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# Teor de óleo e estabilidade fenotípica para rendimento de grãos em cultivares de amendoim

## Oil content and phenotypic stability for grain yield in peanut cultivars

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**Abstract**

This study aimed to evaluate the oil content and estimate the phenotypic stability and adaptability parameters for grain yield in twelve peanut cultivars. The experiment was carried out in 21 different localities in Paraná State, during the dry and rainy seasons of the agricultural year 2010-2011, 2011-2012 and 2012-2013. The experimental design was a randomized block with four replications and plots consisting of four rows of 4m with a population of 16 plants per meter. After maturation, the plots were harvested and grain yield was converted to kg ha$^{-1}$ and corrected to 10 % moisture. The oil content (%) was measured by the ether extract method. Significant effects for cultivars, environments (combination of years, seasons and locations) and G x E interaction was detected for grain yield and oil content in the peanut seeds. The cultivars BRS 151-L7, IAC Tatuí, BRS Havana, IAC Poitara, IAC Oirã and IAC Tupã showed the highest oil content in the grains. Stability and adaptability was estimated for the characteristic grain yield. The cultivars Runner IAC 886 and IAC Caiapó showed specific adaptation to adverse environments, while IAPAR 25 Tição and IAC Tupã to showed specific adaptation to favorable environments. IAC Tatu ST was more stable and Tégua was less stable.

**Additional keywords:** Adaptability; *Arachis hypogaea* L.; peanut improvement.

**Resumo**

Este trabalho teve como objetivo avaliar o teor de óleo e estimar os parâmetros de estabilidade e adaptabilidade fenotípica para rendimento de grãos em doze cultivares de amendoim. O ensaio foi conduzido em 21 ambientes distintos no Estado do Paraná, durante as safras das águas e seca, nos anos agrícolas de 2010-2011, 2011-2012 e 2012-2013. O delineamento experimental utilizado foi o de blocos ao acaso, com quatro repetições, e parcelas constituídas de quatro linhas de 4 m, com uma população de 16 plantas por metro. Após a maturação, as parcelas foram colhidas, e o rendimento de grãos obtido foi transformado para kg ha$^{-1}$ e corrigidos para 10% de umidade. O teor de óleo (%) foi quantificado por extrato etéreo. Para rendimento de grãos e teor de óleo nas sementes de amendoim, foi detectado efeito significativo para cultivares, ambientes (combinação de anos, safras e locais) e para a interação G x A. As cultivares BRS 151-L7, IAC Tatuí, BRS Havana, IAC Poitara, IAC Oirã e IAC Tupã apresentaram os maiores teores médios de óleo nos grãos. A estabilidade e a adaptabilidade foram estimadas para característica rendimento de grãos. As cultivares Runner IAC 886 e IAC Caiapó apresentaram adaptação específica a ambientes desfavoráveis, enquanto IAPAR 25 Tição e IAC Tupã, aos ambientes favoráveis. Em termos de estabilidade, IAC Tatu ST foi a mais previsível, e Tégua, menos estável.

**Palavras-chave adicionais:** Adaptabilidade; *Arachis hypogaea* L.*;* melhoramento de amendoim.

## Introduction

Peanut (*Arachis hypogaea* L.) is grown in Brazil mainly to meet the food industry. The peanut seeds have high oil content, which makes this legume a promising feedstock for biodiesel production (Campos-Mondragon et al., 2009; Santos et al., 2012b). Processing of peanut generates numerous by-products that have various applications in the food and feed industry (Zhao et al., 2012).

According to data from FAO (2013), in 2012, world production was approximately 41 million tons. Peanut is produced by many countries, as it adapts to almost all kinds of weather, and the main producing countries were China, India, Nigeria and the United States; Brazil occupied the 18th position in the world ranking. In Brazil, peanuts are grown in almost all states and the national production of the 2012-2013 harvest was 330 thousand tons, with a 12% increase compared to the 2011-2012 harvest in a cultivated area of 100.9 hectares. The State of São Paulo stands out as the largest national peanut producer (CONAB, 2013), where cultivation occurs mainly in areas aimed at reform of sugarcane fields and pastures (Crusciol & Soratto, 2007).

In the State of Paraná, peanut is grown as a subsistence crop and much of the production comes from small farms. Good soil and climate conditions allow the cultivation in two seasons, during the rainy season, where sowing takes place from September to November, and the dry season, from December to January. In the harvest of 2011-2012, the production was 9,697 tons in an area of 3,743 hectares with an average yield of 2,591 kg ha$^{-1}$ (SEAB, 2013).

Peanuts are grown in different seasons and edaphoclimatic conditions in Brazil. This great variety of environments contributes to the occurrence of genotype x environment interaction (G x E), ie, the change in relative performance of genotypes due to environmental differences (Murakami & Cruz, 2004; Oliveira et al., 2006a). For the purpose of G x E interaction to be minimized or capitalized it is necessary to conduct experiments in the largest possible number of locations and years (Silva & Duarte, 2006).

