Genotype-by-Environment Interaction in Roasted Peanut Attribute[1]

H.E. Pattee*[2], T.G. Isleib[3], and F.G. Giesbrecht[4]

ABSTRACT

Although roasted flavor of peanut (*Arachis hypogaea* L.) seed is an important attribute with respect to consumer acceptance, little is known about the relative influences of cultivar, environment, and their interaction on expression of the trait. From 1986 to 1991, samples of seven peanut cultivars were obtained from peanut research programs representing the three major production areas in the United States. Samples were roasted to a nearly common color, ground into paste, and assessed for roasted flavor and fruity attribute by a trained sensory panel. CIELAB L°a°b° color was also measured for use as a covariate in statistical analysis to adjust for remaining differences in color. Subsets of the data were constructed to be orthogonal for cultivar and environment. Environmental variation was highly significant for all subsets and for the overall data set with variation among years being the largest component. Production regions were not a significant source of variation, but locations within years and regions were significant. Cultivars varied significantly in most cases with the runner cultivars Florunner and Marc I consistently superior in flavor to virginia cultivars Florigiant, NC 7, NC 9, and NC-V 11. There were no significant differences among the virginia cultivars. Pronto, a spanish cultivar, was comparable to the virginia cultivars in flavor. Cultivar-by-environment interaction was significant in the overall data set and in most of the orthogonal subsets. The main component of interaction in the overall set was cultivar-by-location interaction within years and regions. Results were inconsistent in the various subsets with cultivar-by-region interaction being significant only in one subset. Components of variance and standard errors of cultivar mean comparisons estimated from the overall data set indicate that design of field experiments to compare genotypic means should emphasize replication across year-location combinations rather than replication within combinations. For accurate estimation of means, replication across several years is necessary, but for comparison of genotypes, additional locations may be substituted for years.

Key Words: *Arachis hypogaea* L., breeding, variance components, experimental design.

Economic traits of crop species often are influenced by many sources of phenotypic variation. In crop breeding programs, great care is taken to design field experiments such that the genetic and environmental sources of variation can be separated and accurately measured. Flavor of roasted peanut (*Arachis hypogaea* L.) seed is an important characteristic influencing consumer acceptance, yet there has been little research into the genetic and environmental factors influencing roasted flavor. In the recently opened area of inheritance of roasted peanut flavor (Pattee and Giesbrecht, 1990; Pattee *et al.*, 1993), many sources of variation are still under investigation. Documentation of these components of variance is important for the efficient allocation of resources to measure roasted peanut attribute values to be used in comparing genotypes. Two sources of variation that already have been identified and appropriate statistical covariant adjustments proposed are the roast color of the paste and the fruity sensory attribute (Pattee and Giesbrecht, 1994). Although intuitively significant, macroenvironmental effects, such as year and location, need to be tested for significance. Adjustment of flavor scores for environmental effects would provide a basis for comparison of roasted peanut scores across years and locations. The relative importance of various components of genotype-by-environment interaction on flavor determine the optimal distribution of testing resources to identify

[1]The research reported in this publication was a cooperative effort of the USDA-ARS and the North Carolina Agric. Res. Serv., Raleigh, NC 27695-7643. The use of trade names in the publication does not imply endorsement by the USDA or the North Carolina Agric. Res. Serv. of the products named nor criticism of similar ones not mentioned. Partial funding was received from the North Carolina Peanut Growers Association.

[2]Res. Chem., USDA-ARS, Dept. of Botany, North Carolina State Univ., Box 7625, Raleigh, NC 27695-7625.

[3]Assoc. Prof., Dept. of Crop Science, North Carolina State Univ., Box 7629, Raleigh, NC 27695-7629.

[4]Prof., Dept. of Statistics, North Carolina State Univ., Box 8203, Raleigh, NC 27695-8204.

*Corresponding author.

superior genotypes.

In the United States, peanuts are produced mainly in three regions: the Southeast (Georgia, Florida, and Alabama), the Southwest (Texas and Oklahoma), and the Virginia-Carolina area (Virginia and North Carolina). Peanut production in the Virginia-Carolina area is exclusively the virginia market-type while producers in the Southeast grow mainly runner-type peanuts. The ancestors of cultivars in the runner and virginia market-types are predominantly members of *A. hypogaea* ssp. *hypogaea* var. *hypogaea*, but in both types there has been substantial introgression of germplasm from spanish (*A. hypogaea* ssp. *fastigiata* Waldron var. *vulgaris* Harz) ancestors (Isleib and Wynne, 1992). In the Southwest, runner, virginia, and spanish market-types are all produced, but runner and spanish cultivars predominate. Claims of superiority in flavor for one market-type or another are often made, but comparisons of flavor between market-types commonly have been confounded with differences in the predominant production region for those types. Limited location effect on roasted peanut intensity has been published for peanuts grown within the Virginia-Carolina area (Pattee *et al.*, 1993), but differences among the three peanut-growing regions could not be measured. Data collected by the Planters/Lifesavers division of RJR Nabisco Corporation indicated that some cultivars in the virginia market-type developed better roasted flavor when grown in Southeastern locations than when grown in the Virginia-Carolina area while others did not (P. Valenti and R. Capellutti, pers. commun.). Pattee and Giesbrecht (1994) did not find a significant genotype-by-region interaction but did not present data. It was the objective of this paper to determine the effects of year, region, and location within region on roasted peanut scores and to ascertain which, if any, of these environmental effects interacts with genotype in determining flavor.

