n.d.	1.28 ±0.30	n.d.
∑PUFA		44.81	46.88	39.65	50.95

n.d. – not detected

are similar to previous studies and ranged from 2.1 to 18.7 mg/100 g [Wenkam 1990, Leong and Shui 2002]. Yei et al. [2012], reported that malic acid is the main organic acid in the ripe stage of bananas.

Mineral composition. The results for the macro-elements (N, P, K, Ca and Mg) and micro elements (Fe, Zn, Mn and Cu) content in two ripening stages of bananas for both cultivation systems, are given in Table 3 and Table 4. Potassium was higher in both ripening stages followed by nitrogen, magnesium, phosphorus and calcium (Tab. 3). Iron was about four times higher than the other micro-elements. Bananas are a good source of mineral supplement in human diets [Adeyemi and Oladiji 2009]. The daily adequate intake amount of potassium for adults is 4700 mg [IOM 2001]. Therefore, 100 g of banana fruit provides 7% of the K requirement for the average adult. Banana pulp is rich in K and is a good source of phosphorus, magnesium and calcium [Wenkam 1990, Emaga et al. 2007]. Climate conditions, cultural applications and sample position (external, central and internal) can also affect mineral composition of banana pulp. Adeyemi and Oladiji [2009], studied the mineral element composition of banana pulp in various ripening stages and similar to our results, they found that nutritional composition of banana pulp varied according to the ripening stage.

Lipid and faty acid composition. The composition of lipid and fatty acid of bananas in the unripe and the ripe stages under protected and open field conditions, are given in Table 5. The fatty acid compositions as saturated (SFAs), monounsaturated (MUFAs) and polyunsaturated (PUFAs) fatty acids were different in the unripe and the ripe stages of bananas. The lipid content increased during the ripening stages. The percentage of SFAs increased during the ripening progress (Tab. 5). Among SFAs, palmitic acid was detected as the major one and as for the MUFAs, oleic acid was the highest fatty acids, respectively. Similar to our results, Zhu et al. [2006] reported that palmitic, linoleic and linolenic acids were detected as the main fatty acids. SFAs and PUFAs fatty acids increased during the ripening progress while MUFAs fatty acid was found higher in the unripe stage.

Very few studies have been previously published on fatty acid composition in bananas in comparison between protected and open field cultivation. Similar results were reported by Stover and Simmonds [1987] who detected 0.12% of lipids in ripe fruit however, Gowen [1995] implied that ripe bananas consisted 0.30% lipids in ripe fruit. Cardanette [2006], reported that starch is converted to saturated fatty acids during the ripening process.

CONCLUSION

The experimental results showed that many of the physico-chemical characteristics were affected in the ripening stages of the fruit. On the other hand, only a few criteria were affected by the cultivation system. Sucrose was found as the most abundant sugar followed by fructose and glucose in both the unripe and the ripe stage. The concentration of potassium and iron were found to be the highest among the macro and micro-elements in both ripening stages. The values of fatty acids were lower in the unripe stage compared to the ripe stage. SFAs and PUFAs were found higher in the ripe stage and MUFs was found higher in the unripe stage for both the cultivation systems.

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