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Oil Quality and Sugar Content of Peanuts (*Arachis hypogaea*) Grown in Argentina: Their Relationship with Climatic Variables and Seed Yield

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The ratio of oleic to linoleic acids (O/L) and the tocopherol content are important features in determining peanut (*Arachis hypogaea*) seed shelf life. Soluble carbohydrates are known to be important precursors in roasted peanut flavor. The chemical qualities of Argentine grain are different from those of other countries, but no previous studies that associate grain quality and environmental parameters have been performed. Relationships were determined between O/L, tocopherol and sugar contents, and variations in temperature and rainfall during the grain filling period of Florman INTA peanuts. Dry seed yield was used as another explanatory variable. Multiple regression procedure gave mean temperature (positive coefficient) and total precipitation (negative coefficient) as the explanatory variables for variations in O/L. Total precipitation and dry seed yield (both negative coefficients) were found to be predictor variables for tocopherol and sugar contents. Total precipitation was an explanatory variable included in all of the linear regression models obtained in this study.

KEYWORDS: **Peanut; sugars; O/L ratio; tocopherol; *Arachis hypogaea***

INTRODUCTION

Along with the United States (U.S.) and China, Argentina is one of the major exporters of peanuts for human consumption, supplying an average of 245000 ton/year^{-1} during the period 1996−2000 (*1*). In 1998 peanut exports from Argentina were the highest in the world (*2*). Most of the peanuts produced in Argentina (98%) are concentrated in the semiarid region of Córdoba province, delimited by the parallels 31° 30′ and 33° 30′ S and the meridians 63° 00′ W and 64° 30′ W. Florman INTA is a runner market-type, which accounts for 85% of the total peanut production in Argentina.

Peanut storage quality depends on the relative proportion of saturated and unsaturated fatty acids that make up the oil. The degree of unsaturation is inversely proportional to the quality of the oil (e.g., oxidative rancidity increases with increased levels of the polyunsaturated fatty acids that cause associated odors and flavors) (*3*). The ratio of oleic to linoleic acids (O/L) has commonly been used as a means of predicting shelf life and oil stability. A higher O/L trait confers better stability and longer shelf life (*4*, *5*). The other factor contributing to shelf life is tocopherol content, which acts as a lipid-soluble natural antioxidant (*6*). Tocopherols stabilize polyunsaturated fatty acids within lipid bilayers by protecting them from lipoxygenase attack (*7*). Greater sugar content is correlated with a more intense sweet taste (*8*).

The region of Argentina where most peanuts are grown has uniform environmental conditions, as seen in the mean values of seasonal radiation, mean temperature, rainfall regime, and soil characteristics. For the period from November to March, mean temperature and total precipitation ranges in this region are 21.8−22.5 °C and 591−629 mm, respectively. However, some variability in compositional quality has been found in the Florman INTA variety. The variation coefficients across the region found in previous studies were 9% for O/L (*9*, *10*), 10% for tocopherols, and 28% for sugars (*10*). Such a variation might be related to changes in environmental conditions caused by different planting dates, the usual range of which is October 25th to November 28th.

Studies have shown considerable compositional and quantitative changes in the lipids and fatty acids of groundnut seeds during the seed growth period to maturity, that is, between 15 and 80 days after the onset of the seed filling period (*11*). Usually, at the farmer level, the date of harvest is available but the date of the beginning seed stage is unknown. Simulation models previously calibrated, such as CROPGRO-Peanut (*12*), could be a useful tool to estimate the date of this reproductive stage.

The aim of this work is to analyze the relationship among O/L, tocopherol and sugar contents, and variations in temper-

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Table 1. Sowing Date, Dry Seed Yield (DSY), Kernel Composition Data [Ratio of Oleic to Linoleic Acids (O/L), Sum of α-, β-, γ-, and δ-Tocopherols (TOCO), and Sum of Fructose + Glucose + Sucrose Contents (FGS) from Peanut Samples], Environmental Variables Mean Values for the Period from Beginning Seed or R5 Stage (*13*) to Harvest [Mean Daily Air Temperature (TM), Total Precipitation (Tpp), and Interval between Daily Precipitation >5 mm day^{-1} (pp_int)], and Latitude and Longitude of the Nearest Locality from Each Sampling Site

