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Preliminary communication

EFFECT OF WATER SUPPLY ON SUGAR CONCENTRATION OF CARROT

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Carrot is an important source of sugars. The objective of this study was to investigate the effects of water supply (precipitation + irrigation) on the concentration and ratio of fructose, glucose, and sucrose in carrot. Irrigation did not decrease the dry matter content and the summed concentration of the three measured sugars. Glucose accumulation was not influenced either by irrigation or by year. Low amount of precipitation during the early growing period was detrimental for fructose accumulation. Irrigation enhanced sucrose concentration, presumably by ensuring better photosynthetic activity. However, dry and hot weather during the irrigation cut-off period in 2011 also resulted in increased sucrose accumulation, presumably as a stress effect. It was found that irrigation did not influence the ratio of the three investigated saccharides at all, and even the growing year had just a slight effect on that.

Keywords: irrigation, fructose, glucose, sucrose, dry matter content

Carrot (*Daucus carota* L.) is the most important root vegetable, which is extensively cultivated for both fresh market and processing industry (RUBATZKY et al., 1999). Due to its favourable nutritional characteristics carrot has become one of the leading vegetable materials for functional food products (ARSCOTT & TANUMIHARDJO, 2010). Carbohydrates can make up as much as 75% of the dry matter of carrot roots (ARSCOTT & TANUMIHARDJO, 2010). However, its starch content is generally very low (RUBATZKY et al., 1999). The main soluble sugars in carrots are glucose, fructose, and sucrose, with sucrose being present in the biggest ratio. In carrot root, accumulation of hexoses predominates during the early part, while sucrose accumulates during the second half of the growing period (STEINGRÖVER, 1983; NILSSON, 1987; BUFLER, 2013). Beside terpene compounds, sugar composition determines the flavour of raw carrot (TÓTH-MARKUS & TAKÁCS-HÁJOS, 2001). NILSSON (1987) concluded that accumulation of sucrose seems to be under the influence of environmental factors in contrast to the amount of hexoses. Appropriate soil moisture throughout the growing season is one of the most important production requirements for umbelliferous vegetables (RUBATZKY et al., 1999). Irrigation can result in lower carrot dry matter and monosaccharide content (GASIOROWSKA & CEGLAREK, 1996; ALAM et al., 2010), while TÓTH-MARKUS & TAKÁCS-HÁJOS

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(2001) found that irrigation had almost no influence on the sugar content of carrot root. Potassium is involved in sugar and starch formation in umbelliferous vegetables (RUBATZKY et al., 1999). Irrigation can improve potassium availability in soils, as it strongly depends on soil water content (MARSCHNER, 1995).

The objective of this study was to investigate the effects of irrigation on the concentration and ratio of fructose, glucose, and sucrose in orange coloured carrot root, during two years with significantly different precipitation conditions.

1. Materials and methods

1.1. Experimental conditions, plant material, and treatments

Experiments were conducted during 2010 and 2011 in the Experimental Farm of the Institute of Horticulture, Szent István University, Gödöllő, Hungary (47°61' N, 19°32' E). The soil of the experimental site is a loamy sand classified as Cambisol, having a pH of 7.20 and 7.13, electric conductivity of 0.25 and 0.26 dS m^{-1}, and contained 1.61 and 0.91% of organic matter, as well as 15 and 16 mg kg^{-1} water soluble NO_3-N, 1640 and 868 mg kg^{-1} ammonium-lactate soluble P_2O_5, 456 and 384 mg kg^{-1} ammonium-lactate soluble K_2O in 2010 and in 2011, respectively. Climatic data were recorded by a Campbell CR21X meteorological instrument (Campbell Scientific Inc., Loughborough, U.K.). Average air temperature for the growing period was higher by 0.7 °C in 2011 compared to that in 2010 (18.3 °C); especially the pre-harvest period in September was much warmer and drier (Table 1). The amount of precipitation was strikingly different, 576 mm in 2010 and just 190 mm in 2011.

