



## Sugar Accumulation Pattern and Contents in Developing Fruits of two Iranian Melon Cultivars

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### Abstract

Soluble sugar accumulation pattern and contents were studied in two Iranian melon cultivars, 'Suski Sabz' and 'Jalali Zard' (*Cucumis melo* L. Inodorous). Sucrose, glucose and fructose contents were determined in different mesocarp tissues of developing fruits during days after pollination (DAP). They were characterised by enhanced accumulation of glucose and fructose during early fruit developmental stages with almost no sucrose detectable. A sharp increase in sucrose occurred from DAP 30 and 40 in 'Jalali Zard' and 'Suski Sabz', respectively. Then, both glucose and fructose showed a steady decrease with fruit maturation. In mature fruits of both cultivars, an obvious gradient of sucrose accumulation was detected, ascending from pedicel to middle and umbilicus part of mesocarp. Also both cultivars could be considered as high sucrose accumulators. The present results might be useful for future studies on improvement of melon fruit quality.

**Keywords:** Soluble sugars; Mesocarp; Days after pollination; Iranian melons

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### Introduction

Melon is one of the economically important and widely cultivated fruit crops in the world. Iran is the third largest melon-producing country in the world with 1.2 million t/year of fruit

production (FAOSTAT, 2008). Fruit sweetness is the major determinant of fruit quality, and assessing the marketing value in melons reflects the concentration of the three major soluble sugars, *i.e.* sucrose, glucose and fructose, in the fruit flesh (Li et al., 2006). More than 97% of the total soluble solids in melon fruits are soluble sugars, of which sucrose is the predominant sugar

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present in the ripened fruits, accounting for 50% of the total soluble sugars (Pharr, 1994). Also, relative contents of sucrose, glucose and fructose change as the melon fruits mature. In addition, Mizuno et al. (1971) showed that different parts of the flesh of muskmelons have different sugar compositions.

Wide genetic variation in sugar content and composition of melon fruits has been reported. Interestingly, genotypes that accumulate high amount of total sugars are those that accumulate high amount of sucrose, while genotypes having fruits with low total sugar content do not accumulate sucrose (Stepansky et al., 1999). Also Ranwala et al. (1992) found in young muskmelon (10-20 days after pollination) that glucose and fructose (i.e. hexoses) are the only soluble sugars detected in fruits. Conversely, in some genotypes, sucrose accumulation is accompanied by a reduction in the concentration of glucose and fructose, suggesting that the accumulated sucrose is synthesised from available glucose and fructose (Chrost and Schmitz, 1996). Yativ et al. (2010) reported that within the genus *Citrullus* there are genotypes accumulating a high percentage of sucrose in the fruit, while others accumulate high percentages of glucose and fructose.

Long et al. (2004) showed that in orange-fleshed melon (*Cucumis melo* L. *reticulatus* group) glucose and fructose contents were similar, and increased from 160 to 200 mg/g DW during the initial 3 weeks of fruit development, but then decreased reaching about 150 mg/g DW at fruit abscission. They also showed that sucrose content was very low during early fruit development (0-10 mg/g DW), but substantially increased within the last 3 weeks reaching the level equal to that of hexoses.

Zhang and Li (2004) compared sugar accumulation pattern and composition of two Chinese melon varieties 'Huang jingua' and 'Yuegua' and reported that in different parts of young fruits, both glucose and fructose increased during early fruit development with almost no sucrose detectable. The sucrose accumulation was observed at fruit maturation stage in 'Huang jingua' while no such transition was reported for 'Yuegua'. Fructose was the main sugar in both varieties.

So far, less information is available about sugar-accumulation pattern and contents in developing fruits of Iranian melons. The goal of the present work is to study the changes in individual soluble sugar contents during fruit developmental stages until fruit maturation and to compare the sugar accumulation pattern in two Iranian melon cultivars.

## Materials and Methods

### Plant material and growth conditions

The experiments were conducted in the greenhouse in Paris-Sud XI University (Orsay, France) with two commercial Iranian melons, 'Suski Sabz' and 'Jalali Zard' (*Cucumis melo* L. Inodorous group). 'Suski Sabz' and 'Jalali Zard' have dark green and yellow fruits colours respectively (Fig. 1). Both cultivars have oval large-sized fruits weighing approximately 3 kg per fruit at harvest time. The seeds for experiments were collected from Iranian farmers in Garmsar. For early production, a transplant procedure was carried out. The seeds were sown in pot so that they produce 2 to 4 true leaves. After that, they were taken to the greenhouse bed. The cultivation conducted from June to September 2010. After pruning (cutting the main stem), all plants were



Fig. 1. Iranian melon cultivars studied; 'Suski Sabz' (left) and 'Jalali Zard' (right).

trained to two lateral branches and only 2 fruits per plant were allowed to set (i.e. one fruit per lateral branch) on similar node (7<sup>th</sup> node position). Female flowers on the selected position were hand-pollinated to get fruits and other flowers were removed. This method of thinning-pruning procedure is indigenous to Iran context which is traditionally practiced by Iranian melon producers.