locality	latitude; longitude	sowing date	O/L	TOCO, ppm in oil	FGS, g% g^{-1} in defatted flour	TM, °C	Tpp, mm	pp_int, days^{-1}	DSY, kg ha^{-1}
Cnia. Almada	–32° 02′; –63° 54′	Nov 12, 1997	1.12	520.3	10.63	19.5	280	5.6	1926
		Nov 10, 1998	1.30	533.8	n/a	20.8	347	11.0	1875
		Nov 11, 1998	1.25	n/a	10.90	20.2	343	11.1	1805
Gral. Deheza	–32° 47′; –63° 48′	Oct 28, 1997	1.11	525.8	10.86	20.4	340	7.2	1944
		Nov 4, 1997	1.04	533.9	12.91	18.7	417	7.1	1926
		Nov 15, 1997	1.05	537.7	11.49	18.8	406	6.9	1946
		Nov 6, 1998	1.38	505.4	6.16	20.2	305	8.4	n/a
		Nov 11, 1998	1.27	496.1	7.96	20.5	305	8.2	1728
		Nov 20, 1998	1.22	n/a	n/a	19.2	n/a	n/a	n/a
Matorrales	–31° 43′; –63° 30′	Nov 16, 1997	1.12	511.5	11.66	19.5	270	7.7	1485
		Nov 17, 1998	1.26	505.8	8.51	20.1	343	5.4	1083
Pampayasta N	–32° 13′; –63° 41′	Nov 12, 1997	1.14	540.0	12.34	20.1	322	6.4	1944
Pampayasta S	–32° 15′; –63° 42′	Nov 8, 1997	1.29	508.0	12.28	20.3	269	6.7	1909
Pasco	–32° 45′; –63° 21′	Nov 4, 1997	1.21	542.0	13.15	19.9	n/a	n/a	1667
		Nov 7, 1997	1.21	526.6	n/a	20.1	331	8.2	1926
Pilar	–31° 41′; –63° 53′	Nov 16, 1998	1.40	n/a	n/a	20.2	334	6.9	n/a
Va. Del Rosario	–31° 45′; –63° 32′	Nov 11, 1997	1.24	525.7	9.65	19.4	218	7.5	2430
Va. Ascasubi	–32° 11′; –63° 56′	Nov 9, 1996	1.51	n/a	n/a	20.0	141	9.1	1155
		Nov 14, 1997	1.12	540.2	14.29	19.7	355	6.1	2916
		Nov 17, 1997	1.19	538.4	11.18	18.2	419	7.1	n/a
		Nov 12, 1998	n/a	532.6	9.89	19.7	n/a	n/a	n/a
mean			1.22	524.9	10.72	19.8	319	7.6	1854
std error			0.03	3.50	0.52	0.14	17	0.37	101

ature and rainfall during the seed-filling period of Florman INTA peanuts in the main crop area of Argentina.

MATERIALS AND METHODS

Data. Peanut Florman INTA variety samples were obtained from observation plots located in 21 farms covering most of the planted peanut area of Córdoba, Argentina, during the 1996−1997, 1997−1998 and 1998−1999 growing seasons. Each plot size was 168 m^2 (8.4 m wide × 20 m long). Within each plot, weeds were eliminated by hand. Foliage diseases were controlled by regular applications of the fungicide Folicur (tebuconazole, Bayer Argentina S.A.).

The environmental variables taken into account for the period from beginning seed or R5 stage (*13*) to harvest were mean daily air temperature **(**TM**)**, calculated as the average between maximum and minimum daily temperature; total precipitation **(**Tpp**)**; and the interval between daily precipitations >5 mm day^{-1} **(**pp_int**)**. Lower rainfalls were not taken into account to obtain pp_int because they were regarded as insufficient to wet the soil layer where the pods were growing. Dry seed yield **(**DSY**)** at harvest was determined over a subplot of 28 m^2. DSY was used as another explanatory variable of O/L and tocopherol and sugar contents, along with the environmental variables above-mentioned, because it might subsume the effect of other environmental variables not considered in this study. Prior to harvest, pod maturity was examined, and the pod samples were collected when ∼70% of the fruits demonstrated inner pericarp coloration or testa color change, indicating the R8 stage (*13*).

Daily maximum and minimum temperature values were obtained from Argentine Meteorological Network Stations not farther than 50 km from each observational plot. Daily rainfall records were obtained from rain gauges placed close to each plot. Dates of R5 stages were estimated by using the CROPGRO-Peanut simulation model included in DSSAT 3.5 software (*12*). The genetic coefficients needed for CROPGRO-Peanut model simulations were previously obtained for Florman INTA by Ravelo and Dardanelli (*14*) and Seiler and Vinocur (*15*).