Materials and Methods

Genotype Resources. Seed samples were obtained from peanut breeding and cultivar testing programs in Florida, Georgia, North Carolina, Oklahoma, Texas, and Virginia. Nearly all commercially available cultivars and each market-type grown in the United States were represented in the set, but only a limited number of cultivars were represented at five or more test sites (Table 1). All samples were obtained from plants grown and harvested under standard recommended procedures for the specific location. Samples from two programs (T.A. Coffelt, USDA-ARS, and R.W. Mozingo, Virginia Polytechnic Institute and State University) at the Tidewater Agricultural Research Station in Suffolk, VA, were considered to originate from different sources because of different post-harvest handling. Replicate samples for each genotype were obtained from a given site when available.

Sample Handling. Each year, a 1000-g sample of the sound-mature-kernel (SMK) fraction from each replicate of each location-entry was shipped to Raleigh, NC, in February following harvest and placed in controlled storage at 5 C and 60% RH until roasted. SMK fractions were separated using official grading standards for each market type.

Sample Roasting and Preparation. The peanut samples from each year were roasted between May and July using a Blue M "Power-O-Matic 60" laboratory oven, ground into a paste, and stored in glass jars at -20 C until evaluated. The roasting, grinding, and color measurement protocols were as described by Pattee and Giesbrecht (1990).

Sensory Evaluation. A long-standing eight-member trained roasted peanut profile panel at the Food Science Department, North Carolina State University, Raleigh, NC, evaluated all peanut-paste samples using a 14-point intensity scale. Panel orientation and reference control were as described by Pattee and Giesbrecht (1990) and Pattee *et al.* (1993). Two sessions were conducted each week on nonconsecutive days.

Table 1. Distribution of samples of cultivars obtained from peanut breeding and evaluation programs, 1986-1991.

			Cultivar							
Year	Region[a]	Location	Flori-giant	Flo-runner	Marc I	NC 7	NC 9	NC-V 11	Pronto	No. of cv.'s
1986	SE	Marianna, FL	2	2	1	2	--	--	2	5
1986	SE	Tifton, GA	2	2	--	--	--	--	1	3
1987	SE	Tifton, GA	--	2	--	--	--	--	--	1
1988	SE	Tifton, GA	2	2	--	2	--	2	2	5
1990	SE	Marianna, FL	3	2	2	2	3	2	--	6
1990	SE	Tifton, GA	2	6	2	2	2	2	2	7
1991	SE	Marianna, FL	--	5	--	6	4	--	--	3
1991	SE	Tifton, GA	--	3	--	4	--	--	--	2
1986	SW	Stillwater, OK	2	1	--	--	--	--	1	3
1986	SW	College Station, TX	--	1	--	--	--	--	1	2
1986	SW	Stephenville, TX	1	2	--	--	--	--	--	2
1990	SW	College Station, TX	2	9	2	3	--	2	4	6
1990	SW	Stephenville, TX	--	2	--	--	--	--	--	1
1986	VC	Lewiston, NC	1	1	--	2	2	1	--	5
1986	VC	Suffolk (Coffelt), VA	--	1	--	--	--	--	1	2
1986	VC	Suffolk (Mozingo), VA	1	--	--	1	--	1	--	3
1987	VC	Suffolk (Coffelt), VA	--	1	--	--	--	--	1	2
1987	VC	Suffolk (Mozingo), VA	1	--	--	1	1	1	--	4
1988	VC	Northampton Co., NC	3	--	--	3	3	2	--	4
1988	VC	Suffolk (Coffelt), VA	2	2	--	2	2	2	2	6
1988	VC	Suffolk (Mozingo), VA	3	--	--	2	3	2	--	4
1990	VC	Clayton, NC	1	--	--	1	1	1	--	4
1990	VC	Lewiston, NC	1	2	--	2	1	1	--	5
1990	VC	Suffolk (Coffelt), VA	4	4	2	3	3	3	4	7
1991	VC	Lewiston, NC	--	4	--	2	--	--	--	2
1991	VC	Whiteville, NC	--	--	--	2	--	--	--	1
1991	VC	Suffolk (Coffelt), VA	--	4	--	8	--	4	--	3
Number of environments			17	21	5	19	11	14	11	98

[a] SE=Southeast (Georgia, Florida, and Alabama), SW=Southwest (Texas and Oklahoma), VC=Virginia-Carolina (Virginia and North Carolina).

