Identification of Peanut Genotypes with Improved Drought Avoidance Traits[1]

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ABSTRACT

Peanuts (*Arachis hypogaea* L.) are often subjected to drought during some period in the growing season. A large root system may improve the plant's ability to continue growth during a drought. During greenhouse and field screening trials for resistance to the peanut root-knot nematode [*Meloidogyne arenaria* (Neal) Chitwood, race 1], 16 peanut genotypes were observed to have very large root systems. Using these 16 genotypes plus cultivars Florunner, Southern Runner, and germplasm line Tifton 8 as checks, several studies were conducted to evaluate these genotypes for drought avoidance characteristics. In the first study, root and shoot development were observed at 15-d intervals on plants grown from seed in sand-filled pots. In a second 2-yr study, selections were grown in the field under portable rain-exclusion shelters that created controlled periods of stress. In addition, the genotypes were also planted and observed in unsheltered naturally drought stressed field plots. In the sand-filled pot study, plant inventory (PI) numbers 315628, 268885, 318740, 269106, and 314893 developed the largest root systems. In the field drought stress studies, low visual stress ratings were recorded for Southern Runner, Tifton 8, PI 295722, and PI 315628. Low canopy temperatures characterized PI 315628, Tifton 8, and PIs 295722, 259637, and 268885. When averaged over three tests, sheltered (1991 and 1992) and unsheltered (1991), Tifton 8, PI 318740, Florunner, PI 315622, and PI 315628 produced the highest yields. Two of these higher yielding genotypes (Tifton 8 and PI 315628) had low stress and temperature ratings and PI 315628 also had the largest root system measured in this study.

Key Words: *Arachis hypogaea*, breeding, water stress.

Production of a peanut crop is often limited by insufficient water during some period of the growing season. Several researchers have found that the crop's sensitivity to water deficit stress is dependent on the stage of growth when the stress occurs (Klepper, 1973; Martin and Cox, 1977; Pallas *et al.* 1979). Early and late season stresses are not as detrimental to yield as are midseason stresses. However, late season stresses pose the greatest risk to the crop from aflatoxin contamination.

Wilson and Stansell (1983) found that stressing the crop for at least 40 d before harvest increased the likelihood of aflatoxin contamination. Hill *et al.* (1983) and Sanders *et al.* (1981) noted that pod zone temperatures in the 28 to 31 C range increased the probability of aflatoxin contamination when those temperatures occurred in conjunction with water deficits of 30 d or more.

Over half of the peanut crop in the United States is not irrigated. In many peanut-producing areas, irrigation is unavailable or impractical. Where irrigation is available, drought avoidance traits allow plants to efficiently utilize supplemental water. Identification of traits that improve the plant's ability to exploit soil water and withstand drought, and then incorporation of these traits into adapted peanut cultivars is important.

In 1989, several genotypes having larger than average root systems were noticed in a peanut root-knot nematode [*Meloidogyne arenaria* (Neal) Chitwood, race 1] resistance screening program. Large root systems may improve drought avoidance by utilizing deeper soil water or more effectively extracting soil water from the upper soil horizons. To explore the potential of these large-rooted genotypes, we conducted a series of experiments beginning with a root growth study and progressing to field drought response studies using rain exclusion shelters.

Materials and Methods

Root Growth Study. During greenhouse and field

[1]Cooperative investigation between the Univ. of Georgia, College of Agric. and Environ. Sci. and USDA/ARS. Mention of a product name given for information and should not be considered an endorsement to the exclusion of like products.