The chemical variables of interest were O/L; the sum of α-, β-, γ-, and δ-tocopherols **(**TOCO**)**, expressed in ppm in oil; and the sum of fructose + glucose + sucrose contents **(**FGS**)**, expressed in g% g^{-1} in defatted flour. O/L and TOCO were determined following the official methods and recommended practices of the American Oil Chemists' Society (*16*). Methyl esters were separated using a Hewlett-Packard 6890 gas chromatograph equipped with a flame ionization detector, using a 0.32 mm × 30 m capillary column Hewlett-Packard INNOWax (cross-linked polyethylene glycol), with 0.5 μm film thickness. TOCO was determined by measuring the concentrations of α-, β-, γ-, and δ-tocopherols by high-performance liquid chromatography **(**HPLC**)**. Tocopherols were detected by absorbance at 305 nm after separation on a LiChrosorb Si60 column, 25 cm × 4 mm (5 μm) column with a mobile phase of 2-propanol (1% v/v) in hexane. Tocopherol peaks were identified by retention time relative to the standards. Free sugars (fructose, glucose, and sucrose) were determined following the method published by Matissek et al. (*17*) and analyzed by HPLC in a Shimadzu LC 10AS equipped with a Waters model 717 injector plus autosampler. Sucrose, glucose, and fructose were separated in a 25 cm × 4.6 mm Supelco 5NH2 column at a controlled temperature of 25 °C. The eluent was acetonitrile/water (80:20) at an isocratic flow rate of 1 mL min^{-1} and a run time of 15 min. The detector was a Diodex pulsed amperometric detector (PAD) with a gold electrode. All reference carbohydrates were purchased from Sigma Chemical Co., St. Louis, MO.

Statistical Analysis. Principal component analysis **(**PCA**)** (*18*) was performed to explore associations between chemical variables (O/L, TOCO, and FGS) and TM, Tpp, pp_int, and DSY. A multiple regression procedure was carried out to model O/L, TOCO, and FGS as functions of TM, Tpp, pp_int, and DSY. A 5% significance level was used for the *t* test on regression parameter estimates. Model selection was based on Mallow's CP coefficients and residual analyses (*19*). All calculations were done with the statistical software InfoStat (*20*).

RESULTS AND DISCUSSION

Table 1 shows DSY values and kernel composition data from the peanut samples used in this study, along with environmental variable mean values for the period from beginning seed or R5 stage (*13*) to harvest, within localities of the province of Córdoba, Argentina. The duration of the sowing−harvest period was 160 ± 8 days (mean ± standard deviation), close to the 159 ± 4 days predicted with the simulation model used in this study, indicating that all samples were collected at a similar

