Gartenbauwissenschaft, **67** (6). S. 225–233, 2002, ISSN 0016–478X. © Verlag Eugen Ulmer GmbH & Co., Stuttgart

Seasonal Changes in Fructose, Glucose and Sucrose Content of Bark Tissues of Hazelnut Grown in the Black Sea Region

Jahreszeitlich bedingte Veränderungen des Fruktose-, Glukose- und Saccharosegehalts im Rindengewebe von Haselnusssorten aus dem Schwarzmeerraum

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Summary

The seasonal changes of total carbohydrates, fructose, glucose and sucrose of the bark tissues of 'Tombul', 'Palaz', 'Kalınkara', 'Çakıldak' and 'Sivri' cvs. grown in East (Düzce) and West Black Sea regions (Giresun) were determined by HPLC. Similar to other fruit species, fructose, glucose and sucrose levels decreased from the end of spring to summer, showed steady changes with low values in summer and increased starting in middle fall until winter. Despite general tendency of decline during spring season, soluble sugar contents of 'Sivri' raised in Düzce region in April. Annual changes in fructose, glucose and sucrose at the two regions and cultivars did not show significant differences. The differences between the regions and the cultivars were prominent in fall and winter months. Sucrose level was higher in December and January in Düzce which has lower winter temperatures than Giresun. But in December opposite results were obtained for sugars contents except glucose in 'Kalınkara'. Differences between regions during winter period mostly occurred in 'Palaz', 'Çakıldak' and 'Sivri'. Sucrose level was also higher in these cultivars than in the others in January.

Zusammenfassung

In dieser Untersuchung wurden mittels HPLC die jahreszeitlich bedingten Veränderungen der Fruktose-, Glukose- und Saccharosegehalte im Rindengewebe der Haselnusssorten 'Tombul', 'Palaz', 'Kalınkara', 'Çakıldak' und 'Sivri' aus der Schwarzmeerregion bestimmt. Analog zu anderen Fruchtarten nahm der Fruktose-, Glukose- und Saccharosegehalt vom späten Frühjahr bis zu den Sommermonaten ab und zeigte in den Sommermonaten geringere, stabile Werte; wohingegen ab Mitte Herbst bis zum Winter ein Anstieg ersichtlich war. Entgegen einem allgemeinen Abwärtstrend in den Frühlingsmonaten, stiegen die Zuckergehalte von 'Sivri' in Düzce im April an. Zwischen den Regionen und Haselnusssorten traten keine nachweisbaren Unterschiede im jahreszeitlichen Verlauf der Fruktose-, Glukose- und Saccharosegehalte auf. Die Unterschiede zwischen den Regionen und Sorten waren in den Herbst- und Wintermonaten deutlicher. Im Dezember und Januar war der Saccharosegehalt in Düzce, wo die Winter kälter sind, höher als in Giresun. Allerdings wurden im Dezember bei den Zuckergehalten mit Ausnahme von Glukose bei 'Kalınkara' der gegenteilige Zustand festgestellt. Unterschiede zwischen den Regionen waren in den Wintermonaten bei den Sorten 'Palaz', 'Çakıldak' und 'Sivri' deutlicher. Außerdem lagen die Saccharosegehalte dieser Sorten im Januar über denen der anderen Sorten.

Introduction

Carbohydrates play an important role in perennials and especially in deciduous fruit trees. Although storage polysaccharides have a significance in plant physiology, mono- and disaccharides are the most important carbohydrates in plant metabolism (SALISBURY and ROSS 1991). The amount and variety of carbohydrates found in plants differ in plant organs and conditions all throughout the growing season and, as a result, they react differently in terms of vegetative and reproductive development (ABOD and WEBSTER 1991; STREET and OPIK 1991, BIANCO et al. 1999; LIU et al. 1999; MAUST et al. 2000), fruit photosynthesis (BLANKE and LENZ 1989), root formation (DAVIES 1988; RIO et al. 1991), fruit growth, size, and ripening (BLANKE and BOWER 1991; NISHIZAWA and SHISHIDO 1998; LIU et al. 1999; WALL et al. 1999; ZHOU and PAULL 2001), foliage (NIINEMETS 1999), fruit quality (WANG and CAMP 2000), yield (CARUSO et al. 1999), dormancy (DOWLER and KING 1966), periodicity (CRANE et al. 1976; GOLDSMITH and GOLOMB 1982; NZIMA et al. 1999), stress tolerance (PHARR et al. 1999; KOBASHI et al. 2000) and cold and drought response (RODRIGUES and RYAN 1960; PURVIS and YELENOSKY 1982; PALONEN 1999; PREVETE et al. 2000) etc.

In order to understand the underlying regulatory mechanisms of carbohydrate metabolism, it is necessary to measure the changes of carbohydrates in different organs. Turkey is the greatest hazelnut producing country and has 75 % of hazelnut export in the world. However, there seems to be no study on soluble carbohydrates in hazelnut and their changes during the growing season.

The aim of this study is to determine and compare the amounts and seasonal changes of fructose, glucose and sucrose in the bark tissues of some hazelnut culti-

vars grown in East and West Black Sea regions. It could be concluded from the findings how the soluble sugars in the bark tissues of hazelnut cultivars are affected by ecological conditions and which differences are present among cultivars grown in the same region.