When the G x E interaction is significant it is necessary to evaluate the behavior of genotypes within each environment, this information may be obtained through analyzes of adaptability and stability. These analyzes enable a more accurate indication for recommendation of cultivars, for providing a detailed study about their behavior predictability and adaptability to specific or wide environmental conditions (favorable and unfavorable). Therefore, cultivars recommendation based on stability in various environments, and not in one in specific, is a strategy to reduce the effect of G x E interaction (Eberhart & Russell, 1966).

This study aimed to quantify the oil content in the grains and evaluate the adaptability and phenotypic stability for grain yield of twelve peanut cultivars grains in the State of Paraná, to identify cultivars with high yield potential and oil contents adapted to the soil and weather conditions of the location.

## Material and methods

The experiment was established in 21 environments composed by the unbalanced combination of two seasons, three years and five locations in the State of Paraná. The tests were conducted during the rainy season in the agricultural year 2010-2011, 2011-2012 and 2012-2013 and in the dry season in the agricultural year 2011 and 2012. During the rainy season of 2010-2011, the test was established in the municipalities of Irati, Santa Tereza do Oeste, Londrina, Paranavaí and Xambrê. In the rainy season of 2011-2012 it was held in Irati, Londrina, Paranavaí and Xambrê, and in the rainy season of 2012-2013, in Londrina, Paranavaí and Xambrê. In the dry season of 2011 and 2012 the trial was conducted in Irati, Londrina, Santa Tereza do Oeste and Xambrê, and Paranavaí only for the harvest of 2011. Information on the altitude, latitude and longitude of the evaluation locations are shown in Table 1.

**Table 1** - Altitude, latitude and longitude of the locations of the experiments of rainy season 2010-2011, 2011-2012 and 2012-2013 and the dry season of 2011 and 2012.

| Location | Altitude --- (m) --- | Latitude | Longitude |
|---|---|---|---|
| Irati | 836 | 25° 28' South | 50° 39' West |
| Londrina | 550 | 23° 17' South | 51° 10' West |
| Paranavaí | 446 | 23° 04' South | 52° 27' West |
| Santa Tereza do Oeste | 747 | 25° 03' South | 53° 37' West |
| Xambrê | 374 | 23° 43' South | 53° 29' West |

The basic fertilization was done in accordance with chemical analysis of soil, and the control of pests and weeds according to the technical recommendations for culture. The experimental design was a randomized block design with four replications and plots consisting of four rows of 4 m, 0.6 m spaced, with seeding density of 16 viable seeds per meter, considering as useful portion the two central lines. The treatments were composed by 12 peanut cultivars: IAC Tatu ST, Runner IAC 886, Tégua, IAC Poetara, IAC Tatuí, IAC Tupã, IAC Oira, IAC Caiapó, BRS 151-L7, BRS Havana, BR01 and IAPAR 25 Tição. The cultivars IAC Tatu ST and Runner IAC 886 were used as control cultivars.

For the determination of the yield, the plants of the two central rows were harvested. After the tracking and cleaning of the material, with the separation of impurities (leaves, branches and clods), the pods were threshed and the grains were weighed. The yield of peanut kernels per plot was transformed into kg ha$^{-1}$ and corrected to 10% moisture. For analysis of oil content (%) on dry basis, it was taken from each plot a sample of 100 g of peanut grains. The methodology for determination was by ether extract (AOAC, 1990).

From the data obtained for grain yield and oil content, the individual variance analysis for each environment proceeded, according to the model:

$$Y_{ij} = \mu + g_i + b_j + \varepsilon_{ij} \quad (1)$$

On which: $Y_{ij}$= observation of genotype i in block j; μ = mean; $g_i$ = effect of genotype; I = genotype (1, 2, 3,... 12); $b_j$ = effect of the block; j = replicates (1, 2, 3 and 4); $\varepsilon_{ij}$ = deviation of observation (j) in genotype (i). To perform the analysis of variance in all the experiments, it was carried out the homogeneity of variance test, using the ratio between the largest and smallest variance of experimental error, accepting the ratio 7:1, according to Banzatto & Kronka (2006). Being tested the homogeneity of variance, it was performed the joint analysis of the test, for both characteristics, using the following statistical-genetic model:

$$Y_{ijk} = \mu + G_i + A_j + GA_{ij} + B/A_{jk} + \varepsilon_{ijk} \quad (2)$$

On which: $Y_{ijk}$ = observation of genotype i in environment j in block k; μ = general mean; $G_i$= effect of $i^{th}$ genotype (i = 1, 2... 12); $A_j$= effect of $j^{th}$ environment (j = 1, 2... 18); $GA_{ij}$ = effect of the interaction between $i^{th}$ genotype and $j^{th}$ environment; $B/A_{jk}$ = effect of $k^{th}$ block in jth environment (k = 1, 2...4); $\varepsilon_{ijk}$ = random error. For the joint variance analysis, the effects of genotype and environment were considered as fixed. After the joint analysis of data related to grain yield, it was estimated phenotypic stability, with the method proposed by Eberhart & Russell (1966), adopting the following linear regression model (Cruz & Regazzi, 1997):

$$Y_{ij} = \beta_{oi} + \beta_{1i} I_j + \delta_{ij} + \varepsilon_{ij} \quad (3)$$