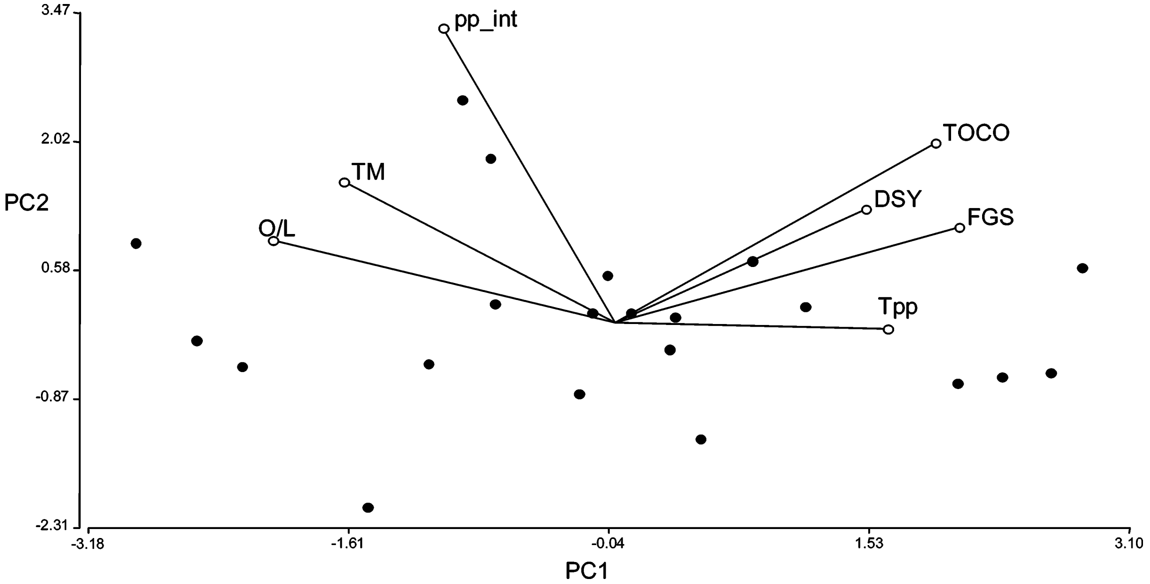

Figure 1. Biplot from the first and second principal components of PCA: variability in 21 peanut samples (●), considering mean daily air temperature (TM), total precipitation (Tpp), interval between daily precipitations >5 mm day^{-1} (pp_int), dry seed yield (DSY), ratio of oleic to linoleic acids (O/L), sum of α-, β-, γ-, and δ-tocopherols (TOCO), and sum of fructose + glucose + sucrose contents (FGS) of each sampling site.

maturity stage. The ranges of TM, Tpp, pp_int, and DSY values across the sampling sites were 18.2−20.8 °C, 141−419 mm, 5.4−11.1 days^{-1}, and 1083−2916 kg ha^{-1}, respectively (**Table 1**). **Figure 1** is the biplot (*21*), obtained from the first two principal components of PCA. It explains 80% of total variability in the peanut samples. The dispersion of the points indicated high variability among samples. Correlations between chemical and environmental variables included in **Table 1** were explored. The O/L was negatively associated with Tpp and positively associated with TM. TOCO and FGS were positively associated with Tpp and DSY. The biplot suggests a poor association between pp_int and the chemical variables considered in this study, particularly TOCO and FGS, because the angle between the corresponding vectors is almost 90° (*21*).

The positive association between O/L and TM agrees with the findings of Holaday and Pearson (*22*), who stated that mean air temperature during the period from pegging to maturity was positively associated with O/L across the United States. To our knowledge, a negative association between Tpp and O/L has not been previously reported.

As responses to environmental variables and DSY, **Table 2** shows fitting information for the selected models for O/L, TOCO, and FGS.

O/L was 1.22 ± 0.12 (mean ± standard deviation), ranging from 1.04 to 1.51 (**Table 1**). Mean and standard deviation values in our study were close to those reported by Grosso et al. (*9*) and Casini et al. (*10*), 1.18 ± 0.11, and 1.31 ± 0.09, respectively. To explain variations in O/L, the selected model included TM and Tpp as significant predictors ($p < 0.05$) (**Table 2**). TM was highly significant ($p < 0.0001$, Mallows CP = 188.03) despite the low range of observed temperature in the sampling (2.6 °C). Meanwhile, Tpp was also a significant predictor but showed a lower weight in the fitted regression model (p = 0.0261, Mallows CP = 6.71). Rainfall causes soil temperature to fall at every value of air temperature, a fact that was confirmed by Giambastiani and Casanoves (*23*) in an experiment conducted in Córdoba with Florman INTA. They reported that irrigation decreased soil temperature and, consequently, O/L. Golombek et al. (*24*), working with several genotypes under controlled conditions, also found a negative relationship between soil temperature and O/L. Assuming that both variables (TM and Tpp) modify soil temperature, which is a main cause of O/L changes, the negative association found for Tpp is explained in the sense that precipitation is responsible for soil temperature changes.

Table 2. Linear Regression Models for Ratio of Oleic to Linoleic Acids (O/L), Sum of α-, β-, γ-, and δ-Tocopherols (TOCO), and Sum of Fructose + Glucose + Sucrose Contents (FGS) on Environmental Variables[a] and Dry Grain Yield (DSY)

dependent variable	explanatory variable	regression coefficient	standard error	*p* value	Mallows CP
O/L	TM	0.07433	0.00527	<0.0001	188.03
	Tpp	−0.00079	0.00032	0.0261	6.71
TOCO	const	442.80000	21.50000	<0.0001	
	Tpp	0.13000	0.05000	0.0330	7.64
	DSY	0.12000	0.01000	0.0118	10.66
FGS	Tpp	0.02000	0.00470	0.0050	12.77
	DSY	0.00290	0.00078	0.0037	13.91

[a] Environmental variables taken into account for fitting regression models were calculated for the period from beginning seed or R5 stage (*13*) to harvest and were mean daily air temperature (TM), total precipitation (Tpp), and interval between daily precipitations >5 mm day^{-1} (pp_int).