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screening trials of 1000 peanut accessions for resistance to the peanut root-knot nematode, 16 genotypes were visually observed to have very large root systems. To verify these observations and collect additional data, we conducted a root growth study using blow-molded polyethylene pots (10 x 10 cm by 45 cm deep). After lining the bottom with cheesecloth, the pots were filled with washed river sand and placed into a frame with a sand bottom (to facilitate drainage). The 16 genotypes, the standard peanut cultivars Florunner and Southern Runner, and the germplasm line Tifton 8, were selected as entries for this study (Table 1). Seed for each entry were screened (8.3 x 25-mm slotted screen for virginia types and 7 x 25-mm slotted screen for all other types) to a uniform size using standard grading screens. The seed were then individually weighed and planted on 12 June 1991 (two seed/pot). After emergence, seedlings were thinned to one per pot by cutting the hypocotyl and leaving the root system of the excised plant in the pot. These plants were grown outside in a small field area at the University of Georgia Gibbs Research Farm near Tifton, GA. The test was conducted using a randomized complete block design with 24 replications. Pots were watered daily until drainage occurred from bottom of pots. The N-free nutrient solution of Burton *et al.* (1972) was applied twice weekly to provide plant nutrients.

Root and shoot measurements of each entry were recorded at 15, 30, 45, and 60 d after planting (DAP). At each harvest date, six replications were individually washed from the pot by immersing in a 100-L water-filled container and then carefully easing the sand mixture from the pot to allow most of the root system to remain intact. Roots adhering to the pot or broken from the plant during the washing process were carefully sieved from the wash water. Root and shoot dry weight were determined on six replications by oven drying at 50 C for 18 hr. Root length was estimated using a line intersection method (Newman, 1966) on two of the six replications. Least squares curve fitting was used to examine growth rates within entries over time. A sigmoidal model was fit. Within sampling dates, the hypothesis of no significant difference among entries was tested using the GLM procedure of SAS (SAS Institute, 1989) and the Waller-Duncan procedure was used for separation of means (Waller and Duncan, 1969).

Drought Response Studies. The same 19 peanut entries used in the previous study were planted in field trials, with and without rain exclusion shelters. In each experiment, entries were planted in a randomized complete block design with five replications. The experiment site was at the Coastal Plain Experiment Station in Tifton, GA. Each plot was one row 1.5 m long. Plots were arranged in adjacent rows with a 0.9 m inter-row spacing. Seed from each entry were planted at a seeding rate of 20 seed/m into a Tifton loamy sand (fine-loamy, siliceous, thermic Plinthic Paleudults, pH 6.2) on 19 June 1991 and 13 May 1992. Soil was prepared by moldboard plowing 25 cm deep followed by tillivating before planting. Due to restrictions in sheltered space, all entries were placed side to side without guard rows. Other cultural practices were consistent with recommendations of the Georgia Cooperative Extension Service (Johnson *et al.*, 1987).

In the sheltered experiments, the 19 peanut entries were grown under normal field conditions until the stress period (from 20 September to 1 November 1991 and 21 August to 24 September 1992) was imposed by placing large (9 x 25 m) polyethylene-covered greenhouse-like structures over the entire plot area. The shelters were Quonset hut-shaped and had reinforced metal tubing skeletons resting on skids. Ventilation was provided by 1.2-m high skirts rolled up along the sides and 1.5-m high screens on the ends. Air and soil temperatures and light energy under the shelter averaged 5 C higher, 4 C higher, and 17% lower, respectively, than those in adjacent unsheltered areas. Rain water shed by the shelters was diverted from the plot area by soil diversions. An unsheltered field trial provided a third test of drought tolerance when 1991 weather conditions created a rainless period from 60 until 97 DAP. All entries were dug 140 DAP in the 1991 sheltered experiment and 134 DAP in the 1992 sheltered experiment.

In the 1991 unsheltered experiment, all entries were dug at 97 DAP when the rainless period ended. This early digging date was used to gather data related to performance under drought rather than to measure recovery from a drought. Pan evaporation and rainfall for the unsheltered plots during the periods 0 to 30 DAP, 30 to 60 DAP, and 60 to 90 DAP were 13.5 and 22.7 cm, 12.4 and 13.0 cm, and 11.4 and 0.2 cm, respectively.