Materials and Methods

Hazelnut is commercially produced in Eastern and Western Black Sea regions of Turkey. The research was carried out in two of the most important regions of hazelnut production, the destricts of Giresun (East Black Sea region) and Düzce (West Black Sea region) with the cultivars 'Tombul', 'Palaz', 'Kalınkara', 'Çakıldak' and 'Sivri'. The orchards represented the ecological conditions of the regions and are in a average altitude from 250–500 m. The samples were taken from 30 years old hazelnut shrubs which had the same vegetative growth vigour. The study with the five cultivars in two locations was performed in 3 replicates with 10 shrubs in each.

Table 1. Monthly mean temperature* (°C) in Giresun and Düzce (1996–1998).
Durchschnittliche Temperaturwerte in Giresun und Düzce (1996–1998).*

	Month	Giresun	Duzce
(1996+1997)	March	5.7	4.9
(1996+1997)	April	9.8	9.6
(1996+1997)	May	16.2	18.1
(1996+1997)	June	19.5	20.1
(1996+1997)	July	23.1	22.7
(1996+1997)	August	23.2	21.5
(1996+1997)	September	18.9	16.8
(1996+1997)	October	16.3	13.4
(1996+1997)	November	12.9	9.9
(1996+1997)	December	11.1	7.9
(1997+1998)	January	7.3	4.9

* Mean temperature of two years

Table 1 shows monthly mean temperatures at Giresun and Düzce. Information about the hazelnut cultivars used in the research is summarized in table 2.

Sample preparation and determination of carbohydrates

Bark tissues of each cultivar were taken 10 cm above the ground of the main branches from March 1996 to January 1998. The tissues were dried at 60 °C to 70 °C for 48 hours before they were grounded. 2 g of the sample were put in 10 ml HPLC grade water, extracted in a 80 °C hot water bath for 4 hours and then roughly filtered. After that the filtrate was passed through a 0.45 µm HPLC filter and used in carbohydrate assay. The Shimadzu model HPLC was used to determine the amount of fructose, glucose and sucrose (MCBEE and MANESS 1983; IRVING et al. 1999).

Working conditions of HPLC

Shimadzu Shim-Pack CLCNH$_2$ (M) 4.6 x 250 mm column, CTO-10A Shimadzu column oven, LC 10 AD Shimadzu pump, flow velocity; 1 ml/ml, column temperature; 40 °C, mobile phase; 75 % acetonitril + 25 % deionized water.

Since all the data obtained from the five cultivars of the two regions in two years showed similar curves, the

Table 2. Properties of hazelnut cultivars used in the research (KOKSAL 2002).
Eigenschaften der untersuchten Haselnusssorten

	Kernel (%)	Bleaching ability	Fat content (%)	Protein content (%)	Other characteristics
'Tombul'	49.9	97.7	64.60	17.51	Productive, of globular shape, delicious, suitable for snacks and processing industry, tendency to alternate bearing is very low, sensitive to spring frosts, not suitable to grow over 550 m elevation, sensitive to big bud mite.
'Palaz'	47.3	94.5	57.65	18.03	Is widely grown, of compressed globular shape, moderately productivity, sensitive to climatic conditions and especially to spring frosts, pest and diseases, tendency to alternate bearing is high.
'Kalınkara'	32.2	62.3	68.52	11.73	Is of ovoid shape, number of catkins and adaptation ability are high, medium season in maturity, not precocious, difficult to separate from husk, low productivity, rate of twins and shriveled are high, resistant to diseases and spring frosts.
'Çakıldak'	47.9	87.8	60.67	19.44	Of globular-ovoid shape, adaptation ability to less fertile soils and high elevations is high, sensitive to drought, fruit set is high on self pollination, shriveled kernel rate and, tendency to alternate bearing are high, late maturing time, sensitive to hazelnut scales and spring frost.
'Sivri'	47.6	72.3	63.89	18.73	Is of conical shape, adaptation ability is good, productive, tendency to alternate bearing is moderate, resistant to pest, diseases and spring frosts.

mean values of experimental years were used to compare the changes. Three-factorial experiment with repeated measures on one factor design (WINER 1971) were used to evaluate the results of two years' mean values.

Results

After comparing all parameters of the study, three factorial interactions among the regions, cultivars and months were found significant (Table 3).

Changes in fructose content

Comparing the regions and cultivars, fructose content changed between 0.0310–2.9603 mg g^{-1} in bark tissues. In all cultivars grown in both regions, the highest fructose values were obtained in late fall and winter and the lowest in spring and summer months. Differently, the highest amount of fructose was obtained in 'Sivri' at Düzce in April. 'Kalınkara' and 'Sivri' at Giresun also had high amounts of fructose in March. The comparison between months showed that the most cultivars had higher amounts of fructose during winter months, especially in December and January, and that these differences are significant. The differences between the fructose values in spring and summer were small and not significantly different (Table 3).

The differences among the cultivars were clearly recognizable in the colder months in both regions. According to the two-year mean of the monthly temperatures (Table 1), March and January are the coldest in Giresun and Düzce.