On which: $Y_{ij}$ = mean response the $i^{th}$ genotype at the $j^{th}$ environment j; $\beta_{oi}$ = mean of the $i^{th}$ genotype at the $j^{th}$ environmental; $\beta_{1i}$ = linear regression coefficient, which measures the response of the ith genotype to the variation of the environment; $I_j$ = environmental index coded ($\sum_j I_j$=0); $\delta_{ij}$ = deviation of regression; $\varepsilon_{ij}$ = experimental error. The significance of the regression coefficient ($\beta_{1i}$ = 1) was evaluated by t test, and the significance of the regression deviations ($\sigma^2_{di}$ = 0) by the F test at 5% and 1% probability. The treatment means were grouped by the method of Scott & Knott at 5% and 1% probability. Statistical analyzes were performed with the help of the Genes software (Cruz, 2006).

## Results and discussions

The individual analyzes of variance were performed for each of the 21 environments. However, it was necessary to discard three environments because of unfavorable weather conditions that have compromised the development of culture, affecting grain yield and raising the experimental error. Deleted environments were: Londrina, dry season 2011-2012; Santa Tereza do Oeste, rainy season 2011-2012; and Londrina, dry season 2012-2013. For grain yield evaluated in peanut cultivars, there was a significant effect of 5% and 1% probability for cultivars in 14 of 18 evaluated environments (Table 2). These results indicate that the cultivars showed phenotypic variation for grain yield.

**Table 2** - Indivudual variance analysis for grain yield (kg $ha^{-1}$) in peanut cultivars evaluated in Irati, Londrina, Paranavaí, Santa Tereza do Oeste (S. T. Oeste) and Xambrê in the rainy season of 2010-2011, 2011-2012 and 2012-2013 and in the dry season of 2011 and 2012.

| Environment | Test | | | [1]Mean Square | | | [3]CV |
|---|---|---|---|---|---|---|---|
| | Season | Agricultural year | Location | Block | [2]Cultivar | Residue | (%) |
| 1 | Rainy | 2010-2011 | Irati | 128,442 | 629,139 ** | 112,951 | 21.3 |
| 2 | | | Londrina | 1801,996 | 232,845 ns | 169,960 | 15.2 |
| 3 | | | Paranavaí | 274,702 | 825,594 ** | 45,994 | 9.0 |
| 4 | | | S. T. Oeste | 426,472 | 1,205,392 ** | 123,377 | 13.8 |
| 5 | | | Xambrê | 588,503 | 95,317 ns | 194,524 | 13.9 |
| 6 | Rainy | 2011-2012 | Irati | 270,516 | 301,056 ** | 65,590 | 20.7 |
| 7 | | | Londrina | 122,560 | 1,463,353 ** | 86,743 | 12.2 |
| 8 | | | Paranavaí | 364,934 | 230,141 ** | 58,264 | 25.0 |
| 9 | | | Xambrê | 46,501 | 680,760 ** | 32,111 | 22.1 |
| 10 | Rainy | 2012-2013 | Londrina | 55,893 | 216,847 ns | 157,136 | 17.4 |
| 11 | | | Paranavaí | 233,085 | 462,317 ** | 89,596 | 13.3 |
| 12 | | | Xambrê | 419,655 | 603,466 ** | 79,195 | 18.8 |
| 13 | Dry | 2011-2012 | Irati | 803,528 | 811,661 ** | 104,731 | 22.9 |
| 14 | | | Paranavaí | 33,681 | 119,952 * | 49,567 | 14.2 |
| 15 | | | S. T. Oeste | 281,551 | 249,858 * | 115,142 | 18.2 |
| 16 | | | Xambrê | 45,977 | 39,036 ns | 34,853 | 16.0 |
| 17 | Dry | 2012-2013 | S.T. Oeste | 73,412 | 419,100 ** | 60,302 | 18.4 |
| 18 | | | Xambrê | 73,263 | 107,259 ** | 32,486 | 23.6 |

[1]Degrees of freedom: 3 (block); 11 (cultivar); 33 (residue). [2]F test: ** ; * significative to 1% and 5% of probability, respectively and [ns] not significant, by F test. [3]Coefficient of environmental variation.

