Soil Temperature Effects on Free Carbohydrate Concentrations in Peanut (*Arachis hypogaea* L.) Seed[1]

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ABSTRACT

Research has indicated that variation in the mean soil temperature of only a few degrees results in quality differences of peanut seed. The importance of the carbohydrate-amino acid interaction in the development of roasted peanut flavor and color is well documented. The objective of this study was to determine the influence of controlled field soil temperatures on free carbohydrates in commercially sized peanut seed. Florunner peanuts were grown in 5.48 x 12.19 m plots. Soil temperatures were modified from 28 days after planting to produce mean temperatures warmer (28.8 C) and cooler (21.7 C) than ambient (24.5 C) at the 5.0 cm depth in 1982 and 28.2, 22.5, and 25.8 C, respectively, in 1983. Carbohydrates were determined by gas chromatography. Sucrose concentrations decreased significantly as accumulated heat units and seed size increased. In general, fructose, glucose, and raffinose concentrations followed the same trends. The carbohydrate differences found in sized seed were similar to those found among maturity stages from each soil temperature treatment. The data indicate that seed carbohydrate concentrations decrease with higher soil temperature.

Key Words: Groundnut, heat unit, seed size, maturity, photosynthesis, chlorophyll.

Maturity and planting location have been shown to cause quantitative physiological changes in peanut seed (1,15,16,17,20). Planting location effects are often difficult to explain due to the range of environments and cultural practices that may be encountered. Recent research (8, 21) indicates that slight variations in mean soil temperature may result in peanut yield and quality differences. Studies on physiological changes occurring in peanuts in response to temperature have been related primarily to measured air temperature with little attention being given to soil temperature. The inherent difficulty in manipulation of soil temperatures in field and plot situations may have been a contributing factor. However, the design and construction of plots for soil temperature manipulation have shown that

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these difficulties can be acceptably overcome (4).

The importance of the carbohydrate interactions in the development of roasted peanut flavor and color is well documented (1). Oupadissakoon *et al.* (15, 16) investigated the effects of cultivar, location, and time of harvest on individual carbohydrate concentrations. Pattee *et al.* (19) reported on the effects of storage on qualitative carbohydrate changes as influenced by seed moisture, size, and length of storage. The wide range of environmental conditions over which peanut production is accomplished may contribute to the diversity of carbohydrate concentrations noted in the literature (1). This study was conducted to determine the effect of soil temperature on the accumulation of water soluble carbohydrates in commercial sizes of Florunner peanuts.

Materials and Methods

On 14 May 1982 and 2 May 1983 Florunner peanuts (*Arachis hypogaea* L.) were planted in soil temperature manipulated plots 5.48 x 12.19 m with 2-m borders surrounding each plot. Plot relationships were changed yearly within the same one ha field. Seed were planted approximately 5 cm apart in rows on 91 cm centers. Soil type was a Greenville sandy loam (clayey kaolinitic thermic rhodic paleudults) soil. Cultural practices were those generally employed in the Southeast and recommended by the Georgia State Extension Service (10). Soil moisture tension was determined with Delmhorst gypsum blocks at six locations within a treatment at 5, 31, and 61 cm below the surface and measured at 2 hr intervals. Throughout the growing season, supplemental irrigation was applied as required. In 1983, as an indicator of plant moisture status within plots, leaf canopy temperatures were determined between 1:00 and 2:00 p.m. from 13 June to 12 August using a Teletemp model AG-42 infrared thermometer (11). The 4∞ field of view instrument measured the canopy temperature at an eastward glancing angle (ca. 16∞ below horizontal) 2.7 m from the target that allowed only plant material to be viewed. Soil temperature treatments (ambient, cooled, and heated) were initiated on 11 June 1982 and 8 June 1983 at approximately first bloom and terminated at harvest. Soil temperatures were increased with electric heating cables and cooled by passing cool water through epoxy-coated copper tubing located approximately 12 cm below the soil Surface. Soil temperatures were monitored with ten copper-constantan thermocouples at 5 and 31 cm below the surface. In 1982, soil temperatures at the 31 cm depth were not acquired due to electronics failure. The mean soil temperature data reported are seasonal averages of daily mean temperatures, based on 2 hr observations for the test period. The maximum and minimum temperatures reported are the daily average of the mean maximum and minimum temperatures for the test periods.