In all three (two sheltered and one unsheltered) field trials, canopy temperatures were measured using a Teletemp infra-red thermometer, and visual ratings were made for stress on each plot. Biweekly temperature and visual ratings began at 79 DAP in 1991 and 108 DAP in 1992 for the sheltered test and continued (at 1300 hr) until harvest. Visual stress ratings were based on a 1-5 scale: 1 showing no stress (leaves raised and turgid, bright green color) and a rating of 5 being the most stressed (leaves folded and lacking turgor, gray cast to the plants). At harvest, plants were dug and inverted, pods harvested by hand, and cured with forced air (35 C) until kernel moisture reached 10% when pod weights were recorded.

Data from each experiment were analyzed using the PROC GLM procedure of SAS (1985). The LSD values were calculated when the F-test showed significant differences ($P=0.05$) among treatment means.

Results

Root Growth Study. Root weight and length during the first 60 DAP showed a sigmoidal growth curve which tapered off between 45 and 60 DAP. These data indicated that pot size became limiting for root growth shortly after the 45-d samples were taken. For this reason, we selected the data collected at 45 DAP for comparisons and correlations to be made from this study.

Data in Table 1 shows all entries ranked from greatest root weight to least. The six PIs 315628, 318740, 269106, 314893, 196744, and 315631 averaged 60% greater root weight than the control cultivars, Florunner and Southern Runner.

The root length of the top five entries differed from the bottom two entries by an average of 86% at the 45 DAP sampling date (Table 1). PIs 196744, 196754, 315631, 269106, and Tifton 8 developed the most extensive root systems (averaging 80% greater root length than the cultivar Southern Runner). In contrast, PI 295722, Southern Runner, and PI 314893 exhibited less root length compared to the other genotypes (Table 1).

Shoot growth lagged root growth for the first 45 d, after which a period of more rapid shoot growth was measured

Table 1. Root and shoot weights and total root length of peanut plants taken from 45 cm deep pots 45 d after planting.[a]

Genotype	Dry root weight	Dry shoot weight	Total root length
	g	g	cm
PI 315628	1.88 A	4.89 B-D	7,939 C-G
PI 318740	1.76 A-B	6.59 A	7,514 C-G
PI 269106	1.75 A-C	5.02 B-C	9,998 B-C
PI 314893	1.75 A-C	4.05 B-E	6,078 F-G
PI 196744	1.73 A-D	4.92 B-D	13,792 A
PI 315631	1.71 A-D	3.75 C-E	9,343 B-E
PI 268885	1.66 A-E	4.34 B-E	8,722 B-F
Tifton 8	1.56 A-E	5.30 B	9,898 B-C
PI 315634	1.51 A-F	3.78 C-E	6,655 D-G
PI 315626	1.50 A-F	5.02 B-C	7,776 C-G
PI 161869	1.46 A-G	4.04 B-E	6,440 E-G
PI 196754	1.45 A-G	4.14 B-E	11,643 B-E
PI 315622	1.43 A-G	3.23 E	7,834 C-G
PI 145681	1.28 B-H	3.22 E	7,326 C-G
PI 319736	1.23 B-H	2.94 E	7,315 C-G
PI 259639	1.16 E-H	2.73 E	7,792 C-G
Florunner	1.14 E-H	3.58 D-E	8,950 B-F
Southern Runner	1.06 F-I	3.29 E	6,047 F-G
PI 295722	0.97 G-I	2.80 E	5,706 G

[a]Means followed by the same letter are not different (P=0.05) according to Duncan-Waller multiple range test.

up to 60 d. Correlations coefficients between root weight and shoot weight were significant (P=0.01) and positive (r=0.76), indicating that plants with large shoots also had large root systems. The correlation coefficient between root weight and root length (r=0.41) was significant at P=0.07 (Table 2).