The averages in culture environments ranged from 762 kg ha$^{-1}$ (Xambrê, dry season 2012-2013) to 3184 kg ha$^{-1}$ (Xambrê, rainy season 2010-2011), with a difference of 2,422 kg ha$^{-1}$ between the environments with higher and lower productivity (Table 3). This amplitude variation is due in part to the cultivation environment that affected plant development. It is known that adverse environmental conditions such as temperature, water availability and sunlight affect the growth of the plant in different ways, depending on the stage of development that it is (Duarte et al., 2013, Silveira et al., 2013 Fachin et al., 2014). The estimated environmental variation coefficients (CV) ranged from 9 to 25%, showing good experimental precision (Table 2).

**Table 3** - Grain yield (kg ha$^{-1}$) of peanut cultivars evaluated in Irati, Londrina, Paranavaí, Santa Tereza do Oeste (S. T. Oeste) and Xambrê in rainy (Ra) and dry (Dry) seasons of 2010-2011, 2011-2012 and 2012-2013.

| Cultivar | Irati | Londrina | Paranavaí | S. T. Oeste | Xambrê | Irati |
|---|---|---|---|---|---|---|
| | Ra 2010-2011 | | | | | Ra 2011-2012 |
| IAC Tatu ST | 1,869 a | 2,742 a | 2,323 b | 2,121 d | 2,925, a | 1,062 b |
| Runner IAC 886 | 1,540 b | 2,732 a | 1,577 c | 2,235 c | 3,372 a | 1,060 b |
| IAPAR 25 Tição | 1,659 b | 3,058 a | 3,056 a | 1,825 d | 3,495 a | 1,290 a |
| Tégua | 1,049 c | 2,472 b | 1,654 c | 2,821 b | 3,104 a | 1,165 b |
| IAC Poitara | 2,176 a | 2,951 a | 2,439 b | 2,266 c | 3,260 a | 1,374 a |
| IAC Tatuí | 1,944 a | 2,486 b | 2,507 b | 3,476 a | 3,171 a | 1,715 a |
| IAC Tupã | 1,617 b | 3,055 a | 2,702 a | 3,205 a | 3,252 a | 957 b |
| IAC Oirã | 1,882 a | 2,739 a | 2,640 a | 2,346 c | 3,087 a | 1,090 b |
| IAC Caiapó | 897 c | 2,529 b | 1,868 c | 1,986 d | 3,051 a | 758 b |
| BRS 151-L7 | 1,741 b | 2,375 b | 2,455 b | 2,466 c | 3,082 a | 1,477 a |
| BRS Havana | 1,468 b | 2,514 b | 2,451 b | 3,381 a | 3,147 a | 1,350 a |
| BR 01 | 1,058 c | 2,935 a | 2,798 a | 2,443 c | 3,263 a | 1,570 a |
| General Mean | 1,574 | 2,715 | 2,372 | 2,547 | 3,184 | 1,238 |
| **Cultivar** | **Londrina** | **Paranavaí** | **Xambrê** | **Londrina** | **Paranavaí** | **Xambrê** |
| | Ra 2011-2012 | | | Ra 2012-2013 | | |
| IAC Tatu ST | 2,267 c | 660 b | 552 c | 2,481 a | 2,450 a | 1,613 b |
| Runner IAC 886 | 3,270 b | 1,396 a | 1,280 b | 2,323 a | 2,024 b | 1,706 b |
| IAPAR 25 Tição | 2,517 c | 1,085 a | 642 c | 2,577 a | 2,618 a | 1,613 b |
| Tégua | 3,658 a | 1,129 a | 1,848 a | 2,382 a | 2,350 a | 2,212 a |
| IAC Poitara | 1,866 d | 985 b | 642 c | 1,955 b | 2,037 b | 1,028 c |
| IAC Tatuí | 1,900 d | 656 b | 481 c | 2,239 a | 2,090 b | 933 c |
| IAC Tupã | 1,708 d | 804 b | 74 c | 2,507 a | 2,857 a | 2,038 a |
| IAC Oirã | 1,865 d | 904 b | 629 c | 2,484 a | 2,449 a | 1,366 c |
| IAC Caiapó | 2,924 b | 977 b | 1,180 b | 1,967 b | 2,046 b | 1,705 b |
| BRS 151-L7 | 2,179 c | 795 b | 483 c | 1,934 b | 2,516 a | 1,279 c |
| BRS Havana | 2,582 c | 847 b | 618 c | 2,347 a | 1,996 b | 1,369 c |
| BR 01 | 2,354 c | 1,344 a | 656 c | 2,101 b | 1,634 b | 1,145 c |
| General Mean | 2,424 | 965 | 812 | 2,274 | 2,255 | 1,500 |
| **Cultivar** | **Irati** | **Paranavaí** | **S. T. Oeste** | **Xambrê** | **S. T Oeste** | **Xambrê** |
| | Dry 2011-2012 | | | | Dry 2012-2013 | |
| IAC Tatu ST | 1,349 b | 1,648 a | 1,740 b | 1,092 a | 1,326 a | 703 a |
| Runner IAC 886 | 911 c | 1,575 a | 1,544 b | 1,270 a | 1,427 a | 1,007 a |
| IAPAR 25 Tição | 1,278 b | 1,409 a | 1,842 b | 1,115 a | 1,025 b | 501 a |
| Tégua | 1,155 b | 1,579 a | 1,479 b | 1,121 a | 784 b | 1,024 a |
| IAC Poitara | 2,125 a | 1,757 a | 2,371 a | 1,229 a | 1,316 a | 650 a |
| IAC Tatuí | 2,104 a | 1,684 a | 2,076 a | 1,197 a | 1,644 a | 749 a |
| IAC Tupã | 1,700 a | 1,789 a | 1,989 a | 1,214 a | 934 b | 549 a |
| IAC Oirã | 1,896 a | 1,586, a | 2,052 a | 1,137 a | 1,375 a | 757 a |
| IAC Caiapó | 703 c | 1,676 a | 1,646 b | 1,383 a | 1,132 b | 913 a |
| BRS 151-L7 | 1,258 b | 1,287 a | 1,766 b | 1,128 a | 1,587 a | 668 a |
| BRS Havana | 1,194 b | 1,238 a | 1,851 b | 1,052 a | 1,891 a | 812 a |
| BR 01 | 1,297 b | 1,567 a | 1,968 a | 1,039 a | 1,603 a | 816 a |
| General Mean | 1,414 | 1,566 | 1,860 | 1,164 | 1,337 | 762 |