Panelists evaluated six samples per session in 1986, five samples per session in 1987-88, and four samples per session in all subsequent years. Sensory evaluation commenced mid-June and continued until all samples were evaluated. The averages of individual panelists' scores on sensory attributes were used in all analyses in this study.

Statistical Analysis. The full data set was examined to derive all possible subsets orthogonal for cultivar and source (environment). Subsets chosen for analysis (Table 2) had special characteristics. Subset 1 was the largest, having 40 cultivar-environment combinations, but included only virginia-type cultivars. Subset 3 was the largest subset including virginia cultivars with Florunner, the runner-type cultivar used as a flavor standard by the peanut industry. Subset 7 included all four of the virginia cultivars and Florunner. Subset 13 included only Florunner and NC 7 but represented 13 of the 21 environments. Subset 17 was the largest subset to include Pronto, a common cultivar of the spanish market-type. Subset 22 included all data on Pronto with Florunner as a check. Subset 27 included all data on Marc I, a recent release in the runner market-type (Gorbet *et al.*, 1992). The subset including all data, although not orthogonal for genotype and environment, was also subjected to analysis of variance. Unfortunately, there was no subset with a balanced structure of years, regions, and locations within years and regions.

In each analysis, variation was partitioned into parts due to environment, genotype, genotype-by-environment interaction, and error. Error sums of squares were reduced further by the application of paste color (linear and quadratic effects) and fruity attribute (linear effect only) as covariates. Paste color was selected as a covariate to correct for the unavoidable sample-to-sample variation in degree of roast. Fruity attribute reflects a combination of immaturity and improper handling after harvesting. While it can be argued that the frequency of immature kernels may have a genetic component, the importance of cultural practices such as time of harvest and handling of the crop justify the use of fruity attribute as a covariate (Pattee and Giesbrecht, 1994). Environmental effects were further divided into portions due to region, year, region-by-year interaction, and location within region and year. The sum of squares for cultivar-by-environment interaction was divided in an analogous manner. When appropriate, orthogonal contrasts were used to partition variation among cultivars. All effects were considered fixed, and significance was tested by constructing F-ratios with partial means squares for effects in the numerator and the error mean square in the denominator. All statistical analyses were performed using procedures in the SAS (1987) system, version 6.

A second analysis was performed to obtain estimates of the standard errors of differences between cultivar means. In this analysis, the effects of year, year-by-region interaction, location, cultivar-by-year interaction, cultivar-by-year-by-region interactions, and cultivar-by-location interactions were assumed to be random rather than fixed effects. The

Table 2. Subsets of data used for statistical analysis of genotype-by-environment interaction.

Subset	Cultivar	Region[a]	Year	Location
1	Florigiant	SE	1990	Marianna, FL
	NC 7			Tifton, GA
	NC 9	VC	1986	Lewiston, NC
	NC-V 11			Suffolk (Mozingo), VA
			1988	Northampton Co., NC
				Suffolk (Coffelt), VA
				Suffolk (Mozingo), VA
			1990	Clayton, NC
				Lewiston, NC
				Suffolk (Coffelt), VA
3	Florigiant	SE	1988	Tifton, GA
	Florunner		1990	Marianna, FL
	NC 7			Tifton, GA
	NC-V 11	SW	1990	College Station, TX
		VC	1986	Lewiston, NC
			1988	Suffolk (Coffelt), VA
			1990	Lewiston, NC
				Suffolk (Coffelt), VA
7	Florigiant	SE	1990	Marianna, FL
	Florunner			Tifton, GA
	NC 7	VC	1986	Lewiston, NC
	NC 9		1988	Suffolk (Coffelt), VA
	NC-V 11		1990	Lewiston, NC
				Suffolk (Coffelt), VA
13	Florunner	SE	1986	Marianna, FL
	NC 7		1988	Tifton, GA
			1990	Marianna, FL
				Tifton, GA
			1991	Marianna, FL
				Tifton, GA
		SW	1990	College Station, TX
		VC	1986	Lewiston, NC
			1988	Suffolk (Coffelt), VA
			1990	Lewiston, NC
				Suffolk (Coffelt), VA
			1991	Lewiston, NC
				Suffolk (Coffelt), VA
17	Florigiant	SE	1986	Marianna, FL
	Florunner			Tifton, GA
	Pronto		1988	Tifton, GA
			1990	Tifton, GA
		SW	1986	Stillwater, OK
			1990	College Station, TX
		VC	1988	Suffolk (Coffelt), VA
			1990	Suffolk (Coffelt), VA
22	Florunner	SE	1986	Marianna, FL
	Pronto			Tifton, GA
			1988	Tifton, GA
			1990	Tifton, GA
		SW	1986	Stillwater, OK
				College Station, TX
			1990	College Station, TX
		VC	1986	Suffolk (Coffelt), VA
			1987	Suffolk (Coffelt), VA
			1988	Suffolk (Coffelt), VA
			1990	Suffolk (Coffelt), VA
27	Florigiant	SE	1986	Marianna, FL
	Florunner		1990	Marianna, FL
	Marc I			Tifton, GA
	NC 7	SW	1990	College Station, TX
		VC	1990	Suffolk (Coffelt), VA