The degree day heat accumulation for each of the three treatments was determined with the following formula:

$Hu = n(m_k - t)$, where:
Hu = Degree day heat unit accumulation
k = Treatment day number
m = Daily mean soil temperature averaged for the total number of treatment days
n = Total number of treatment days
t = 15 C (minimum soil temperature for growth)

A temperature of 15 C was selected as a representative base for minimum peanut plant growth, based on the reported temperature for pod growth (14), seed germination and plant growth (13).

Plants were harvested 23 September 1982 and 12 September 1983. In 1982, immediately after digging, ca 200 of the peanut pods were hand-picked from random plants and separated into maturity classes by the hull-scrape method (24). Peanuts were then cured with forced ambient air to approximately 8% moisture and hand-shelled. The remainder of the plants were cured 3 days in windrow and then picked with a stationary combine and dried as above. The combined peanuts were machine shelled and separated into four commercial size categories using 8.33, 7.14, 6.35 and 5.56 mm width slotted screens (7). All peanuts were stored at 0 C.

In 1982, main stem and cotyledonary branches were collected from 10 plants per plot for length determinations. Roots from these plants were washed from the soil, freeze dried, and weighed. The roots were then ground to pass a 40 mesh screen and soxhlet extracted for 15 hrs in 80% ethyl alcohol for carbohydrate determination by gas chromatography.

Using similar temperature controlled plots, leaf chlorophyll and carbohydrate concentrations were determined in 1985 and photosynthetic measurements were made in 1987. Main stem leaves, at the third node, were harvested on May 20, June 10, 25, July 10, August 5, 19, and September 3, 16, and 30, 1985, and freeze dried. The leaf material was ground to pass a 40 mesh screen and extracted in 80% acetone at room temperature and the optical density determined immediately for chlorophyll determinations according to the method of Arnon (3). Leaf carbohydrates were determined as previously described for roots. Net photosynthetic (Pn) measurements were made on the first, fully expanded main stem leaf on May 29, June 29, July 27 and August 26, 1987, on randomly selected plants in each treatment plot. Morning and afternoon observations were made on each date by the standard open-system differential method with a LI-COR-600 portable photosynthetic system. Leaf area was determined using a LI-COR-3100 leaf area meter before leaves were freeze dried for weight determinations.

Approximately 25 g of peanut seed from each commercial size or maturity class were ground in a Krups coffee mill and from this pool 2 g of the ground meal were extracted and derivatized for the determination of free carbohydrates (15). The derivatives remained overnight at room temperature before analysis by gas chromatograph using 2 m x 3.18 mm stainless steel columns packed with 2% OV-17 on 80/100 mesh chromosorb W-HP with a helium flow rate of 55 mL/min. After a 6 min hold, oven temperature of 150 C was programmed at 6 degrees/min until 12.5 min when the temperature rate was increased to 10 degrees/min to a final temperature of 330 C. Injector and flame ionization detector temperatures were 295 and 330 C, respectively. Carbohydrates were identified by comparison of retention times and co-chromatographing with known standards. Carbohydrate concentrations were determined by the internal standard method. Differences among means were determined by Duncan's New Multiple Range Test.

Results and Discussion

Seasonal soil temperatures varied with treatment, time and depth (Table 1). Between years differences in the two temperature controlled soils was less than one degree and the ambient soil was 1.3 C warmer in 1983. The mean maximum and minimum soil temperatures are included to indicate the diurnal variation among plots. While the mean maximum and minimum observations are useful indicators of diurnal soil temperature variations, they do not indicate possible differences in heat available for plant growth. A useful estimation of available heat is the degree day concept. There were approximately twice as many degree days in the heated plots as in the cooled at the 5 cm depth, while the ambient plots were intermediate at approximately 1.5 times the cooled (Table 1). In 1983, in corresponding treatments, degree days were slightly less at the 31 cm depths than the 5 cm depth.

Peanut seed carbohydrates fructose, glucose, sucrose, raffinose, and stachyose are known to change with growing area and harvest date (15). In our study, carbohydrate concentrations were affected in two ways: (A) by differences

Table 1. Soil temperature and calculated degree days for three temperature treatments, 1981-1982, Dawson, Georgia.