Values followed by the same lowercase letters vertically are not statistically different from each other. Scott-Knott test at 5% probability.

The joint analysis of variance of the 18 environments revealed significant effect at 1% probability for the cultivar, the environment and the interaction cultivar x environment, which shows different behavior among cultivars, and the inconsistent behavior of them due to environmental variations (Table 4). Changes in the productive performance of peanut lines when grown in different environments were also observed in previous studies in other regions of the country (Oliveira et al., 2006b, Santos et al., 2010; 2012a,b). The occurrence of the effect of G x E interaction is predictable, because the crops were carried out during the rainy and dry seasons, and the localities have different edaphoclimatic conditions.

**Table 4** - Joint analysis of variance for grain yield (kg ha$^{-1}$) in 12 peanut cultivars evaluated in 18 environments of Paraná State, Brazil.

| Sources of Variantion | Degrees of Freedon | Mean Square | [1]F values |
|---|---|---|---|
| Block/Environment | 54 | 335,815 | - |
| Block | 3 | 186,474 | - |
| Block x Environment | 51 | 344,600 | - |
| Cultivar (Cult) | 11 | 325,632 | 3.64** |
| Environment (Env) | 17 | 23,947,461 | 71.31** |
| Cult. x Env. | 187 | 492,200 | 5.49** |
| Cult / Env | 198 | 482,947 | 5.39** |
| Cult / Env 1 | 11 | 629,466 | 7.02** |
| Cult / Env 2 | 11 | 232,971 | 2.60** |
| Cult / Env 3 | 11 | 825,580 | 9.21** |
| Cult / Env 4 | 11 | 1,205,962 | 13.46** |
| Cult / Env 5 | 11 | 95,134 | 1.06$^{ns}$ |
| Cult / Env 6 | 11 | 301,238 | 3.36** |
| Cult / Env 7 | 11 | 1,463,249 | 16.33** |
| Cult / Env 8 | 11 | 229,980 | 2.56 ** |
| Cult / Env 9 | 11 | 680,747 | 7.59 ** |
| Cult / Env 10 | 11 | 216,257 | 2.41 ** |
| Cult / Env 11 | 11 | 462,366 | 5.16** |
| Cult / Env 12 | 11 | 603,725 | 6.73** |
| Cult / Env 13 | 11 | 811,263 | 9.05** |
| Cult / Env 14 | 11 | 119,867 | 1.33$^{ns}$ |
| Cult / Env 15 | 11 | 249,768 | 2.78** |
| Cult / Env 16 | 11 | 38,873 | 0.43$^{ns}$ |
| Cult / Env 17 | 11 | 419,122 | 4.67 ** |
| Cult / Env 18 | 11 | 107,476 | 1.19$^{ns}$ |
| Env / Cult | 204 | 2,446,805 | 27.31** |
| Env / Cult 1 | 17 | 2,143,704 | 23.92 ** |
| Env / Cult 2 | 17 | 2,135,898 | 23.84** |
| Env / Cult 3 | 17 | 3,098,594 | 34.58** |
| Env / Cult 4 | 17 | 2,715,987 | 30.31** |
| Env / Cult 5 | 17 | 2,213,726 | 24.71** |
| Env / Cult 6 | 17 | 2,688,712 | 30.01** |
| Env / Cult 7 | 17 | 3,207,109 | 35.79** |
| Env / Cult 8 | 17 | 2,149,056 | 23.98** |
| Env / Cult 9 | 17 | 2,020,851 | 22.55** |
| Env / Cult 10 | 17 | 2,064,769 | 23.04** |
| Env / Cult 11 | 17 | 2,641,412 | 29.48** |
| Env / Cult 12 | 17 | 2,281,845 | 25.47** |
| Residue | 594 | 89,584 | - |
| Total | 863 | - | - |
| Mean (kg ha$^{-1}$) | 1,776 | - | - |
| CV (%) | 16.85 | - | - |

[1] F test: ** ; * significant at 1% and 5% probability, respectively.