Three fruits were analysed for each DAP (days after pollination) and each cultivar. Fruits were harvested at 5-day intervals starting from DAP 0 (pollination day) until fruit maturity (DAP 50 and 60 for 'Jalali Zard' and 'Suski Sabz', respectively). Each sampled fruit was divided in three edible parts: pedicle (mesocarp close to peduncle), middle part of mesocarp and distal part close to umbilicus. Samples were immediately frozen in liquid nitrogen, stored at  $-80^{\circ}\text{C}$  until they were freeze-dried and then finely ground with a Retsch MM200 mortar (Bioblock Scientific, Illkirch, France) to obtain dry powder.

### Analysis of soluble sugar contents

An aliquot of 30 mg of dry powder was suspended with 1 ml of fresh distilled water in an Eppendorf tube, vortexed and maintained in ice for 60 min (vortexed again every 10 min). After 15 min centrifugation at 14000g at  $5^{\circ}\text{C}$ , water soluble fraction was heated at  $100^{\circ}\text{C}$  for 5 min and then kept in ice for 30 min to precipitate the heat-denatured proteins, which were then removed after centrifugation at 14000g for 5 min at  $5^{\circ}\text{C}$ . The protein-less water soluble fraction (supernatant) was filtered (filter HV 0.45  $\mu\text{m}$  type, Nihon Millipore Kogyo K.K, Japan). Individual soluble sugar contents in filtered extracts were determined by HPLC analysis on 20  $\mu\text{l}$  aliquots applied to a Sugar-Pak1 column (6.5 mm diameter and 300 mm length, Waters, U.S.A). The flow rate was maintained at  $0.5\text{ ml min}^{-1}$ , the pressure at 700 psi and the temperature of the column at  $90^{\circ}\text{C}$ . The sugar peaks (sucrose, glucose and fructose) were evidenced by refractometry (IOTA-2 refractometer, Precision Instruments, Marseilles, France). Commercial sugars were used at different concentrations (0.1, 0.25, 0.5, 1 and 1.5 mg/ml) to obtain the HPLC calibration curves for each sugar form.

### Results

The soluble sugars of melon fruits ('Jalali Zard' and 'Suski sabz') were measured from DAP 0 until fruit maturity. Fruits of 'Jalali zard' and 'Suski Sabz' were mature at DAP 50 and 60, respectively.

In both cultivars, sucrose level was very low and almost did not or only slightly change during the first days of fruit developmental stages, whereas both glucose and fructose contents increased rapidly during the first fruit developmental stages and then decreased until fruit maturation (Fig. 2). In both cultivars, for each sugar, the 3 mesocarp parts show similar accumulation pattern and similar contents, the latter increased in mesocarp from peduncle to the umbilicus (Table 1).

### Sugar accumulation in different parts of mesocarp

In pedicel mesocarp of 'Suski Sabz', both glucose and fructose began to increase strongly during the first 5 weeks of fruit development until DAP 30 (Fig. 2A). Thereafter, they both increased more slightly until DAP 40 and then decreased until fruit maturation (Fig. 2A). While no sucrose was detectable in developing fruits at DAP 35, its accumulation started at DAP 40 and rapidly increased until fruit maturity, reaching the values of glucose and fructose at DAP 60 (Fig. 2A). In the middle and umbilicus mesocarps of 'Suski Sabz', fructose and glucose contents also increased until DAP 40, and then decreased with fruit maturity (Fig. 2B). In contrast to glucose and fructose, sucrose content was low until DAP 35. Thereafter a sharp increase was observed, reaching its highest value at fruit maturity (Fig. 2C). In pedicel mesocarp of 'Jalali Zard' cultivar, hexose (*i.e.* fructose and glucose) contents increased from DAP 0 to 35 and DAP 40, respectively, then both sugars decreased with fruit maturation (Fig. 2D). In pedicel mesocarp, sucrose level was very low at first 30 DAP and increased sharply until fruit maturation (Fig. 2D). In middle and umbilicus mesocarp parts, both glucose and fructose showed a rapid increase until DAP 35, and then they decreased with fruit maturity (Fig. 2E and F). In contrast, no sucrose accumulation was found before DAP 30. At fruit maturation stage, sucrose content was the highest in both fruit parts (Fig. 2E and F).