In Giresun, the highest and the lowest fructose values were obtained in March for 'Sivri' (1.5030 mg g^{-1}), 'Kalınkara' (1.1015 mg g^{-1}), 'Tombul' (0.8250 mg g^{-1}); and in 'Palaz' (0.0735 mg g^{-1}), 'Çakıldak' (0.4525 mg g^{-1}) respectively. In the same region, fructose in the bark tissues of 'Sivri' (2.9630 mg g^{-1}), 'Palaz' (2.3190 mg g^{-1}) and 'Tombul' (2.2640 mg g^{-1}) in January is significantly higher than in the other cultivars. There was no difference among the cultivars in April and May (Table 3). The differences among the cultivars grown in Düzce were not significant during March and October, except for 'Sivri' in April. But differences were detected in November, December and January. The Fructose amount of 'Tombul' (1.6000 mg g^{-1}) and 'Palaz' (1.4065 mg g^{-1}) in November, of 'Çakıldak' (1.8710 mg g^{-1}) in December, and of 'Tombul' (2.8820 mg g^{-1}) in January were significantly higher than the amounts of the other cultivars (Table 3).

Significant differences between the two regions were determined for 'Tombul' in July, for 'Palaz' in December and January, for 'Çakıldak' in December and for 'Sivri' in March, September and January. There were no significant differences between the regions for 'Kalınkara'. During the months in which the differences between the fructose content of the cultivars in the two regions were significant, the contents of the cultivars grown at Giresun were higher then those at Duzce (Table 3).

Following a small decrease in spring, a slight change in fructose content occurred during summer and started to increase during September and October in some cultivars and during November in the others, and remained high during winter period. The exception was 'Sivri' at Duzce, which showed a decrease in fructose content during winter. 'Cakıldak' demonstrated a slight decrease of fructose in January after reaching the highest value in December in both regions. Although fructose in summer were higher than in spring in 'Tombul' and 'Çakıldak' at Giresun, changes of the values were similar. 'Palaz' and 'Cakıldak' at Giresun and 'Sivri' at Duzce showed an increase in fructose content in April and May, followed by a decrease during the summer period (Figure 1).

Changes in glucose content

The glucose content of bark tissues of all cultivars in both regions ranged between 0.1030 and 4.1860 mg g^{-1}. All cultivars had lower glucose in summer and higher in late fall and winter. 'Tombul' at Giresun and 'Sivri' at Duzce also had a high amount of glucose in April. The differences between the months in which the highest and lowest glucose content were obtained were statistically significant in all cultivars except 'Tombul' and 'Sivri' at Duzce. In the months of spring and summer the glucose content of the cultivars was lower and the differences between the cultivars were smaller (Table 3).

Comparing the glucose contents of the cultivars it was shown that significantly high values were obtained in 'Sivri' (2.025 mg g^{-1}), 'Tombul' (2.5750 mg g^{-1}) and 'Cakıldak' (4.1860 mg g^{-1}) at Giresun in March, April and January, respectively (Table 3). No significant differences between cultivars were detected during spring, summer and autumn periods at Düzce except of 'Sivri' in April. The significantly high values were obtained at Düzce in 'Kalınkara' (2.9910 mg g^{-1}) in December and in 'Kalınkara' (2.3370 mg g^{-1}) and 'Çakıldak' (1.5450 mg g^{-1}) in January (Table 3).

Significant differences were found between the regions during September, October, December and January except in April and March for 'Tombul' and 'Sivri' respectively. No significant differences in glucose content of 'Palaz' were found. In comparison with the fructose content, glucose values were higher at Giresun than at Duzce during the months in which the differences between regions were significant except in 'Kalınkara' during December (Table 3).

The yearly changes of glucose content were similar to the changes of fructose in spite of some exceptions. Glucose content of 'Tombul', 'Palaz' and 'Cakıldak' at Giresun and 'Cakıldak' and 'Sivri' at Duzce slightly increased in March and April. The glucose level partially decreased in both regions throughout the summer and started to increase from the beginning of the fall (Figure 1).

Changes in sucrose content

In the regions and cultivars used in this research, sucrose content of bark tissues ranged between 0.0225 and 3.0220 mg g^{-1}. The values reached there maximum between September and January. But 'Sivri' at Duzce had also high sucrose content in April. Sucrose levels were low during spring and summer months and no significant differences were determined among the values (Table 3).

Table 3. The amounts of fructose, glucose and sucrose in bark tissues of some hazelnut cultivars grown in East and West Black Sea region (mg g^{-1}).*
Fruktose-, Glukose- und Saccharosegehalte im Rindengewebe einiger Haselnusssorten aus der Ost- und West-Schwarzmeer-Region (mg g^{-1}).