The joint analysis of variance of experiments does not provide detailed information of the genotypes with respect to environmental variations. In this context, adaptability and phenotypic stability studies are required to identify genotypes with predictable performance in diverse environments. The methodology of Eberhart & Russell (1966) uses the estimates of the regression coefficients ($\beta_{1i}$) and regression deviations ($\sigma_d^2$) for obtaining the parameters of adaptability and stability, respectively. The adaptability of a genotype refers to its ability to advantageously utilize the environmental stimuli. The cultivars that showed wide adaptation ($\beta_{1i}$=1) were IAC Tatu ST, Tégua, IAC Poitara, IAC Tatui, IAC Oirã, BRS 151-L7, BRS Havana and BR01, indicating satisfactory response to environmental improvements and ability to maintain their income on adverse conditions. The cultivars IAPAR 25 Tição and IAC Tupã had specific adaptation to favorable environments ($\beta_{1i}$>1), these cultivars respond satisfactorily to improvements in environmental conditions. The cultivars Runner IAC 886 and IAC Caiapó had specific adaptation to harsh environments ($\beta_{1i}$<1), being indicated for environments where it is used low technological content or with occurrence of adverse edaphoclimatic conditions (Table 5).

**Table 5** - Estimate parameters of adaptability and phenotypic stability for grain yield of 12 peanut cultivars evaluated in 18 environments in the Paraná State, Brazil.

| Cultivar | [1]Mean (kg ha$^{-1}$) | [2]$\beta_{1i}$ | [3]$\sigma_d^2$ | [4]$R^2$ (%) |
|---|---|---|---|---|
| IAC Tatu ST | 1,717 | 1.00 ns | 16,455.5 * | 93.1 |
| Runner IAC 886 | 1,791 | 0.89 * | 124,096.3 ** | 74.1 |
| IAPAR 25 Tição | 1,811 | 1.17 ** | 66,659.4 ** | 89.1 |
| Tégua | 1,832 | 0.90 ns | 261,912.8 ** | 60.5 |
| IAC Poitara | 1,801 | 0.93 ns | 103,154.9 ** | 78.6 |
| IAC Tatuí | 1,836 | 1.01 ns | 145,878.6 ** | 76.4 |
| IAC Tupã | 1,867 | 1.17 ** | 98,912.7 ** | 85.7 |
| IAC Oirã | 1,793 | 0.98 ns | 37,066.1 ** | 89.5 |
| IAC Caiapó | 1,629 | 0.87 * | 105,450.1 ** | 76.1 |
| BRS 151-L7 | 1,693 | 0.97 ns | 21,951.0 * | 91.9 |
| BRS Havana | 1,783 | 1.07 ns | 62,443.3 ** | 87.9 |
| BR 01 | 1,754 | 0.98 ns | 67,897.2 ** | 85.1 |

[1]Mean grain yield. [2]Regression coefficient **, * statistically different from 1, by the t test, at 1% and 5% probability, respectively. [3]Regression deviation, **, * statistically different from zero, by the F test, at 1% and 5% probability, respectively. [4]Determination coefficient.

One way to minimize the effect of G x E interaction is through the recommendation of high phenotypic stability cultivars for the desired trait. However, cultivars showed low predictability of behavior with regression deviation statistically different from zero ($\sigma^2 \neq 0$) by the F test (Cruz & Regazzi, 1997) (Table 5). Among the cultivars studied, 58.3% had coefficient of determination ($R^2$) above 80%, showing linearity of response to the evaluated environments.

It is noteworthy that the adaptability and phenotypic stability are parameters related to the set of genotypes and environments studied, therefore, the non-coincidence of the performance of some genotypes evaluated in other environments, not used in this study, is admissible. The assessment carried out in the country's Northeast region, with erect peanut cultivars, showed that cultivars BR1, BRS Havana, BRS 151-L7 and IAC Tatu showed broad adaptation, high stability of production and high grain yield, except for IAC Tatu, that was inserted into the group with lower grain yield (Gomes et al., 2007). These results are partially in agreement with those obtained in this study, since these cultivars also showed broad adaptation to 18 evaluated environments in Paraná State, but did not show behavioral stability.