In three mesocarp parts of mature fruits in 'Suski Sabz', sucrose level reached a maximum value of  $266 \pm 32\text{ mg/g DW}$  in umbilicus part,

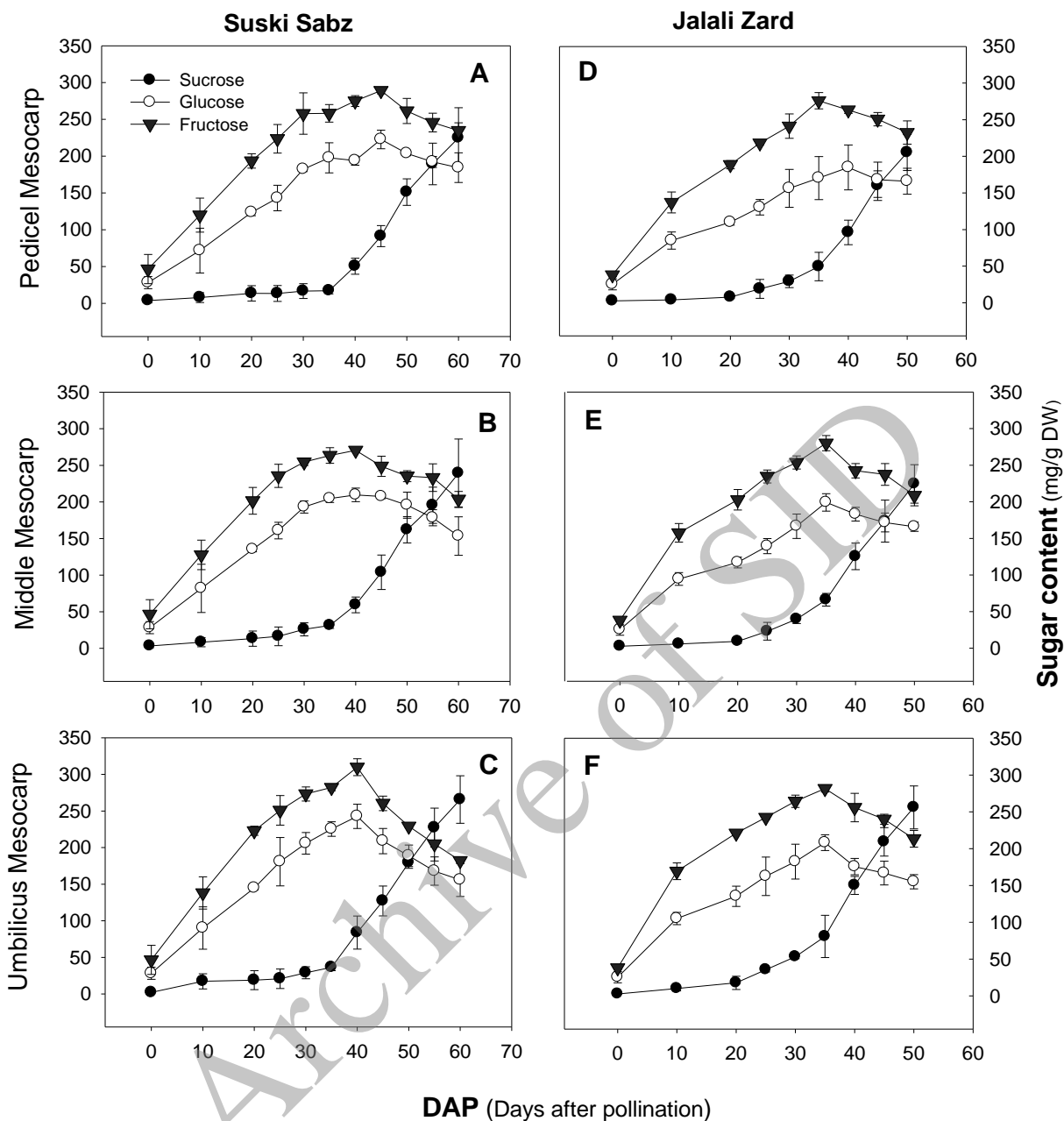


Fig. II. Individual soluble sugar accumulation pattern in pedicel mesocarp (A, D), middle mesocarp (B, E) and in umbilicus mesocarp parts (C, F) of two Iranian melon cultivars ('Suski Sabz': left side panels and 'Jalali Zard': right side panels) during fruit development (days after pollination). Different symbols correspond to different sugar forms: sucrose (closed circles), fructose (triangles) and glucose (open circles). Each data point represents mean value ( $\pm$  SE) of all replications of DAP and three mesocarp parts of fruits in both cultivars ( $n=81$  and  $n=90$  for 'Jalali Zard' and 'Suski Sabz', respectively).

followed by  $239 \pm 47$  mg/g DW in middle part and  $225 \pm 41$  mg/g DW in pedicel. In 'Jalali Zard' the contribution of sucrose was  $256 \pm 29$  mg/g DW in umbilicus,  $224 \pm 26$  mg/g DW in middle part and  $205 \pm 25$  mg/g DW in pedicel (Table 1).