[a] SE=Southeast (Georgia, Florida, and Alabama), SW=Southwest (Texas and Oklahoma), VC=Virginia-Carolina (Virginia and North Carolina).

MIXED procedure in SAS (1992) was used to compute modified or residual maximum likelihood (MML or REML) estimates of the variance components corresponding to the random effects in the overall data set. These estimates differ from the conventional maximum likelihood estimates in that the likelihood is based on the error contrasts remaining after fitting the fixed effects of the model (Patterson and Thompson, 1971).

For a balanced test of cultivars across a number of years (y), regions (r), and locations (l) in each year-region combination, and with the same number of observations (n) obtained from a completely random design at each location, the expected mean squares from the analysis of variance are presented in Table 3 and the standard error of the difference between two cultivar means was estimated as:

$$s_{Diff} = \sqrt{2\left(\frac{\hat{\sigma}^2_{CY}}{y} + \frac{\hat{\sigma}^2_{CL(YR)}}{yrl} + \frac{\hat{\sigma}^2}{yrln}\right)}$$

where $\hat{\sigma}^2_{CY}$ is the estimate of cultivar-by-year interaction, $\hat{\sigma}^2_{CL(YR)}$ is the estimate of cultivar-by-location interaction within year and region, and $\hat{\sigma}^2$ is the estimate of experimental error variance.

Results and Discussion

The coefficient of variation measured for different subsets ranged from 6.4 to 12.4% (Table 4). Covariates accounted for significant amounts of variation in all subsets. The cultivar-by-environment interaction sums of squares were reduced by 23 to 56% in the various subsets by applying the covariates. It has been documented that the degree of roast, indicated by paste color, exerts a linear and quadratic effect on roasted peanut score (Pattee and Giesbrecht, 1994). The relationship of the fruity attribute to genotype-by-environment interaction has not yet been fully explained. Nonsignificant F-ratios for individual covariates indicated that simplification of the covariate model would be possible in some subsets. Nevertheless, these analyses confirm the utility of adjusting the data using covariates.

Table 3. Expected mean squares from analysis of variance of flavor scores of samples from y years, r regions, l locations per year-region combination, and n samples per test.

Source	df	Expected mean square
Year	y-1	$\sigma^2 + nc\,\sigma^2_{L(YR)} + nclr\,\sigma^2_Y$
Region	r-1	$\sigma^2 + nc\,\sigma^2_{L(YR)} + ncl\,\sigma^2_{YR} + ncly\,\theta^2_R$
Year x region	(y-1)(r-1)	$\sigma^2 + nc\,\sigma^2_{L(YR)} + ncl\,\sigma^2_{YR}$
Location in year, region	yl(r-1)	$\sigma^2 + nc\,\sigma^2_{L(YR)}$
Cultivar	c-1	$\sigma^2 + n\,\sigma^2_{CL(YR)} + nlr\,\sigma^2_{CY} + nlry\,\theta^2_C$
Cultivar x year	(c-1)(y-1)	$\sigma^2 + n\,\sigma^2_{CL(YR)} + nlr\,\sigma^2_{CY}$
Cultivar x region	(c-1)(r-1)	$\sigma^2 + n\,\sigma^2_{CL(YR)} + nl\,\sigma^2_{CYR} + nly\,\theta^2_{CR}$
Cultivar x year x region	(c-1)(y-1)(r-1)	$\sigma^2 + n\,\sigma^2_{CL(YR)} + nl\,\sigma^2_{CYR}$
Cultivar x location in year, region	yr(c-1)(l-1)	$\sigma^2 + n\,\sigma^2_{CL(YR)}$
Error	yrlc(n-1)	σ^2

where σ^2_Y is the component of variance associated with years,

θ^2_R is the variance of region effects,

σ^2_{YR} is the component of variance associated with year-by-region interaction,