Drought Response Studies. Visual drought stress ratings were correlated with canopy temperature (r=0.75) (P=0.01) and with yield (r=0.57) (P=0.01) (Table 2). The lowest stress ratings were recorded for Tifton 8, Southern Runner, and PI 315628 whereas PIs 315631, 169744, and 196754 received the highest stress rating (Table 3). Entries showing the lowest stress ratings in one environment also showed low stress in the other two environments. The three entries showing the highest stress were similar in the three environments.

Canopy temperatures were significantly (P=0.03) correlated (r= -0.48) with yield (Table 2). In 1991, the entries with the lowest mean canopy temperatures included PI 315628 and Tifton 8, whereas PI 169754 was among the entries with the highest canopy temperatures (Table 4). However, both Florunner and Southern Runner were also among the entries with high canopy temperatures. In 1992, there were few differences among canopy temperatures. Entries with the highest or lowest canopy temperatures in one environment were also in the highest and lowest canopy temperature group in the other two environments.

Tifton 8, PI 318740, and Florunner were the top yielding entries as averaged over the three study environments (Table 5). The three entries recording the lowest mean pod yields were PIs 169754, 161869, and 315626.

Table 2. Correlations among mean root and shoot weight and root/shoot weight ratio taken in the pot study and mean yield and canopy temperature and visual stress ratings taken in the drought response studies for the 19 genotypes.

	Root wt[a]	Shoot wt[a]	Root/shoot[a]	Yield[c]	Canopy temp.[d]	Visual rating
Shoot weight	0.76[b]					
Root/shoot	0.02	-0.62				
Yield	0.07	0.21	-0.18			
Canopy temp.	-0.10	-0.09	0.01	-0.48		
Visual rating	0.15	0.06	0.09	-0.57	0.75	
Root length	0.41	0.40	-0.16	-0.16	0.16	0.57

[a]Root weight (g), shoot weight (g), root/shoot weight ratio (g/g), and root length (cm) were computed for each cultivar as the mean of six replications sampled 45 DAP.

[b]Number in each cell is the correlation coefficient.

[c]Yields (kg/ha) were computed for each genotype as the mean over three field studies.

[d]Canopy temperatures (C) and visual ratings were computed for each genotype as the means of all observations of the six replications of the three field experiments.

Table 3. Mean visual stress ratings of peanut genotypes during drought period of the three study environments.[a]

Genotype	1991 Sheltered	1991 Unsheltered	1992 Sheltered	Mean
Tifton 8	2.1 E	2.4 F-G	2.1 E	2.2 D
Southern Runner	2.2 G	2.1 G	2.6 C-E	2.3 C-D
PI 315628	2.2 G	2.4 F-G	2.4 D-E	2.3 C-D
PI 145681	2.2 G	2.7 C-E	2.2 E	2.4 C-D
PI 269106	2.3 G	2.6 D-F	2.5 D-E	2.5 B-D
PI 295722	2.2 G	2.3 F-G	3.0 B-E	2.5 B-D
PI 314893	2.4 F-G	2.4 F-G	2.7 C-E	2.5 B-D
PI 268885	2.4 E-G	2.5 E-F	2.9 B-E	2.6 B-D
PI 259639	2.6 D-F	2.5 E-F	2.7 B-E	2.6 B-D
PI 315622	2.7 C-D	2.8 C-D	2.7 B-E	2.7 B-D
Florunner	2.8 C-D	3.0 C	2.6 C-E	2.8 B-C
PI 318740	2.9 C	3.0 C	2.6 C-E	2.8 B-C
PI 315634	2.7 C-E	2.8 C-D	3.4 B-D	3.0 B
PI 319736	2.7 C-D	2.6 D-F	3.6 B-C	3.0 B
PI 315626	2.8 C-D	2.9 C	3.3 B-D	3.0 B
PI 161869	2.6 C-F	2.9 C	3.6 B-C	3.0 B
PI 315631	3.5 A	3.7 A	3.7 B	3.6 A
PI 196744	3.3 A-B	3.4 B	4.8 A	3.8 A
PI 196754	3.2 B	3.6 A-B	4.9 A	3.9 A

[a]Drought stress ratings are visual ratings on a 1-5 scale: 1=no stress and 5=most stress. Means followed by the same letter are not different (P=0.05) according to Duncan-Waller multiple range test.