For both cultivars, in pedicel part of mature fruits, fructose was the most abundant sugar ( $238 \pm 10$  and  $232.5 \pm 15$  mg/g DW in 'Suski Sabz' and 'Jalali Zard', respectively) followed by sucrose and glucose, whereas in the middle and

Table 1

Comparison between sucrose, glucose and fructose contents in different mesocarp parts of mature melon fruits in 'Jalali Zard' and 'Suski Sabz'. Data correspond to means of (n=81 and n=90 for 'Jalali Zard' and 'Suski Sabz', respectively) measurements  $\pm$ SE. ( $P < 0.01$ ).

	Suski Sabz			Jalali Zard		
	Pedicle	middle	umbilicus	pedicle	Middle	Umbilicus
Glucose	184.4 $\pm$ 20	153.3 $\pm$ 26	155.8 $\pm$ 23	166 $\pm$ 18	166 $\pm$ 6	155 $\pm$ 10
Fructose	234.8 $\pm$ 10	203.7 $\pm$ 10	182.1 $\pm$ 3	232.5 $\pm$ 16	208.6 $\pm$ 14	213.3 $\pm$ 11
Sucrose	224.8 $\pm$ 41	239.2 $\pm$ 47	265.6 $\pm$ 32	205.3 $\pm$ 24	224.4 $\pm$ 26	256 $\pm$ 29

umbilicus parts sucrose was the most abundant sugar followed by fructose and glucose (Table 1).

## Discussion

Sweetness (*i.e. sugar content*) is the most important factor determining the eating quality of melon fruits (Mutton et al., 1981). Changes in individual soluble sugar contents during fruit developmental stages until fruit maturation and sugar accumulation pattern have been studied in two Iranian melon cultivars. In the present study, we analysed soluble sugar contents in fruits harvested at 5-day intervals starting from DAP 0 until fruit maturity (DAP 50 and 60 for 'Jalali Zard' and 'Suski Sabz', respectively) in three edible parts of fruit mesocarp *i.e.* pedicle, middle part of mesocarp and umbilicus. Our results showed that hexoses (glucose and fructose) were the main soluble sugars in mesocarp tissues at the first stages after pollination. Sucrose content was very low during early fruit development (between DAP 0 and 30-35), but increased substantially within three weeks. This is consistent with the results of Ranwala et al. (1992), who indicated that in young muskmelon fruits (DAP 10-20), glucose and fructose were the only soluble sugars detected. We showed that the amount of sucrose in the middle and umbilicus parts of mesocarp tissues of mature melon fruits was markedly higher than glucose and fructose (Table 1). Also as reported by many researchers, sucrose is the predominant sugar present in the ripened fruits of melon, accounting for 50% of the soluble sugars (Lester and Dunlap 1985; Pharr 1994; Lester et al. 2001). In contrast to our results, Zhang and Li (2004) found in the Chinese melons that fructose was the predominant sugar. Also, relatively low levels of

sucrose in a few orange-fleshed cantaloupes have been reported (Lingle and Dunlap, 1987; Stepansky et al., 1999).

In accordance with the decline of glucose and fructose levels, sucrose concentration rapidly increased during the last stages of fruit development. Although source leaf photosynthetic activity and fruit position on the stem play a role in determining the assimilate supply to melon fruit (Barzegar et al. 2013), the accumulation of sucrose appears to be controlled by the metabolism of carbohydrates in the sink (*i.e.* fruits) itself (Lester et al. 2001). Chrost and Schmitz (1996) suggested that the accumulated sucrose is synthesised from available glucose and fructose. On the other hand, the changes in the sugar composition of developing fruits corresponded to changes in the activity of sucrose metabolising enzymes (Lingle and Dunlap, 1987). They showed that during early period of fruit development, acid and neutral invertase (AI) activities were high, and sucrose phosphate synthase (SPS) activity was low. As fruits matured, relative increase in sucrose content occurred associated with decline in invertase activity and increase in SPS activity (Lingle and Dunlap, 1987).