$\sigma^2_{L(YR)}$ is the component of variance associated with locations in year and region,

θ^2_C is the variance of cultivar effects,

σ^2_{CY} is the component of variance associated with cultivar-by-year interaction,

θ^2_{CR} is the variance of cultivar-by-region interaction effects,

σ^2_{CYR} is the component of variance associated with cultivar-by-year-by-region interaction,

$\sigma^2_{CL(YR)}$ is the component of variance associated with cultivar-by-location interaction in year and region,

σ^2 is the component of variance associated with experimental error.

Table 4. Partial mean squares from analysis of variance of flavor data subsets.

	Subset 1		Subset 3		Subset 7		Subset 13		Subset 17		Subset 22		Subset 27		All Data	
	df	MS	df	MS	df	MS	df	MS	df	MS	df	MS	df	MS	df	MS
Environment	9	1.5238**	7	1.4369**	5	2.3479**	12	1.4440**	7	1.8293**	10	1.3863**	4	1.9219**	26	1.8115**
Region	1	0.0115	2	0.0264	1	0.0357	2	0.0226	2	0.3015†	2	0.3737†	2	0.1050	2	0.0994
Year	3	1.7958**	2	3.3883**	2	4.1056**	3	4.6882**	2	5.4155**	3	3.3047**	1	6.4555**	4	6.5718**
Region x year			1	0.0964			3	0.0522	2	0.0497	3	0.1556			5	0.0624
Location in region, year	5	0.7874*	2	0.4823*	2	0.3629†	4	0.1421	1	0.0727	2	0.0128	1	0.8450**	15	0.4045**
Cultivar	3	0.3831	3	1.4814**	4	0.7362**	1	5.7611**	2	2.1180**	1	2.3646**	3	2.3540**	6	1.6417**
Cultivar x environment	27	0.3065	21	0.1946†	20	0.2630*	12	0.3296**	14	0.3368**	10	0.4506**	12	0.0898	65	0.3079**
Cultivar x region	3	0.2062	6	0.0579	4	0.0460	2	0.3532*	4	0.0455	2	0.0892	6	0.0802	11	0.1411
Cultivar x year	9	0.4275	6	0.4394**	8	0.4969**	3	0.1043	4	0.1834	3	0.8119**	3	0.0889	18	0.2782†
Cultivar x region x year			3	0.4315			3	0.0902	4	0.6220**	3	0.4192*			10	0.2658
Cultivar x location in region, year	15	0.3276	6	0.1350	8	0.1247	4	0.6222**	2	0.1137	2	0.3821†	3	0.0593	26	0.4543**
Covariates	3	0.7444*	3	1.1168**	3	0.2814*	3	1.9607**	3	1.4186**	3	1.1278**	3	1.0487**	3	2.8786**
Color (linear)	1	0.8985†	1	1.5666**	1	0.4649*	1	2.2664**	1	1.4975**	1	0.7373*	1	1.0525**	1	3.0981**
Color (quadratic)	1	0.8500†	1	1.5076**	1	0.4605†	1	2.2047**	1	1.4154**	1	0.6801*	1	0.9928**	1	2.9593**
Fruity	1	0.3341	1	0.2420	1	0.3682†	1	1.3748**	1	0.6208*	1	0.3630†	1	0.0563	1	2.5783**
Error	36	0.2707	43	0.1183	34	0.1122	57	0.1007	37	0.1192	27	0.1190	34	0.0765	121	0.1695
Coefficient of variation	12.4%		8.3%		8.2%		7.1%		7.7%		7.3%		6.4%		9.1%	
Mean roasted flavor	4.18		4.14		4.08		4.50		4.48		4.70		4.30		4.51	
Mean color	56.39		56.38		56.12		57.13		56.71		56.48		56.42		56.94	
Mean fruity	2.65		2.41		2.61		2.57		2.44		2.42		2.27		2.54	

†,*, ** Denote significance at the 0.10, 0.05, and 0.01 levels of probability, respectively.

Environments were a highly significant source of variation in all subsets (Table 4). Production regions were not a major source of environmental variation, being significant only at the 10% a-level in only two subsets (Subsets 17 and 22) and not significant for the overall data set. Region-by-year interactions, when measurable, likewise were not significant contributors to environmental variation. Years were the main contributors with year effects highly significant for all subsets and for the overall data set. It must be recognized that the set of environments represented in the various subsets were not orthogonal with respect to years and regions, and the partial confounding of year and region effects could result in apparent nonsignificance of one adjusted for the other. Variation among locations within year and region was significant at the 5% or lower level of probability in three of the four subsets, at the 10% level in another, and at the 1% level for the overall data set. Based upon these results, one would conclude that future sampling of cultivars to ascertain relative flavor scores should cross years and locations within years but not necessarily production regions. The implication for breeding programs is that it is not necessary to test lines for flavor across regions in order to improve accuracy of estimation.