FRUCTOSE										
	TOMBUL		PALAZ		KALINKARA		CAKILDAK		SIVRI	
MONTHS	GIRESUN	DUZCE	GIRESUN	DUZCE	GIRESUN	DUZCE	GIRESUN	DUZCE	GIRESUN	DUZCE
MARCH	0.8250 BCDE ab *A*	0.4870 CDE a *A*	0.0735 C c *A*	0.5430 BC a *A*	1.1015 AB ab *A*	0.4320 AB a *A*	0.4525 CD bc *A*	0.7870 BC a *A*	1.5030 BC a *A*	0.3835 AB a *B*
APRIL	0.3070 E a *A*	0.2690 DE b *A*	0.4860 BC a *A*	0.2025 C b *A*	0.6285 BC a *A*	0.5085 AB ab *A*	0.7795 BCD a *A*	0.6020 C ab *A*	0.1730 D a *A*	1.0345 A a *A*
MAY	0.4690 DE a *A*	0.7855 CDE a *A*	0.9145 B a *A*	0.0930 C a *A*	0.3760 BC a *A*	0.2495 AB a *A*	0.2120 D a *A*	0.5865 C a *A*	0.8100 CD a *A*	0.7875 AB a *A*
JUNE	1.0790 BCDE a *A*	0.4780 CDE a *A*	0.2860 BC b *A*	0.0670 C a *A*	0.3325 BC b *A*	0.3160 AB a *A*	0.2020 D b *A*	0.2825 C a *A*	0.3370 D ab *A*	0.2255 AB a *A*
JULY	1.0565 BCDE a *A*	0.0625 E a *B*	0.2545 BC b *A*	0.6485 ABC a *A*	0.7090 BC ab *A*	0.2870 AB a *A*	0.9295 BCD ab *A*	0.1510 C a *A*	0.3985 D ab *A*	0.5025 AB a *A*
AUGUST	1.4100 B a *A*	0.7690 CDE a *A*	0.4790 BC bc *A*	0.1505 C a *A*	0.0985 C c *A*	0.1870 AB a *A*	0.9205 BCD ab *A*	0.3160 C a *A*	0.7290 CD abc *A*	0.3815 AB a *A*
SEPTEMBER	0.5995 CDE b *A*	0.0405 E a *A*	0.6565 BC b *A*	0.1925 C a *A*	0.4095 BC b *A*	0.1350 B a *A*	1.0630 BC b *A*	0.4355 C a *A*	1.9925 B a *A*	0.4115 AB a *B*
OCTOBER	0.5330 DE b *A*	1.1850 BC a *A*	0.4495 BC b *A*	0.7375 ABC a *A*	0.4160 BC b *A*	0.7900 AB a *A*	1.4370 B a *A*	0.9090 BC a *A*	1.3345 BC a *A*	0.5815 AB a *A*
NOVEMBER	1.3485 BC ab *A*	1.6000 B a *A*	1.7130 A a *A*	1.4065 A a *A*	0.4260 BC c *A*	0.1895 AB b *A*	1.0025 BCD abc *A*	0.6350 C b *A*	0.7800 CD bc *A*	0.5090 AB b *A*
DECEMBER	1.2400 BCD b *A*	0..9850 BCD b *A*	2.3510 A a *A*	1.0420 AB b *B*	0.7515 BC b *A*	0.9170 AB bc *A*	2.6640 A a *A*	1.8710 A a *B*	0.8365 CD b *A*	0.2180 AB c *A*
JANUARY	2.2640 A a *A*	2.8820 A a *A*	2.3190 A a *A*	1.1580 AB b *B*	1.5165 A b *A*	0.9900 A b *A*	1.4115 B b *A*	1.4920 AB b *A*	2.9630 A a *A*	0.0310 B c *B*
GLUCOSE										
	TOMBUL		PALAZ		KALINKARA		CAKILDAK		SIVRI	
MONTIIS	GIRESUN	DUZCE	GIRESUN	DUZCE	GIRESUN	DUZCE	GIRESUN	DUZCE	GIRESUN	DUZCE
MARCH	0.4515 CDE b *A*	0.4720 A a *A*	0.3690 B a *A*	0.3250 AB a *A*	1.3760 AB ab *A*	0.5275 B a *A*	0.4670 D b *A*	0.3560 C a *A*	2.0205 A a *A*	0.3915 B a *B*
APRIL	2.5750 CDE a *A*	0.1735 A b *B*	0.8485 B b *A*	0.2805 AB b *A*	0.2790 C b *A*	0.1030 B b *A*	0.8165 D b *A*	0.4535 C b *A*	1.2430 ABC b *A*	1.5635 A a *A*
MAY	0.2935 DE a *A*	0.2290 A a *A*	0.7420 B a *A*	0.3865 AB a *A*	0.3815 BC a *A*	0.3750 B a *A*	1.2895 CD a *A*	0.2555 C a *A*	0.2680 C a *A*	0.6740 AB a *A*
JUNE	1.3045 CD a *A*	0.1340 A a *A*	0.7240 B a *A*	0.5825 AB a *A*	0.5470 BC a *A*	0.2235 B a *A*	0.8495 D a *A*	0.4120 C a *A*	0.4865 BC a *A*	0.3070 B a *A*
JULY	0.4230 CDE a *A*	0.3170 A a *A*	0.5490 B a *A*	0.7180 AB a *A*	0.5665 BC a *A*	0.1095 B a *A*	0.6100 D a *A*	0.7275 BC a *A*	0.2125 C a *A*	0.1275 B a *A*