Entries that produced the highest and lowest yields in one environment responded similarly in the other environments. The variability in rankings among environments for pod yield was, however, slightly greater than

Table 4. Mean canopy temperatures (C) during drought period of the three study environments.[a]

Genotype	1991 Sheltered	1991 Unsheltered	1992 Sheltered	Mean
	C		C	
PI 315628	32.1 F-H	34.4 H	37.3 AB	34.6 E
Tifton 8	31.4 H	35.2 F-H	37.3 AB	34.6 E
PI 314893	32.4 E-G	34.9 G-H	37.1 AB	34.8 D-E
PI 259639	32.0 F-H	34.9 G-H	37.6 AB	34.8 D-E
PI 269106	32.6 C-G	35.2 F-H	36.8 B	34.9 D-E
PI 295722	31.8 G-H	34.9 G-H	37.9 AB	34.9 D-E
PI 268885	32.2 C-G	34.9 G-H	38.2 AB	35.1 C-E
PI 315622	32.7 B-F	35.9 E-F	37.7 AB	35.3 B-E
PI 318740	33.1 A-E	36.0 D-F	37.7 AB	35.6 A-E
PI 145681	33.3 A-C	36.9 A-C	36.8 B	35.7 A-E
PI 319736	33.1 A-E	35.3 F-G	38.6 AB	35.7 A-E
PI 315626	33.0 A-E	36.0 D-F	38.1 AB	35.7 A-E
Florunner	33.3 A-D	36.8 A-D	37.4 AB	35.8 A-E
Southern Runner	33.1 A-E	36.9 A-C	37.6 AB	35.9 A-D
PI 196744	33.4 A-C	36.3 B-E	39.1 AB	36.3 A-C
PI 196754	33.4 A-C	36.3 C-E	39.4 A	36.4 A-B
PI 315631	33.5 A-B	37.1 A-B	38.6 AB	36.4 A-B
PI 315634	33.4 A-C	37.0 A-C	39.0 AB	36.5 A-B
PI 161869	33.8 A	37.3 A	39.2 A	36.8 A

[a]Means followed by the same letter are not different (P=0.05) according to Duncan-Waller multiple range test.

Table 5. Mean pod yield (kg/ha) of the three study environments.[a]

Genotype	1991 Sheltered	1991 Unsheltered	1992 Sheltered	Mean
		kg/ha		
Tifton 8	2432 A	2323 A-B	1526 A	2094 A
PI 318740	1873 A-D	2545 A	1533 A	1984 A-B
Florunner	2203 A-B	2404 A	1287 A-C	1965 A-C
PI 315622	1643 A-E	2244 A-B	1441 A-B	1776 A-D
PI 315628	1945 A-C	2222 A-B	1123 A-D	1763 A-D
PI 315634	2050 A-B	1659 C-E	1058 A-E	1589 A-E
Southern Runner	2171 A-B	1674 C-E	823 B-E	1556 A-F
PI 268885	1564 B-F	2122 A-D	909 A-E	1532 A-F
PI 314893	1686 A-D	1843 C-E	968 A-E	1499 A-F
PI 295722	1984 A-C	1658 C-E	633 C-E	1425 A-F
PI 259639	1917 A-C	1619 D-F	593 D-E	1377 A-F
PI 145681	1702 A-D	1341 E-F	1038 A-E	1360 B-F
PI 315631	786 F	2166 A-C	948 A-E	1300 B-F
PI 319736	1675 A-D	1659 C-E	482 D-E	1272 C-F
PI 269106	1535 B-F	1659 C-E	428 E	1207 C-F
PI 196744	1012 D-F	1373 E-F	1124 A-D	1170 D-F
PI 315626	1140 C-F	1360 E-F	507 D-E	1002 E-F
PI 161869	1476 C-F	713 G	491 D-E	896 E-F
PI 196754	817 E-F	1121 F-G	626 C-E	855 F

[a]Means followed by the same letter are not different (P=0.05) according to Duncan-Waller multiple range test.

for visual rating and canopy temperature.