Cultivar effects were significant in all subsets except Subset 1 which included only virginia-type cultivars. In subsets containing only virginia and runner cultivars, the runner cultivars were consistently superior in roasted peanut scores to the virginia cultivars. The significant variation among cultivars in Subset 3 was found to be due to the superior roasted peanut scores of Florunner compared with the average of the virginia cultivars (4.61 vs. 4.08, P<0.01); there was no significant variation among the virginia cultivars Florigiant, NC 7, and NC-V 11. Inclusion of another virginia cultivar, NC 9, in Subset 7 resulted in significant variation among virginia cultivars although Florunner was still significantly higher in roasted peanut score than the average of virginia cultivars (4.57 vs. 4.16, P<0.05). Pairwise comparison of Florunner with NC 7 in Subset 13 confirmed the superiority of Florunner across 13 environments (4.85 vs. 4.25, P<0.01). In Subset 27, the mean for Florunner and Marc I was higher than that for Florigiant and NC 7 (4.86 vs. 4.04, P<0.01), and Marc I was significantly better than Florunner (4.73 vs. 3.96, P<0.05). In subsets comparing the spanish cultivar Pronto with runner or virginia cultivars, Florunner had significantly higher roasted peanut scores than Pronto (5.02 vs. 4.70, P<0.05 in Subset 17 and 5.34 vs 4.76, P<0.01 in Subset 22). In least-squares means estimated from the overall data set, these trends are again evident (Table 5). Marc I and Florunner consistently had the highest mean flavor scores. Pronto was intermediate between the runner and virginia cultivars, and there was a trend of improved flavor for more recently released virginia cultivars in the cultivar main effect means, but the relative rankings of virginia cultivars and Pronto were not consistent across environments.

One or more components of cultivar-by-environment interaction was significant for all subsets except Subset 1 which included only four virginia-type cultivars and Subset 27 which included two virginia and two runner cultivars. Cultivar-by-region interaction was significant only for Subset 13 which contrasted Florunner with NC 7. Florunner's mean roasted peanut score was greater than that of NC 7 in each region, but the difference between the cultivars varied somewhat from region to region. Cultivar-by-year interaction was highly significant in Subsets 3, 7, and 22, but it was only significant at the 10% level of probability for the overall data set. Cultivar-by-region-by-year interactions were estimable only for four subsets and were significant in Subsets 17 and 22, the only ones including the spanish cultivar Pronto. These effects were not significant in the overall data set.

If one makes the assumption that year and location effects are random, then the corresponding interactions with region and cultivar will also be random. Estimates and

Table 5. Least squares (LS) means for roasted peanut flavor from combined analysis of samples from peanut breeding and evaluation programs, 1986-1991.