		Temperature C						Degree days	
Soil	Sensor	1982			1983				
treatment	depth	max.	min.	mean	max.	min.	mean	1982	1983
	cm								
Cool	5.0	34.1	18.0	21.7	30.8	19.6	22.5	697	705
	31.0				25.6	20.8	22.3		686
Ambient	5.0	36.7	19.8	24.5	35.1	19.6	25.8	988	1015
	31.0				28.8	22.3	25.5		987
Heat	5.0	39.7	25.0	28.8	36.9	24.3	28.2	1435	1249
	31.0				31.6	24.1	27.9		1213

in degree days or soil temperatures and (B) seed size (Tables 2,3). Water soluble carbohydrate concentrations were significantly affected by the different degree days. Increased soil temperatures generally resulted in decreased fructose, glucose, sucrose and raffinose concentrations, while stachyose concentrations were apparently not affected. This agrees with the observed reduction in sugar beet (*Beta vulgaris*) carbohydrate concentrations when grown under high soil temperatures (6). In general, carbohydrate concentrations decreased as seed size increased and is in agreement with Pickett's 1950 findings (20). Pickett (20) also reported that decreased carbohydrate concentrations were correlated with increased oil. Pattee *et al.* (18) reported that carbohydrate concentrations were generally highest in the small seed. Additional data presented by Pattee *et al.* (18) showed a general increase in seed size with maturity and, thus, the data may be extrapolated to show high carbohydrate concentrations in the immature seed. Oupadissakoon *et al.* (15) reported carbohydrate concentrations decreased in sound mature kernels with increasing days to harvest but did not indicate a seed size separation.

The observed significant differences in seed carbohydrate concentrations grown under different soil temperature treatments may be due to maturity differences within a size. This is indicated by the work of Sanders and Blankenship (21) who reported that maturation rate decreased and the seed size distribution contained a greater proportion of larger seed at cooler soil temperatures. Dreyer (8) has also shown that seed size is reduced with increased soil temperatures. Ono (14) reported that pod maturation and size were affected by soil temperature. In general, when seed carbohydrate concentrations were determined for similar maturity stages among the soil temperature treatments, results followed the same temperature trends as seed size results (Table 4). For a maturity class, significantly higher carbohydrate concentrations generally occurred in seed from reduced soil temperature. Carbohydrate concentrations were highest in immature seed from all treatments. Reduced soil temperatures resulted in increased fructose, glucose, sucrose, raffinose and stachyose concentrations. These data collectively indicate that the

Table 2. Carbohydrate concentration in peanut seed sizes grown at three soil temperatures, 1982, Dawson, Georgia.

Carbohydrate	Soil temperature treatment	Seed size mm 5.56	6.35	7.14	8.33
		q/kg			
Fructose	cool	*a0.276 A**	b0.199 A	c0.146 A	c0.120 A
	ambient	a0.227 AB	b0.171 AB	c0.116 B	c0.100 B
	heat	a0.189 B	b0.140 B	c0.090 B	c0.064 C
Glucose	cool	a0.427 A	b0.258 A	c0.182 A	c0.163 A
	ambient	a0.284 AB	b0.207 AB	b0.153 AB	b0.142 A
	heat	a0.240 B	b0.169 B	bc0.130 B	c0.101 B
Sucrose	cool	a75.678 A	b54.571 A	c44.428 A	c43.314 A
	ambient	b69.179 B	b44.848 B	b38.898 B	b38.489 B
	heat	a49.137 C	a41.402 C	b30.028 C	b29.032 C
Raffinose	cool	b1.202 B	a1.424 A	b1.136 A	b1.148 A
	ambient	a1.310 B	a1.566 A	b0.950 A	b0.628 B
	heat	a1.561 A	b1.184 B	c0.554 B	c0.546 B
Stachyose	cool	a2.383 A	a2.333 A	a2.520 A	b1.640 A
	ambient	a2.272 A	a2.114 A	a2.723 A	a1.833 A
	heat	a2.678 A	a2.473 A	b1.708 A	b1.698 A

*Means (in rows) for seed sizes within a soil treatment preceded by the same lower case letter are not significantly different (DNMR, P = 0.05)

**Means (in columns) for soil temperature treatments within a seed size followed by the same capital letter are not significantly different (DNMR, P = 0.05).