Environmental indices ($I_j$) calculated are shown in Table 6. It is observed that the values given by the indices are indicative of environmental quality (Cruz & Regazzi, 1997). $I_j$ negative values indicate unfavorable environments, showing growing areas where the technological index used is low or regions with adverse soil and climatic conditions. Negative environmental indices were observed for the environments 1, 6, 8, 9, 12, conducted during the rainy season, and the environments 13, 14, 16, 17 and 18 in the dry season. Positive ratings indicate favorable environmental settings associated with the regions with appropriate climatic and edaphic conditions to the aptitude of the culture or cultivation areas where high production technology is used. Values of positive environmental indices were found to environments 2, 3, 4, 5, 7, 10 and 11 conducted in the rainy season, and to environment 15 in dry season.

Analyzes of individual variance for oil content showed significance at 1% probability to cultivate at all locations evaluated in the rainy season 2010-2011 (Table 7). The ratio between the highest and the lowest mean square (Table 7) found for oil content was 1.75, which enabled the joint analysis, because the residual variances can be considered homogeneous (Banzatto & Kronka, 2006).

**Table 6** - Environmental indices ($I_j$) and average yield of peanut cultivars in 18 environments in Paraná State, Brazil.

| Environment | Season | Agricultural Year | Location | General mean (kg ha$^{-1}$) | Index ($I_j$) (kg ha$^{-1}$) |
|---|---|---|---|---|---|
| 1 | Rainy | 2010-2011 | Irati | 1575 | -201 |
| 2 | | | Londrina | 2716 | 939 |
| 3 | | | Paranavaí | 2372 | 596 |
| 4 | | | Santa Tereza do Oeste | 2548 | 771 |
| 5 | | | Xambrê | 3184 | 1408 |
| 6 | Rainy | 2011-2012 | Irati | 1239 | -537 |
| 7 | | | Londrina | 2424 | 648 |
| 8 | | | Paranavaí | 965 | -811 |
| 9 | | | Xambrê | 813 | -964 |
| 10 | Rainy | 2012-2013 | Londrina | 2275 | 499 |
| 11 | | | Paranavaí | 2255 | 479 |
| 12 | | | Xambrê | 1501 | -276 |
| 13 | Dry | 2011-2012 | Irati | 1414 | -362 |
| 14 | | | Paranavaí | 1566 | -210 |
| 15 | | | Santa Tereza do Oeste | 1860 | 84 |
| 16 | | | Xambrê | 1165 | -611 |
| 17 | Dry | 2012-2013 | Santa Tereza do Oeste | 1337 | -439 |
| 18 | | | Xambrê | 762 | -1014 |

**Table 7** – Analyzes of individual variances for oil content (%) in grains of peanut cultivars evaluated in Irati, Londrina and Santa Tereza do Oeste in the rainy season 2010-2011.

| Test | | | [1]Mean Square | | | [3]CV |
|---|---|---|---|---|---|---|
| Season | Year | Location | Block | [2]Cultivar | Residue | (%) |
| Rainy | 2010-2011 | Irati | 1.637 | 7.576** | 1.375 | 2.503 |
| Rainy | 2010-2011 | Londrina | 3.382 | 8.087** | 2.402 | 3.277 |
| Rainy | 2010-2011 | Santa Tereza do Oeste | 0.014 | 4.869** | 1.690 | 2.807 |

[1]Degrees of freedom: 3 (block); 11 (cultivar); 33 (residue). [2]F test: ** ; * significative at 1% and 5% of probability, respectively.
[3]Coefficient of environmental variation.

The joint analysis of variance showed a significant effect for cultivar and environment at 1% probability for the oil content (Table 8). Currently it is observed that most peanut varieties have an average oil content on a dry basis of 45-51% in the grains, it is noted that these values vary depending on the cultivation area and the genetic constitution of the cultivar (Santos et al., 2012b; Wilson et al., 2013). It is verified that the cultivar x environment interaction was also significant, with 5% probability, indicating a differential behavior of these cultivars depending on the environment. In this work, the estimated coefficient of variation in joint analysis of variance was 2.88%, indicating good experimental precision in the results (Table 8).

The average oil content in the grains was approximately 47% (Table 9), within the average found in peanut cultivars (Campos-Mondragon et al., 2009). The higher oil contents were observed in BRS 151-L7 (48.4%), IAC Tatuí (48.2%), BRS Havana (48.1%), IAC Poitara (47.3%), IAC Oirã (47.1%) and IAC Tupã (47%). The identification of cultivars with high yield potential of oil is interesting for the production of biodiesel. Peanut oil, along with other vegetable oils, has been studied with promising results to be used as biofuel in diesel engines (Nakagawa & Rosolem, 2011). In fact, historical records report that peanut oil was one of the first oils used in the diesel engine in the first decades of the twentieth century (Silva & Freitas, 2008). The IAC Tatu ST and IAC Runner 886 cultivars showed the lowest oil content at all sites (Table 8). The oil content in cultivars ranged from 44.2% (IAC Tatu ST in Santa Tereza do Oeste) to 49.6% (BRS 151-L7 in Londrina) (Table 8). However, taking into account other species of the genus *Arachis*, an even higher amplitude variation can be observed, from 41.7% to 61.3% oil in the grains (Wang et al., 2010).