			Cultivar							Env.
Year	Region[a]	Location	Flori-giant	Flo-runner	Marc I	NC 7	NC 9	NC-V 11	Pronto	LS mean
1986	SE	Marianna, FL	5.2[b]	6.4	6.3	5.2	--	--	4.9	5.42
1986	SE	Tifton, GA	5.6	6.1	--	--	--	--	5.3	5.67
1987	SE	Tifton, GA	--	5.2	--	--	--	--	--	4.80
1988	SE	Tifton, GA	4.4	4.9	--	4.1	--	4.3	4.4	4.48
1990	SE	Marianna, FL	3.6	4.1	4.5	3.4	4.0	3.7	--	3.87
1990	SE	Tifton, GA	3.8	4.4	5.0	4.1	4.1	4.2	4.9	4.25
1991	SE	Marianna, FL	--	4.6	--	4.5	4.1	--	--	4.54
1991	SE	Tifton, GA	--	5.6	--	3.9	--	--	--	4.62
1986	SW	Stillwater, OK	4.3	5.5	--	--	--	--	5.7	5.12
1986	SW	College Station, TX	--	6.3	--	--	--	--	4.7	5.26
1986	SW	Stephenville, TX	6.1	5.5	--	--	--	--	--	5.59
1990	SW	College Station, TX	3.8	4.3	4.6	3.6	--	3.8	3.8	3.93
1990	SW	Stephenville, TX	--	4.4	--	--	--	--	--	4.00
1986	VC	Lewiston, NC	3.8	6.3	--	5.4	5.3	5.7	--	5.45
1986	VC	Suffolk (Coffelt), VA	--	6.9	--	--	--	--	5.0	5.77
1986	VC	Suffolk (Mozingo), VA	6.0	--	--	5.4	--	5.3	--	5.74
1987	VC	Suffolk (Coffelt), VA	--	5.5	--	--	--	--	5.1	5.20
1987	VC	Suffolk (Mozingo), VA	5.4	--	--	4.2	5.2	4.7	--	5.17
1988	VC	Northampton Co., NC	4.1	--	--	4.4	4.5	4.6	--	4.56
1988	VC	Suffolk (Coffelt), VA	4.3	4.4	--	4.1	3.6	4.2	4.5	4.32
1988	VC	Suffolk (Mozingo), VA	4.5	--	--	5.0	5.3	4.5	--	5.07
1990	VC	Clayton, NC	3.4	--	--	3.9	4.2	4.5	--	3.91
1990	VC	Lewiston, NC	4.3	4.2	--	3.9	2.6	4.3	--	4.17
1990	VC	Suffolk (Coffelt), VA	3.3	4.4	4.5	4.0	4.3	4.1	4.2	4.13
1991	VC	Lewiston, NC	--	4.8	--	4.1	--	--	--	4.71
1991	VC	Whiteville, NC	--	--	--	4.7	--	--	--	4.41
1991	VC	Suffolk (Coffelt), VA	--	4.8	--	4.6	--	4.3	--	4.74
		Cultivar LS mean	4.39	5.08	5.35	4.54	4.69	4.64	4.73	4.51

[a] SE=Southeast (Georgia, Florida, and Alabama), SW=Southwest (Texas and Oklahoma), VC=Virginia-Carolina (Virginia and North Carolina).

[b] Higher mean scores indicate more intense roasted peanut flavor.

standard errors of the variances of random effects in the model were $\hat{\sigma}^2_Y = 0.2832 \pm 0.2072$ for year, $\hat{\sigma}^2_{YR} = 0$ for year-by-region interaction, $\hat{\sigma}^2_{L(YR)} = 0.0106 \pm 0.0135$ for locations in years and regions, $\hat{\sigma}^2_{CY} = 0$ for cultivar-by-year, $\hat{\sigma}^2_{CYR} = 0$ for cultivar-by-year-by-region interaction and $\hat{\sigma}^2_{CL(YR)} = 0.0409 \pm 0.0237$ for cultivar-by-location interaction in years and regions. Error variance was estimated to be $\hat{\sigma}^2 = 0.1805 \pm 0.0229$. Variation among locations within years and regions was relatively small. Because the year-to-year variance dominates the environmental variance components, it is important to sample years extensively to obtain precise estimates of flavor scores for individual genotypes either within or across regions. In other words, if the objective is to obtain mean scores *per se*, then sampling across several years is necessary. Such sampling is not problematic for released cultivars, but it is problematic for breeding lines. Unfortunately, breeders do not have the luxury of retaining numerous advanced breeding lines over several years simply for the purpose of precise estimation of flavor score.

Because of the regional nature of production of the various cultivars of peanut, breeders are concerned more about the flavor of cultivars when grown in their particular regions rather than when grown in others. As a rule, they will be testing in a single region only (r=1), so that

$$s_{Diff} = \sqrt{2\left(\frac{\hat{\sigma}^2_{CY}}{y} + \frac{\hat{\sigma}^2_{CL(YR)}}{yl} + \frac{\hat{\sigma}^2}{yln}\right)}$$

Interaction between locations and cultivars was the predominant source of cultivar-by-environment interaction. Because the estimate of $\hat{\sigma}^2_{CY}$ is zero, it is apparent that there is no inherent advantage in sampling over large numbers of years if the objective is to compare the flavor scores of cultivars or breeding lines relative to one another. In comparing cultivars for roasted flavor using a fixed number of samples for each (n'=yln), precision of comparison is enhanced by maximizing the number of test environments (yl) and minimizing replication within environments (n) (Table 6). Carrying this argument to its extreme, the most efficient scheme for testing would be to let n'=l, i.e., test at as many locations as possible in a single year with a single replication at each location. Testing at several locations in a single year results in confounding of large year effects with the overall mean, but the cultivar-by-year and cultivar-by-year-by-region interactions that are confounded with cultivar effects are negligible in magnitude. Because cultivar-by-region effects were generally not significant, confounding them with cultivar effects would not produce serious bias in comparisons of means across locations in a single year. The predicted standard errors of the difference between two cultivar means can be checked experimentally by examining the results of Pattee *et al.* (1993) who reported a least significant difference ($P<0.05$) of 0.6 for comparing genotype means obtained from two environments with two reps per environment. The corresponding LSD found by multiplying the predicted standard error ($s_{Diff}=0.36$) by $t_{29,.05}=2.045$ is 0.74. Sixteen observations from the data set used by Pattee *et al.* (1993) were included among the 222 observations in the present study. While it must be recognized that the two estimates of s_{Diff} are not entirely independent, this is fairly close agreement.