Table 1. Meteorological data of the growing periods. Gödöllő, 2010–2011

Year	Sowing–April 30	May	June	July	August	September 1–Harvest
			Average air temperature (°C)			
2010	10.7	15.5	18.8	22.7	20.0	14.8
2011	12.0	15.8	20.1	19.9	21.3	19.6
			Precipitation (mm)			
2010	36.2	190.0	149.5	51.1	49.0	99.8
2011	18.4	31.0	60.8	67.5	11.8	0.5

Seeds of the orange-fleshed, storage type carrot cultivar 'Bangor' (Bejo Zaden B.V., Warmenhuizen, the Netherlands) were sown on 8th April 2010 and on 7th April 2011 into 20 cm high ridges. Distance between centres of ridges was 70 cm. Seeds were seeded in two rows about 10 cm apart at a seeding rate of 50 seeds per metre. Fertilizers were applied at the total rate of 80–15–125 kg ha^{-1} N-P-K. Carrots were harvested on 15th September and on 20th September in 2010 and in 2011, respectively.

A rain-fed control and an irrigated treatment were compared. A randomized experimental design was used with four replications. Every plot was comprised of five ridges, and had an area of 42 m^2. Sampling was done on the middle 8 m of the central ridge of each plot. To ensure adequate plant establishment, both treatments were irrigated during the first 21 days of the growing period, with a total amount of 15 mm and 20 mm of water in 2010 and in 2011, respectively. Later, the rainfed plots were not irrigated at all. For the treated plots, irrigation was carried out with sectorial overhead sprinkler system, and was started when the soil water tension reached 30 kPa. An irrigation cut-off period was planned for the last three weeks of the growing period. In 2010 just three irrigations were necessary during a rainless period in July, with a total amount of 69 mm. In 2011 eleven irrigations were applied with a total amount of 238 mm.

1.2. Analytical measurements

From each plot a one-kilogram sample was selected for chemical analysis. Dry matter was measured after freeze drying of homogenized carrot roots. As dry matter content was significantly affected by the treatments, concentration of individual sugars was expressed on dry-weight (DW) basis to ensure better comparability among different years and treatments.

For measurement of soluble sugars, carrot samples were homogenized and stored at –80 °C until analysis. For the HPLC analysis a Perkin-Elmer (Perkin-Elmer Inc., Waltham, MA, USA) system was used that consisted of a binary LC pump, a column thermostat and a refractive index detector. The column was Shodex, Asahipak NH2 P-50 (25 cm×4.6 mm). The eluent was a mixture of acetonitrile–water (30:70) and an isocratic elution was used. The injected amount of the sample was 20 µl. Further chromatographic conditions were the following: column heat control 35 °C, flow rate 1 ml min^{-1}. For the qualification and quantification of different sugar components (fructose, glucose, and sucrose) a standard curve and Total Chrom Navigator 6.3 (Perkin-Elmer Inc., Waltham, MA, USA) analysing software were used.

1.3. Statistical analysis

Data were compared by two-way analysis of variance with irrigation treatment, year, and treatment × year as main effects. Mean separations were performed using Fisher's protected least significant difference test at $P \leq 0.05$. Correlation and regression analyses were performed using SPSS 22 software (IBM Co., Armonk, NY, USA).

2. Results and discussion

Concentrations of fructose and glucose expressed on DW basis were affected significantly neither by irrigation nor by year (Table 2). Fructose concentration for the rainfed treatment in 2011 was significantly lower than in the other three cases, due to the significant effect of the irrigation × year interaction. In this study, glucose concentration was very stable, its synthesis and accumulation was not influenced by either factors (Table 2). On the other hand, for fructose accumulation, the very low amount of precipitation during the early growing period in 2011 was clearly detrimental.