AUGUST	0.9995 CDE a *A*	0.7435 A a *A*	1.0720 AB a *A*	0.1775 B a *A*	0.4300 BC a *A*	0.4845 B a *A*	1.1660 CD a *A*	0.3690 C a *A*	0.6300 BC a *A*	0.1165 B a *A*
SEPTEMBER	0.1435 E b *A*	0.3820 A a *A*	0.2890 B b *A*	0.2560 B a *A*	0.1175 C b *A*	0.7915 B a *A*	1.9905 BC a *A*	0.3815 C a *B*	1.4135 AB a *A*	0.1965 B a *B*
OCTOBER	2.6660 A ab *A*	0.5390 A a *B*	0.9994 AB c *A*	0.3315 AB a *A*	1.8360 A bc *A*	0.7480 B a *A*	2.8830 B a *A*	0.5780 BC a *B*	1.7605 A bc *A*	1.0160 AB a *A*
NOVEMBER	1.4625 BC ab *A*	0.5280 A a *A*	1.2920 AB ab *A*	0.4260 AB a *A*	1.7365 A a *A*	0.5850 B a *A*	1.1920 CD ab *A*	0.6380 BC a *A*	0.5420 BC b *A*	0.3925 B a *A*
DECEMBER	0.6675 CDE b *A*	0.2750 A c *A*	1.8770 A a *A*	1.3520 A b *A*	1.8825 A a *B*	2.9910 A a *A*	2.1615 BC a *A*	1.7280 A b *A*	1.5015 AB ab *A*	1.0850 AB bc *A*
JANUARY	2.4000 AB b *A*	0.1830 A c *B*	0.4170 B c *A*	1.2320 AB b *A*	1.7490 A b *A*	2.3370 A a *A*	4.1860 A a *A*	1.5450 AB ab *B*	2.2155 A b *A*	0.7330 AB bc *B*
SUCROSE										
	TOMBUL		PALAZ		KALINKARA		CAKILDAK		SIVRI	
MONTHS	GIRESUN	DUZCE	GIRESUN	DUZCE	GIRESUN	DUZCE	GIRESUN	DUZCE	GIRESUN	DUZCE
MARCII	0.1725 BC ab *A*	0.1120 C a *A*	0.4950 B ab *A*	0.2120 C a *A*	0.0415 B b *A*	0.6245 AB a *A*	0.7955 BC a *A*	0.4260 DE a *A*	0.8720 AB a *A*	0.6430 BC a *A*
APRIL	0.6120 BC a *A*	0.1345 C b *A*	0.3055 B a *A*	0.1390 C b *A*	0.6875 AB a *A*	0.0785 B b *A*	0.6690 BC a *A*	0.3490 E ab *A*	0.2600 BC a *A*	0.8865 BC a *A*
MAY	0.5555 BC ab *A*	0.3140 C a *A*	0.5700 B ab *A*	0.3625 C a *A*	0.9465 A a *A*	0.1530 B a *A*	0.2245 C ab *A*	0.2820 E a *A*	0.1290 BC b *A*	0.3010 C a *A*
JUNE	0.0845 BC a *A*	0.1665 C a *A*	0.3185 B a *A*	0.2010 C a *A*	0.3450 AB a *A*	0.2245 B a *A*	0.1740 C a *A*	0.4615 DE a *A*	0.0225 C a *A*	0.2375 C a *A*
JULY	0.2910 BC a *A*	0.1710 C a *A*	0.6015 B a *A*	0.2945 C a *A*	0.1105 B a *A*	0.4585 B a *A*	0.2515 C a *A*	0.1415 E a *A*	0.2875 BC a *A*	0.7210 BC a *A*
AUGUST	0.0520 C b *A*	0.1395 C a *A*	0.3725 B ab *A*	0.1305 C a *A*	0.0805 B b *A*	0.2785 B a *A*	0.8625 BC a *A*	0.4970 DE a *A*	0.4940 ABC ab *A*	0.4660 C a *A*
SEPTEMBER	0.6240 BC b *A*	0.0950 C b *A*	0.2015 B b *A*	0.6930 BC ab *A*	0.1185 B b *A*	0.4020 B b *A*	2.3795 A a *A*	1.3025 C a *B*	0.1295 BC b *A*	0.6690 BC ab *A*
OCTOBER	0.8645 B b *A*	0.2805 C b *A*	1.7270 A a *A*	0.1090 C b *B*	1.1185 A ab *A*	0.5830 AB b *A*	0.3970 C b *B*	2.0320 B a *A*	0.5510 ABC b *A*	1.3765 B a *A*
NOVEMBER	0.6300 BC a *B*	1.6740 B a *A*	0.5440 B a *A*	0.3430 C b *A*	0.3625 AB a *A*	0.8290 AB b *A*	0.6880 BC a *B*	3.0220 A a *A*	0.1775 BC a *A*	0.4595 C b *A*
DECEMBER	1.5730 A a *B*	2.8010 A a *A*	0.2035 B b *B*	1.3670 B b *A*	0.6035 AB b *A*	1.3020 A b *A*	0.1110 C b *B*	1.1210 CD b *A*	0.3210 BC b *A*	0.0910 C c *A*
JANUARY	0.2355 BC b *A*	0.3350 C b *A*	0.1700 B b *B*	2.1250 A a *A*	0.1570 B b *A*	0.3120 B b *A*	1.3075 B a *B*	2.5960 AB a *A*	1.2055 A a *B*	2.4600 A a *A*