Table 3. Carbohydrate concentration in peanut seed sizes grown at three soil temperatures, 1983, Dawson, Georgia.

Carbohydrate	Soil temperature treatment	Seed size mm 5.56	6.35	7.14	8.33
		q/kg			
Fructose	cool	*a0.212 A**	ab0.184 A	bc0.143 A	c0.105 A
	ambient	a0.165 B	a0.147 AB	b0.073 B	b0.070 B
	heat	a0.157 B	a0.110 B	c0.087 B	c0.052 B
Glucose	cool	a0.323 A	ab0.235 A	bc0.212 A	c0.157 A
	ambient	a0.257 B	b0.196 B	c0.150 B	d0.107 B
	heat	a0.217 B	a0.198 B	b0.112 C	b0.082 C
Sucrose	cool	a80.206 A	b64.142 A	c49.505 A	d42.559 A
	ambient	a67.678 B	b55.818 B	c39.098 B	d35.429 B
	heat	a60.475 C	b48.306 C	c33.800 C	c31.453 C
Raffinose	cool	a2.909 A	b1.438 A	c1.046 A	c0.902 A
	ambient	a1.710 B	a1.443 A	b0.895 AB	b0.911 A
	heat	a1.423 B	a1.232 A	b0.741 B	b0.636 B
Stachyose	cool	a2.470 A	a2.249 A	a2.355 A	a2.245 A
	ambient	a2.529 A	a2.470 A	b1.541 A	b1.352 A
	heat	a2.698 A	ab2.263 A	b1.914 A	c1.442 A

*Means (in rows) for seed sizes within a soil treatment preceded by the same lower case letter are not significantly different (DNMR, P = 0.05)

**Means (in columns) for soil temperature treatments within a seed size followed by the same capital letter are not significantly different (DNMR, P = 0.05).

Table 4. Carbohydrate concentration in peanut seed maturity classes grown at three soil temperatures, 1982, Dawson, Georgia.

Carbohydrate	Soil temperature treatment	Maturity class color yellow 2	orange	brown	black
		q/kg			
Fructose	cool	*a0.167 A**	b0.117 A	c0.075 A	--
	ambient	a0.097 B	b0.054 B	c0.035 B	c0.035 A
	heat	a0.082 B	b0.035 C	bc0.030 B	c0.025 B
Glucose	cool	a0.280 A	b0.177 A	c0.123 A	--
	ambient	a0.182 B	b0.109 B	c0.066 B	c0.069 A
	heat	a0.158 C	b0.075 C	c0.053 B	c0.051 B
Sucrose	cool	a26.920 A	b18.888 A	c16.185 A	--
	ambient	a24.571 B	c13.946 B	c14.366 A	b18.750 A
	heat	a22.618 C	b14.357 B	b12.744 B	b12.456 B
Raffinose	cool	a0.594 A	b0.419 A	c0.255 A	--
	ambient	a0.528 A	b0.355 B	c0.195 B	c0.230 A
	heat	a0.528 A	b0.365 B	c0.162 C	c0.149 B
Stachyose	cool	a1.183 A	a1.114 A	a1.140 A	--
	ambient	a0.899 B	a0.944 B	a0.873 B	a0.892 A
	heat	a0.999 B	b0.844 B	c0.523 C	a0.392 B

*Means (in rows) for maturity classes within a soil temperature treatment preceded by the same lower case letter are not significantly different (DNMR, P = 0.05)

**Means (in columns) for soil temperature treatments within a maturity class followed by the same capital letter are not significantly different (DNMR, P = 0.05).

concentrations. These data collectively indicate that the observed significant differences in carbohydrate concentrations occurring in the various seed sizes from different soil temperatures are directly related to the temperature-mediated carbohydrate concentration differences in equivalent maturity classes from each temperature treatment.