Although the model estimated is for prediction in the domain of values used in our study, extrapolation to TM and Tpp values of the main U.S. planted peanut area (northern Florida and southeastern Georgia) yielded O/L values close to those reported for the area. We estimated the mean daily temperature and total precipitation during the R5-maturity period for a typical planting date in Gainesville, FL, for Florunner (*13*). Florman INTA is a close relative of Florunner obtained from this variety by mass selection (*25*). Weather data were obtained from 20-year Gainesville meteorological records from DSSAT 3.5 weather data sets. Higher differences between the data used in this study and the U.S. planted peanut region for these variables corresponded to mean daily air temperatures. Mean daily temperature for grain filling, in our study, was 19.5 °C, whereas the value estimated for Gainesville was 27.2 °C. Using our regression model the predicted O/L value at 27.2 °C and 401 mm of total precipitation (historical value) was 1.73. Published studies indicated that O/L for Florunner, grown in the main U.S.

peanut area, varied from 1.47 (*26*) to 1.92 (*27*) and 1.97 (*28*). More frequently reported O/L ranged between 1.71 and 1.77 (*29*−*31*). Therefore, the prediction obtained from the estimated model involving TM and Tpp extrapolated to U.S. values is consistent with published results.

TOCO mean and standard deviation were 524.9 and 14.5, respectively; TOCO values ranged from 496.1 to 542.0 ppm in oil (**Table 1**). The mean value in our study was close to the 528 ppm obtained by Casini et al. (*10*) from a 145 sample study. Moreover, the mean TOCO content in our study was lower than the reported results for Florunner planted in the main U.S. peanut area (northern Florida and southeastern Georgia). In fact, transformed data from Hashim et al. (*26*, *32*), assuming 50% of grain oil content, resulted in 515 and 538 ppm of tocopherol in oil, but Grimm et al. (*31*) reported 656 ppm in oil. Sanders et al. (*33*) found that the tocopherol values for Florunner were ∼590−650 ppm in oil across three growing locations—Georgia, Virginia, and Texas—and they suggested that the tocopherol content is lower in cooler climates. As previously mentioned, Córdoba is considerably cooler than the main U.S. peanut area, and this may explain why the TOCO values we found were lower than those reported in the United States. However, the multiple regression model estimated for TOCO included Tpp and DSY as predictor variables (**Table 2**), but not TM. It should be noted that DSY is a variable which subsumes other environmental features not recorded in our study. Variables such as soil temperature may explain tocopherol variations across the planted peanut region in Córdoba. Further studies are needed to test this hypothesis.

FGS values ranged from 6.16 to 14.29 g% g^{-1} in defatted flour (**Table 1**) with 10.72 and 2.08 g% g^{-1} as mean and standard deviation values. These values were close to those obtained by Casini et al. (*10*) from a 74 sample study. The FGS contents found in our study were remarkably higher than values reported for the main U.S. peanut area (northern Florida and southeastern Georgia), which were 3.90 (*31*), 5.20 (*34*), and 5.37 g% g^{-1} (*35*); all data are re-expressed as g% g^{-1} of defatted flour. It has been demonstrated that the accumulation of sugars increases in storage organs at low temperatures (*36*). A possible explanation of this is that cooler temperatures in the Córdoba planted peanut region promote an increase of FGS content in peanut seeds. McMeans (*34*) found that a 7 °C decrease in the upper layer soil temperature increased the FGS content by 40% in Florunner variety seeds. All of the differences between Argentina and the United States can be explained by differences in air temperatures, which have significant influences on soil temperatures. The multiple regression model estimated for FGS gave Tpp and DSY as predictor variables (**Table 2**). Within the Argentinean peanut area, we could assume that higher Tpp helps to increase FGS by cooling the upper soil layer in which the peanut seeds are growing. Because the model needed DSY as an explanatory variable, as we mentioned above for TOCO, other environmental variables may be used to better explain FGS variations.

ABBREVIATIONS USED

O/L, ratio of oleic to linoleic acids; TM, mean daily air temperature, °C; Tpp, total precipitation, mm; pp_int, interval between daily precipitations >5 mm day^{-1}; DSY, dry seed yield, kg ha^{-1}; TOCO, sum of α-, β-, γ-, and δ-tocopherols, ppm in oil; FGS, sum of fructose + glucose + sucrose contents, g% g^{-1} in defatted flour; HPLC, high-performance liquid chromatography; PCA, principal component analysis.

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