*Capital letters, letters and italic capital letters indicate that the differences among of the months (at the same region and cultivar), cultivars (at the same region and month) and regions (at the same cultivar and month) respectively. The differences among the means have different capital letters, letters and italic capital letters are significantly different from each other at $p<0.05$ level.

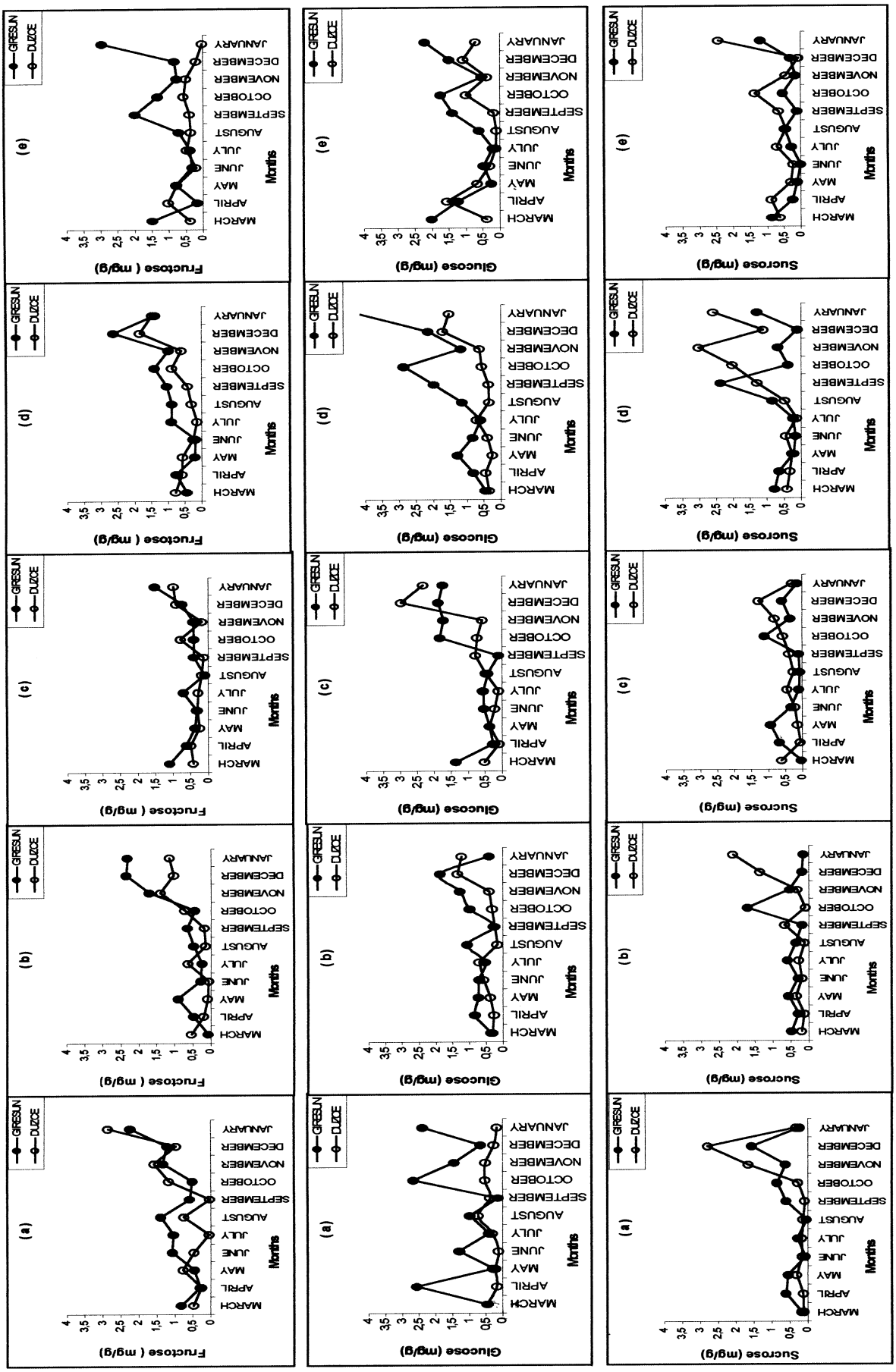


Fig. 1. The seasonal changes of fructose, glucose and sucrose in bark tissues of some hazelnut cultivars grown in East and West Black Sea region (mg/g).
Jahreszeitlich bedingte Veränderungen in Fruktose-, Glukose- und Saccharosegehalte in Rindengewebe einiger Haselnusssorten aus Ost- und West-Schwarzmeer (mg/g).