Table 6. Estimated standard error of a difference in roasted peanut flavor between two cultivar means.

Number of environments (yl)	Number of replicates per environment (n) 1	2	3	4	5	6	7	8
1	.67	.51	.45	.41	.39	.38	.37	.36
2	.47	.36	.32	.29	.28	.27	.26	.25
3	.38	.30	.26	.24	.23	.22	.21	.21
4	.33	.26	.22	.21	.20	.19	.18	.18
5	.30	.23	.20	.19	.18	.17	.16	.16
6	.27	.21	.18	.17	.16	.15	.15	.15
7	.25	.19	.17	.16	.15	.14	.14	.13
8	.24	.18	.16	.15	.14	.13	.13	.13
9	.22	.17	.15	.14	.13	.13	.12	.12
10	.21	.16	.14	.13	.12	.12	.12	.11
11	.20	.15	.14	.13	.12	.11	.11	.11
12	.19	.15	.13	.12	.11	.11	.11	.10
13	.18	.14	.12	.12	.11	.10	.10	.10
14	.18	.14	.12	.11	.10	.10	.10	.10
15	.17	.13	.12	.11	.10	.10	.09	.09
16	.17	.13	.11	.10	.10	.09	.09	.09
17	.16	.12	.11	.10	.10	.09	.09	.09
18	.16	.12	.11	.10	.09	.09	.09	.08
19	.15	.12	.10	.10	.09	.09	.08	.08
20	.15	.11	.10	.09	.09	.08	.08	.08
21	.15	.11	.10	.09	.09	.08	.08	.08
22	.14	.11	.10	.09	.08	.08	.08	.08
23	.14	.11	.09	.09	.08	.08	.08	.07
24	.14	.10	.09	.08	.08	.08	.07	.07
25	.13	.10	.09	.08	.08	.08	.07	.07
26	.13	.10	.09	.08	.08	.07	.07	.07
27	.13	.10	.09	.08	.08	.07	.07	.07
28	.13	.10	.08	.08	.07	.07	.07	.07
29	.12	.10	.08	.08	.07	.07	.07	.07
30	.12	.09	.08	.08	.07	.07	.07	.07

Recommendations for future evaluation of roasted flavor of breeding lines include the following. Replication across environments should be emphasized at the expense of replication within environments. Preliminary evaluations should be made on a single replicate from as many locations as possible. In the advanced stages of testing, it may be desirable to sample at two replicates per location to obtain estimates of experimental error, but again the emphasis should be on increasing the number of test environments rather than the number of replicates per test. The consistent significance of CIELAB L* color and fruity attribute as covariates indicates the need to continue to measure these traits.

Literature Cited

1. Gorbet, D. W., D. A. Knauft, and A. J. Norden. 1992. Registration of 'Marc I' peanut. Crop Sci. 32: 279.
2. Isleib, T. G., and J. C. Wynne. 1992. Use of plant introductions in peanut improvement, pp. 75-116. *In* H. L. Shands and L. E. Weisner (eds.), Use of Plant Introductions in Plant Improvement, Part 2. CSSA Spec. Publ. no. 20. Crop Sci. Soc. Amer., Madison, WI.
3. Pattee, H. E., and F. G. Giesbrecht. 1990. Roasted peanut flavor variation across germplasm sources. Peanut Sci. 17:109-112.
4. Pattee, H. E., and F. G. Giesbrecht. 1994. Adjusting roast peanut scores for fruity attribute and non-optimum CIELAB L° values. J. Sensory Studies 9: 353-363.
5. Pattee, H. E., F. G. Giesbrecht, and R. W. Mozingo. 1993. A note on broad-sense heritability of selected sensory descriptors in virginia-type *Arachis hypogaea* L. Peanut Sci. 20:24-26.
6. Patterson, H. D., and R. Thompson. 1971. Recovery of inter-block information when block sizes are unequal. Biometrika 58: 545-554.
7. SAS Institute, Inc. 1987. SAS/STAT Guide for Personal Computers, Vers. 6 Ed. SAS Institute, Inc. Cary, NC.
8. SAS Institute, Inc. 1992. SAS/STAT Software: Changes and Enhancements, Release 6.07. Technical Report P-229. SAS Institute, Inc. Cary, NC.

Accepted July 2, 1994