**Table 8 -** Joint analysis of variance for the oil content (%) in grains of peanut cultivars evaluated in Irati, Londrina and Santa Tereza do Oeste in the rainy season 2010-2011.

| Sources of Variantion | Degrees of Freedon | Mean Square | [1]F values |
|---|---|---|---|
| Block/Environment | 9 | 1.678 | - |
| Block | 3 | 0.295 | - |
| Block x Environment | 6 | 2.369 | - |
| Cultivar (Cult) | 11 | 13.837 | 7.59** |
| Environment (Env) | 2 | 11.615 | 6.92** |
| Cult. x Env. | 22 | 3.347 | 1.83* |
| Cult / Env | 33 | 6.844 | 3.75** |
| Cult / Env 1 | 11 | 7.576 | 4.15** |
| Cult / Env b 2 | 11 | 8.087 | 4.43** |
| Cult / Env 3 | 11 | 4.869 | 2.67** |
| Env / Cult | 24 | 4.036 | 2.214** |
| Env / Cult 1 | 2 | 5.231 | 2.870$^{ns}$ |
| Env / Cult 2 | 2 | 2.657 | 1.457$^{ns}$ |
| Env / Cult 3 | 2 | 5.634 | 3.091$^{ns}$ |
| Env / Cult 4 | 2 | 0.193 | 0.105$^{ns}$ |
| Env / Cult 5 | 2 | 14.786 | 8.112** |
| Env / Cult 6 | 2 | 1.693 | 0.929$^{ns}$ |
| Env / Cult 7 | 2 | 0.009 | 0.005$^{ns}$ |
| Env / Cult 8 | 2 | 1.387 | 0.761$^{ns}$ |
| Env / Cult 9 | 2 | 3.951 | 2.168$^{ns}$ |
| Env / Cult 10 | 2 | 9.363 | 5.137** |
| Env / Cult 11 | 2 | 2.856 | 1.567$^{ns}$ |
| Env / Cult 12 | 2 | 0.670 | 0.367$^{ns}$ |
| Residue | 99 | 1.822 | - |
| Total | 143 | - | - |
| Mean (%) | 46.81 | - | - |
| CV (%) | 2.88 | - | - |

[1] F test: ** ; * significant at 1% and 5% probability, respectively.

**Table 9 -** Oil content (%) in dry basis in grains of peanut cultivars evaluated in Irati, Londrina and Santa Tereza do Oeste in the rainy season 2010-2011.

| Cultivars | Locations | | | General mean (%) |
|---|---|---|---|---|
| | [1]Irati | [1]Londrina | [1]Santa Tereza do Oeste | |
| IAC Tatu ST | 44.7B b | 46.4A b | 44.2B b | 45.1 b |
| Runner IAC 886 | 44.6A b | 45.1A b | 46.2A a | 45.3 b |
| IAPAR 25 Tição | 46.8A a | 47.0A b | 44.8B b | 46.2 b |
| Tégua | 46.3A b | 46.4A b | 46.7A a | 46.5 b |
| IAC Poitara | 47.7A a | 49.0A a | 45.2B b | 47.3 a |
| IAC Tatuí | 48.5A a | 48.6A a | 47.4A a | 48.2 a |
| IAC Tupã | 47.0A a | 47.1A b | 47.0A a | 47.0 a |
| IAC Oirã | 47.7A a | 46.7A b | 46.7A a | 47.1 a |
| IAC Caiapó | 45.7A b | 46.4A b | 47.6A a | 46.6 b |
| BRS 151-L7 | 48.9A a | 49.6A a | 46.7B a | 48.4 a |
| BRS Havana | 47.9A a | 49.1A a | 47.4A a | 48.1 a |
| BR 01 | 46.5A b | 46.2A b | 45.7A b | 46.1 b |
| Mean | 46.9 | 47.3 | 46.3 | 46.8 |

[1]Values followed by the same capital letters in horizontal and lowercase letters in vertical belong to the same group. Scott-Knott test, 5% probability.

## Conclusions

The cultivars showed genetic variability for oil content in grain, highlighting BRS 151-L7, IAC Tatuí, BRS Havana, IAC Poitara, IAC Oirã and IAC Tupã, with the highest average levels of oil.

Regarding grain yield, the Runner IAC 886 and IAC Caiapó cultivars had specific adaptation to harsh environments, while IAPAR 25 Tição and IAC Tupã had it to favorable ones. In terms of stability, IAC Tatu ST was the most predictable and Tégua the least stable, since the estimate of its determination coefficient was the lowest among the tested cultivars.

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