The differences in the sucrose content of the bark tissues between the cultivars were definite for both regions from September to January. In March, the coldest month in both regions, no significant differences among the cultivars were determined. However, in January 'Çakıldak' (1.3075 mg g^{-1}) and 'Sivri' (1.2055 mg g^{-1}) at Giresun and 'Çakıldak' (2.5960 mg g^{-1}), 'Sivri' (2.4600 mg g^{-1}) and 'Palaz' (2.1250 mg g^{-1}) at Düzce had significantly higher sucrose content. No significant differences between cultivars were detected in April, June and July at Giresun and in March, May, June, July and August at Düzce (Table 3).

While there were no significant differences between the regions in terms of sucrose content of 'Kalınkara', statistically significant differences for other cultivars were found during the period from September to January. Higher sucrose values were obtained at Duzce district during the months in which the differences between regions were significant while only 'Palaz' and 'Cakıldak' showed higher values at Giresun district in October and September, respectively (Table 3).

In despite of the differences in the regions and the cultivars, sucrose level begins to decrease during late spring and summer and reaches a low level in summer, and starts to rise from August and September until midwinter. 'Palaz' at Giresun shows a noticeable increase in October with a decrease in the following winter months. 'Tombul' in both regions had an elevation starting from September, reached the highest level in December, and decreased in January. The same pattern was observed for 'Kalınkara' (Figure 1).

Discussion

Synthesis, usage and storage of carbohydrates in plants show a lot of changes in different seasons. Stored carbohydrates are used in the spring time shooting period and newly synthesized carbohydrates were used for growing, flowering and fruit setting. For this reason, storage compounds of trees moderately decrease to minimum level in spring time. Trees start to store carbohydrates after dormancy in vegetative growth in the summer, and after that, they loose their leaves (OLIVERIA and PRIESTLEY 1989; STREET and OPIK 1991). It was determined that the soluble sugar, glucose and fructose, were at maximum level in winter period. In spring time, the shooting period, they decrease and during vegetation period they slowly increase. In autumn, a second maximum level of these compounds was observed. Sucrose was found at the least amounts in spring and the following shoot formation. Especially in fruit shoots, it again tended to increase and during the summer period, it reached the maximum level. In autumn, it again decreased either in branches or in roots. Starch, the most important storage compound in fruit trees, was at the maximum level in autumn (SAKAI 1966; KANDIAH 1979; VOLENEC et al. 1991; PALONEN 1999). SALISBURY and ROSS (1991) indicated that, besides food crops, most native perennial plants have stored starch before and during the dormant period, and this starch is used as energy source for growth in the next season. In addition, sucrose acts as an energy source in photosynthetic cells and is translocated through the phloem in growing season.

Fructose, glucose and sucrose content of bark tissues in all cultivars in both regions investigated increased from summer to winter and during dormancy period when they act as storage compounds. Their highest amounts were found at the end of autumn when translocation commences, and during winter months. Amounts of the mentioned substances were at lower and similar levels during spring and summer period. Moreover, results of this study show that annual variation of carbohydrates in hazelnut cultivars is similar to that of other fruits. The findings observed in the study agreed with the findings of other studies carried out with citrus (PURVIS and YELENOSKY 1982; SONG et al. 1998; MATAA et al. 1998; HOLLAND et al. 1999), apple (YASTIOKA et al. 1988; YAMAKI and INO 1992), peach (DOWLER and KING 1966; CARUSO et al. 1999), avocado (RODRIGUES and RYAN 1960; LIU et al 1999), chestnut (PROIETTI et al. 2000), pineapple (CHING-CHENG and PAULL 2000) and blueberry (MAUST et al. 2000). An increase in sugar and polyhydric alcohol were recorded by SAKAI (1966) during the period from summer to winter in apple, plum, pear, peach, persimmon, grape, tangerine and navel orange trees. High glucose levels were also obtained in some cultivars during April in our study similar to olive (DROSSOPOULOS and NIAVIS 1988) and pistachio (IDEM and GEZEREL 1995). The glucose content in the bark of olive trees had a tendency to rise from spring to the beginning of summer and remained stable in hot summer, fall and winter periods. It was also found that starch content of the leaves diminished with decreasing sucrose and increasing glucose in plant tissues during spring. They concluded that this might be due to the hydrolysis of polysaccharides (DROSSOPOULOS and NIAVIS 1988; NIINEMETS 1999; WANG and CAMP 2000). IDEM and Gezerel (1995) also determined higher reducing sugars content in the spring in pistachio seedlings.

Seasonally performed analyses showed that carbohydrate diminished in especially older parts of plants starting with the growing season (MATAA et al. 1998). It is followed by an increase during longitudinal growth of shoots (LIU et al. 1999). It was determined in this study that in hazelnut shrubs, with active growth in spring, there was a decreasing tendency in the amounts of fructose and sucrose. However, sugars in the bark increased with the period of growth of newly formed shoots.