Hubbard et al. (1991) showed that sucrose accumulation in melon fruits was characterised by a developmental increase in SPS activity, in addition to the developmental loss of AI activity. Lester et al. (2001) confirmed the importance of the loss in AI activity and the increase in SPS activity in two sweet melon cultivars and emphasised particularly the necessity for SPS activity to be higher than that of AI. Also Burger et al. (2007) indicated Sucrose accumulation in the developing fruits of *Cucumis melo* began only

when AI activity declined to less than an experimentally determined threshold value, and continued until removal of the fruit from the plant. In addition, the activities of sucrose phosphate synthase, sucrose synthase and neutral invertase were all positively correlated with sucrose accumulation among the genotypes.

Yativ et al. (2010) reported that sugar composition in watermelon, as in all cucurbit fruits, includes sucrose, fructose and glucose. They indicated that, within the genus *Citrullus*, there are genotypes that accumulate a high percentage of sucrose in fruits, while others accumulate glucose and fructose.

Our results indicate that there is a significant ( $P \leq 0.01$ ) difference in sugar accumulation (*i.e.* glucose, fructose and sucrose) among mesocarp parts, ascending from pedicel to middle and umbilicus parts (Fig. 3A and D). This result is consistent with that of Mizuno et al. (1971) who showed that different parts of the flesh of muskmelon have different sugar compositions. The pattern of sugar accumulation in both cultivars, 'Suski Sabz' and 'Jalali Zard', was similar with sharp increase of glucose and fructose in early fruit developmental period and rapid sucrose enhancement accompanied by detectable decline in reducing sugars at the later stages until fruit maturation.

Developmental studies have shown that total sugars, especially sucrose, increased sharply in muskmelon fruits approximately 15 day prior to full-slip (Lester and Dunlap, 1985). The relative contents of sucrose, glucose, and fructose also change as the melons mature. Kano (2009) suggested a relationship between cell size and the form of sugar accumulated in melon fruits. As small cells have potentialities to develop further, the cells suppress sucrose synthesis in the fruits and preferentially accumulate glucose and fructose, which are immediately utilised for cell development. On the other hand, sucrose is accumulated preferentially as a reserve substance in larger and fully developed cells because of no need to save glucose and fructose for their further development.

## Conclusion

'Suski Sabz' and 'Jalali Zard' had different development lengths, *i.e.* about 10 days longer for

'Suski Sabz' compared with 'Jalali Zard'. So, sugar contents during days after pollination were different between cultivars, but sugar change patterns were similar. In both cultivars, glucose and fructose contents rapidly increased during first DAPs and then decreased with fruit maturity. In contrast, sucrose content was low until DAP 30-35 and then strongly increased with fruit maturity. The results indicate changes in the relative contents of sucrose, glucose, and fructose as the melon fruits mature. Also both cultivars are characterised with low sucrose content during fruit development but accumulating high amounts in mature fruits. In both cultivars, sugar concentrations were different in fruit parts. The highest and lowest sugar concentrations were found in umbilicus and pedicel parts, respectively. Pattern of soluble sugar accumulation in Iranian melon fruits have not been studied in detail yet, therefore the results of present study might have implications for future studies in improving melon fruit quality

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## مروری مطالعه الگوی تجمع قندها در طول نمو میوه خربزه ایرانی

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### چکیده فارسی

الگوی تجمع قندها در دو توده خربزه ایرانی، "سوسکی سبز" و "زردجلالی" بررسی شد. محتوای قندهای ساکارز، گلوکز و فروکتوز در بافت‌های مختلف مزوکارپ در طول نمو میوه در طی روزهای پس از گرده‌افشانی اندازه‌گیری شد. در طی مراحل اولیه نمو میوه، مقدار گلوکز و فروکتوز سریعاً افزایش یافت و غلظت ساکارز بسیار پایین بود. یک افزایش سریع در غلظت ساکارز، ۳۰ و ۴۰ روز بعد از گرده‌افشانی به ترتیب در "زرد جلالی" و "سوسکی سبز" اتفاق افتاد. سپس، گلوکز و فروکتوز با بلوغ میوه کاهش یافتند. در هر دو توده، یک شیب افزایشی ساکارز و قندهای احیاء از سمت مزوکارپ دم‌میوه به مزوکارپ میانی و مزوکارپ نوک میوه، مشاهده شد. در زمان رسیدن، ساکارز قند غالب بوده که شاخص شیرینی در خربزه‌ها می‌باشد. مطالعه حاضر می‌تواند برای مطالعات بعدی در جهت بهبود کیفیت میوه خربزه مفید باشد.

**کلمات کلیدی:** خربزه ایرانی، مزوکارپ، روزهای پس از گرده‌افشانی، خربزه ایرانی.