The use of supplemental irrigation and verification of moisture stress levels should minimize the potential for variations in stress among plots that could promote differences in photosynthetic rates or photosynthate translocation out of leaves and thus seed carbohydrate concentrations. Soil moisture was maintained below -0.5 bars at the 5 cm level. Among the soil temperature treatments there were no significant differences in leaf canopy temperatures which ranged from 32 to 26 C with a mean of 28 C. Leaf temperature measurements were taken between 1:00 and 2:00 p.m. when potential transient moisture stress would be most evident. The average canopy temperatures were approximately 2 C below air temperature within a range reported by Sanders *et al.* (22) for peanuts, and by investigators (11,12,23) for other crops, as indicating adequate soil moisture.

In the ensuing years, one-year studies were conducted in attempts to ascertain the potential relationship of specific physiological factors to the observed effects of soil temperature on seed carbohydrate concentrations. Highest photosynthetic rates (Pn) for peanuts were reported to occur in the youngest fully expanded leaf (9) and were used in this study. There were no significant differences in the monthly Pn observations or the four monthly treatment means due to soil temperature differences (Table 5). There was a slight but significant reduction in Pn with time in the mean of the four monthly treatments (31.3, 30.6, 29.6, and 22.3 for May through August, respectively) and has been reported previously (9). Brouwer (5) reported that Pn of the three plant species grown under constant soil temperatures ranging from 5-40 C was affected only at the two temperature extremes. Under the diurnal temperature conditions of this study, the temperature extremes between the soil temperature maximums and minimums were less than 17 C in both test years (Table 1). As the temperature extremes in the present study are not as great as those reported by Brouwer (5) to affect photosynthesis, it would seem reasonable to expect an absence in Pn response to these different soil temperatures.

Andreenko and Kerechki (2) reported that the chlorophyll content per unit dry weight was affected by soil temperature and was positively correlated with photosynthetic intensity. However, in our studies, total leaf chlorophyll was not affected by soil temperatures (Table 5). Leaf fructose, glucose or sucrose concentrations were not affected by soil temperatures, also substantiating the Pn and chlorophyll observations (Table 5).

Table 5. Effect of soil temperature on some peanut leaf characteristics.

Soil Temperature Treatment	Net Photosynthesis μ mole $m^{-2}s^{-1}$	Total Chlorophyll mg/g	Area cm^2	Carbohydrates Fructose mg/g	Glucose mg/g	Sucrose mg/g
Cool	28.0	6.99	46.4	4.30	3.30	2.68
Ambient	28.2	6.93	47.7	3.93	3.87	3.24
Heat	29.5	7.32	46.2	3.59	3.43	3.01

No significant differences in treatment means were found, Duncan's New Multiple Range Test 0.05 level.

Main stem length was significantly greater for plants grown in the heated soil, least in the cooled soil, and intermediate from the ambient soil (Table 6); however, there were no significant differences in main stem dry weights due to soil temperature treatments. Similar significant differences in length of cotyledonary branches also occurred. Root dry weight was significantly greater for plants grown in the heated soil and least in the cooled soil. Sucrose concentration was significantly greater in roots from the heated soil. There were no significant differences in fructose or glucose concentrations in roots among the soil temperature treatments. The significant differences in main stem and cotyledonary branch lengths and the increased weight and sucrose concentration of roots, suggests a change in the sink demand for photosynthates. This supposition is supported by the reports of Dreyer *et al.* (8) and also Sanders and Blankenship (21) who found reduced seed size of peanuts grown in heated soil.

Table 6. Effect of soil temperature on peanut stem and root characteristics.

Soil Temperature Treatment	Main Stem Length cm	Main Stem Dry Weight gm	Root Dry Weight gm	Root Sucrose mg/g
Cool	56.2 C	26.1 A	1.3 C	10.14 B
Ambient	60.7 B	27.6 A	1.8 B	9.26 B
Heat	67.3 A	28.1 A	2.1 A	14.44 A

Treatment means followed by the same letter are not significantly different, Duncan's New Multiple Range Test 0.05 level.

The apparent change in sink demand for photosynthate may change during the growing season due to possible differences in fruiting patterns that may occur. Also, the observed carbohydrate differences may be due to a direct effect on the pod resulting from a temperature-driven change in respiration. However, these data indicate that at harvest there is a significant difference in carbohydrate concentrations in peanut seed grown at different soil temperatures and these differences may be due in part to a changed sink demand for photosynthates.

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