It can be thought that lower levels of sugars found in this research in summer period is related with temperature besides of seasonal usage cycle of carbohydrates in the plant body. It has been reported that carbohydrate assimilation increased to an optimum level at increasing temperature. If transpiration increases by high temperatures, stomata start to close, so, carbondioxide amount decreases and sugar synthesis is blocked. In contrast, respiration increases with temperature and carbohydrate usage also increases. In this situation, a decrease of carbohydrate amount is observed instead of an increase, because of failure in reaching the optimum temperature level (SALISBURY and ROSS 1991; STREET and OPIK 1991). It has been reported that temperature is an effective factor also in translocation of carbohydrates in plants. Carbohydrate translocation rapidly increases up to definite temperature, and after this temperature, translocation sharply decreases (HEWITT and

CURTIS 1948). HARTT (1965) determined that translocation of sugars to the root increased but translocation to apex decreased at higher root temperature than ambient temperature. In the opposite case, sugar translocation to the apex increased and translocation to the roots decreased. Translocation of reserve carbohydrates has tended to upper organs, buds and flowers during spring. Assimilates synthesized in leaves especially in summer period are translocated to the different organs such as shoot tips, fruits and branches, and also an important part of them is translocated down and stored (OLIVERIA and PRIESTLEY 1989). According to JENNINGS and CARMICHAEL (1975) and PALONEN (1999), seasonal changes in carbohydrate content were related to changes in cold hardiness and air temperatures. In addition, PALONEN (1999) reported that the simultaneous increase in starch contents and the primary transportable carbohydrate sucrose in early spring in raspberry buds may be explained by mobilization of root carboydrate reserves to support the beginning of new growth.

Many researchers state that sugars and starch in plants play an important role in the resistance mechanism against salt, drought and cold. GAO et al (1998) found that tomato plants under salt stress had high sucrose concentrations in their leaves. KOBASHI et al (2000) indicate that water-stress-induced ABA accelerated sugar accumulation in peaches by activating sorbitol metabolism. Conversion of sucrose to glucose and fructose may facilitate osmotic adjustment in the leaves of plants under water stress (PREVETE et al. 2000). LIU and HUANG (2000) stated in their study with creeping bentgrass plants that the balance between photosynthesis and respiration were disrupted at high temperatures, and sucrose and glucose in the root and stem tissues was reduced in great amounts under heat stress. SAKAI (1966) and PALONEN (1999) stated that plants acquire cold resistance by consuming starch and rising their soluble carbohydrates in early winter. Moreover, it is stated that sugars, especially sucrose, have an important role to increase the cell protoplasm density, and that through their deposition more than others, plants are less damaged by low winter temperatures. According to SAKAI and YOSHIDA (1968) sugars accumulate during cold hardening in woody plants, when starch is hydrolyzed to low-molecular weight carbohydrates. JENNINGS and CARMICHAEL (1975) state that sugar accumulation may be important factor in increased hardiness. Accumulation of soluble carbohydrates in raspberry canes during fall hardening and the decline in spring have been observed. Changes in sugar content were not associated with changes in dormancy status, but rather induced by weather changes.

As an interesting result, the differences in both cultivars and regions were noticeable especially during winter while there was no significant differences in the amount of carbohydrates during spring and summer. This result can also explain the differences among the cultivars at the same region and between the regions for the same cultivar. Sugar content of cold resistant cultivars during December, January and March which is the coldest period were determined higher than others. Those differences were especially clear for glucose and sucrose in January. Fructose contents of 'Tombul', 'Palaz', 'Sivri' in Giresun and 'Tombul' in Düzce; glucose contents of 'Cakıldak' in Giresun and 'Kalınkara' in Düzce; and sucrose contents of 'Cakıldak', 'Sivri' in Giresun and 'Palaz', 'Cakıldak', 'Sivri' in Düzce were significantly higher than the other cultivars in January which is the coldest month of winter in both regions. Likewise, BONHEVI and COLL (1993) and SAVAGE and MC NEILL (1998) indicate that the levels of sucrose in typical mountainous hazelnut cultivars are higher than other cultivar. Similarily, PALONEN (1999) stated that high level sucrose, total soluble carbohydrates, and a high ratio of sucrose to glucose plus fructose were characteristic of a hardy cultivar in raspberry.

Differences among regions mainly occurred between September and January in our experiment and the mean temperatures of months in Giresun were higher than Düzce (Table 1). This is especially noticable for sucrose level. Differences in fructose, glucose and sucrose were probably due to temperatures. Almost in all months for which differences were significant among regions, fructose and glucose values were higher in Giresun than in Düzce, except glucose content of 'Kalınkara' in December. Consistent with interpretations of researchers on the importance of sucrose in cold resistance, higher sucrose values were obtained in Düzce district during the months in which the differences between the regions were significant while only 'Palaz' and 'Çakıldak' showed higher values in Giresun in October and September, respectively. Although high sucrose levels were determined in cold regions and periods, differences between cultivars were effected by sugar type. While there are no significant differences between resistant and susceptible cultivars, in some cases, cold resistant cultivars showed high levels. The results show both the importance of sugars especially sucrose and the existence of different mechanisms other than carbohydrates on cold resistance. Detailed researches planned on correlation between levels of carbohydrates and fruitfulness, resistance to coldness etc. will be useful.

It has been determined that hazelnut cultivars behave similar to other fruit species in seasonal variation of carbohydrate content. This is also true for the cultivars grown in various regions. Only some differences could be seen probably due to ecological conditions in the periods in which increases and decreases in carbohydrate content started.

This research was supported by Ankara University Research Fund.

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Eingereicht: 17.05.02 / 30.10.02

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