Discussion

With the exception of Southern Runner, Tifton 8, and Florunner, all entries in this study were selected in a preliminary screening for large root systems. From this group we hoped to identify genotypes with traits that may be used to improve the ability of future peanut cultivars to withstand drought.

Plants adapt to water deficit and to the often associated heat stress in many ways. This gives plant breeders several possible traits to select when attempting to improve the ability of a plant to withstand a drought. Normally these traits fall in one of two categories: tolerance or avoidance. Tolerance mechanisms allow the plant to survive and possibly function by preventing, decreasing, or repairing damages. For example, a heat-tolerant plant is able to carry on photosynthesize and respiration at a high plant temperature.

In this study, we initially identified genotypes that may be using a drought avoidance mechanism. Examples of avoidance mechanisms include those that insulate plant cells from tissue desiccation, allowing them to function normally even though soil water is depleted. For example, the thickening of a plant's cuticle, or as in the case of this study, increased water uptake by roots. Thorough water extraction from the soil profile is also an avoidance mechanism. Passioura (1983) noted that despite being severely water stressed, many plants leave large amounts of unused, available water in the subsoil. If roots are able to tap this unused water source it may help increase the yield in a water limited environment. Like Ketring *et al.* (1982), we found considerable diversity in root growth and a high correlation between shoot and root growth among genotypes. Our controlled root study identified PIs 315628, 318740, 269106, and 314893 as having large root systems. However, we did not measure soil moisture in any of these studies and therefore cannot conclude that these large root systems actually extracted more water from the soil.

Low visual stress ratings (Southern Runner, Tifton 8, PI 295722, and PI 315628) or low canopy temperatures (PI 315628, Tifton 8, PI 295722, and PI 259637) also indicate genotypes that may be using an avoidance mechanism to maintain turgor and temperature. The low stress rating and temperature measurements of PI 315628 may be related to its large root system. However, PI 295722 had the smallest root system tested, yet low temperature and stress ratings. This indicates that the genotype may be avoiding stress in a way other than through extraction of available soil water, such as reducing the thermal load through reflectance or leaf angles.

Yield progressively decreases as duration of the drought increases and as the midseason approaches (Pallas *et al.*, 1979). Past studies have shown early season drought to have little effect on the yield of peanut, but water deficit during the late flowering and pod-forming periods (71-105 DAP) is detrimental to peanut yield (Stansell and Pallas, 1985; Roy *et al.*, 1988). These studies also found late season droughts to be responsible for increased risk of aflatoxin, yet yield losses were not as severe as with midseason stress. We imposed our drought periods from late midseason to harvest in order to identify genotypes best suited to survive the mid- to late season drought which is often encountered in the peanut growing regions of the United States.

In our studies, the cultivar Florunner was among the highest yielding genotypes despite its relatively low root weight. This study, however, did not address many of the other traits known to influence pod yield such as dry matter partitioning and fruit set patterns, nor did it examine all drought avoidance and tolerance mechanisms. Years of selection for yield have resulted in a multitude of traits that collectively have made Florunner an excellent yielding cultivar under a wide range of environmental conditions.

We have identified germplasm that could be used in a peanut breeding program to improve the yield under drought stress. Genotypes were initially selected with large root systems, and several of these genotypes were found to have improved ability to avoid drought. PIs 318740 and 315628, the two entries having the largest root weight in our pot study, were also among the highest yielding entries. In conclusion, this research resulted in the identification of several genotypes possessing traits which have the potential to improve drought tolerance in Southeastern United States-grown peanuts.

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