The tendency for sucrose data was different from that of the two hexoses. Both irrigation and year affected sucrose concentration; irrigation has significantly increased it (Table 2). Under dry conditions, irrigation results in larger canopy and presumably higher photosynthetic activity compared to the rainfed conditions. Hence, accumulation of sucrose and other storage carbohydrates in the root, as a storage organ, becomes higher during the growing period. On the other hand, sucrose concentration was significantly higher in 2011 than in 2010 (Table 2). The pre-harvest, irrigation cut-off period was unusually warm and dry in 2011 (Table 1), and

Table 2. Effect of growing year and irrigation on the dry matter content and fructose, glucose, and sucrose concentrations of carrot cv. Bangor

Treatment	Dry matter	Sum of the three sugars		Concentration (g kg^{-1} DW)			Ratio from the sum (weight %)		
	(g kg^{-1} FW)	(g kg^{-1} FW)	(g kg^{-1} DW)	fructose	glucose	sucrose	fructose	glucose	sucrose
Rainfed 2010	106c	55.3c	523b	126a	186	211b	24.0a	35.5	40.4
Irrigated 2010	118bc	65.1b	551b	116a	173	262a	21.1ab	31.5	47.5
Rainfed 2011	129b	68.5b	531b	89b	193	249ab	16.8c	36.3	46.9
Irrigated 2011	177a	107.0a	606a	123a	191	293a	20.2b	31.4	48.4
Rainfed average	117	61.9	527	107	190	230	20.4	35.9	43.7
Irrigated average	147	86.1	579	119	182	278	20.6	31.5	47.9
Significance	<0.001	<0.001	<0.001	N.S.	N.S.	<0.05	N.S.	N.S.	N.S.
2010 average	112	60.2	537	121	180	237	22.5	33.5	44.0
2011 average	153	87.8	569	106	192	271	18.5	33.9	47.6
Significance	<0.001	<0.001	<0.05	N.S.	N.S.	<0.05	<0.01	N.S.	N.S.
Irrigation × year significance	<0.01	<0.001	<0.05	<0.05	N.S.	N.S.	<0.05	N.S.	N.S.

a,b,c: means sharing the same letter for a single parameter do not differ significantly at P≤0.05 according to Fisher's protected least significant difference test; N.S.: not significant sucrose is the predominant sugar mobilised from starch in case of stress conditions (Kovács et al., 2007; Bufler, 2013). We presume that higher rate of sucrose resynthesis during the cut-off period was the reason of higher sucrose concentrations in 2011. However, based on the data of both years, we could not find any correlation between the amount of water supply and DW based total concentration of fructose, glucose, and sucrose (R^2=0.003, N=16, N.S.).

Fructose, glucose, and sucrose have accounted for 52 to 60% of the whole dry matter content (Table 2) in agreement with the results of Nilsson (1987). A very strong positive correlation was found between fresh weight based total concentration of these three saccharides and dry matter content (y= 0.712x–20.3; R^2=0.971, N=16, P<0.001). Correlation between these parameters was not affected either by year or by irrigation. As concentrations of hexoses were not influenced significantly by the treatments, tendencies of the summed concentrations of the three measured sugars and of dry matter content were similar to that of the sucrose data, being significantly higher for the irrigation treatment and for 2011 (Table 2).

Ratio of the three investigated saccharides was relatively stable. Ratios of sucrose and glucose were not influenced either by year or by irrigation (Table 2). Ratio of fructose became significantly lower in 2011, mainly because of the very low value for the rainfed treatment in that year.

3. Conclusions

Irrigation did not decrease dry matter and sugar contents of carrot root in our experiment. We presume that sucrose accumulation played a key role in this process. Based on the measurement results we can state that irrigation did not affect the ratio of fructose, glucose, and sucrose in carrot root, and even the year did not have a pronounced effect on that. This could be an important factor from the viewpoint of the manufacture of functional food products, where the relatively stable composition of the raw material has a much bigger importance than in case of conventional food products.

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