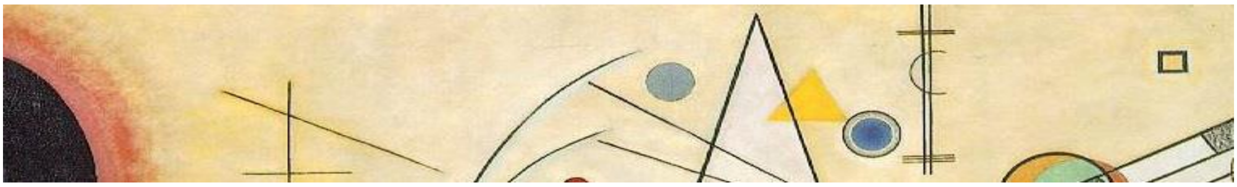


Contemporânea
Contemporary Journal
Vol.4 No.3: 01-19, 2024
ISSN: 2447-0961

Artigo

CRUDE PROTEIN CONTENT IN PIGEON PEA GRAIN LINES

TEOR DE PROTEÍNA BRUTA EM LINHAGENS DE GUANDU GRANÍFERO

CONTENIDO DE PROTEÍNA CRUDA EN LÍNEAS DE GRANO DE GUISANTE DE PALOMA

DOI: 10.56083/RCV4N3-093
Originals received: 02/01/2024
Acceptance for publication: 02/27/2024

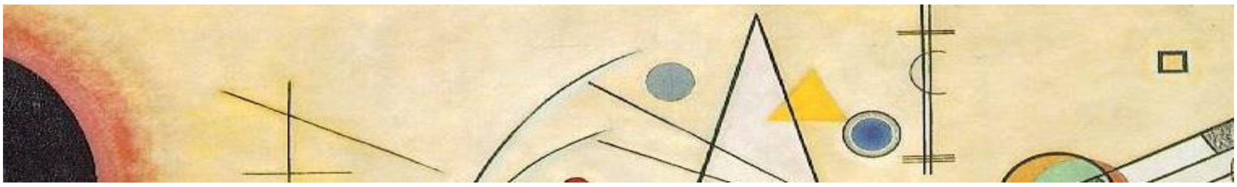
Filipe de Souza Nascimento
Graduate in Agronomic Engineering
Institution: Universidade Federal do Vale do São Francisco (UNIVASF)
Address: Av. Antônio C. Magalhães, 510, Country Club, Juazeiro - BA, CEP: 48902-300
E-mail: filipe.gl@hotmail.com

Carlos Antônio Fernandes Santos
PhD in Genetics and Genetic Improvement
Institution: Empresa de Pesquisa Agropecuária – Embrapa Semiárido
Address: Rodovia BR-428, Km 152, s/n, Zona Rural, Petrolina - PE, CEP: 56302-970
E-mail: carlos-fernandes.santos@embrapa.br

Acácio Figueiredo Neto
Doctor of Agricultural Storage
Institution: Universidade Federal do Vale do São Francisco (UNIVASF)
Address: Av. Antônio C. Magalhães, 510, Country Club, Juazeiro - BA, CEP: 48902-300
E-mail: acacio.figueiredo@univasf.edu.br

Luiz Gabriel Vieira Bezerra
Graduating in Agronomic Engineering
Institution: Instituto Federal Sertão Rural
Address: N4, Projeto Senador Nilo Coelho, Zona Rural, CEP: 56300-000
E-mail: luizgabrielvieira.blg@gmail.com

Samira Angélica Mota Ferreira da Silva
Graduating in Agricultural and Environmental Engineering
Institution: Universidade Federal do Vale do São Francisco (UNIVASF)
Address: Av. Antônio C. Magalhães, 510, Country Club, Juazeiro - BA, CEP: 48902-300
E-mail: ferreira_samira10@hotmail.com



ABSTRACT: Pigeon pea (*Cajanus cajan* (L.) Millspaugh) is a multipurpose legume, which can be used as a grain producer, fodder and soil improver. Its nutritional composition has high protein, on average 22%, characterizing a relevant species in several emerging countries. Although it is an important crop in semi-arid regions of other countries, in Brazil has been little used and studied, so that it is still considered a subsistence culture. The goal of the present study was to evaluate the protein content in 21 lines of pigeon pea, from the breeding program of Embrapa Semiárido, including the control variety ‘guandu Petrolina’. The experiments were conducted in Barbalha/CE, Petrolina/PE and Juazeiro/BA, years of 2019, 2020 and 2021, distributed in four environments, three under irrigated cultivation and one under rainfed cultivation. The experiments were arranged in plots with two planting lines measuring 2.4m x 2.5m, spaced between rows by 1.2m and between plants by 0.5m, with two plants per hole, using a randomized block design with three replications. The cultural treatments consisted of manual weeding, without any type of fertilization in the experimental area. The determination of total nitrogen and crude protein was performed using the Kjeldahl method. The genotype × environment interaction was highly significant ($p<0.01$) for protein content. There was no significant difference between the levels of protein under irrigated and rainfed cultivation. After joint analysis of variance among the four environments, the control cultivar 'Petrolina presented the highest average, with 24.60%. The lowest protein average was presented by treatment 17 (ICPL 900053 x Anagé), 20.12%. Lines 12 (ICPL 90053 x D2 Type), 9 (ICPL 90045 x ICPL 89027) and 19 (ICPL 89027 x D3 Type) expressed acceptable values for protein content, 22.35, 21.99 and 22.72%, respectively, associated with high productivity, broad adaptability and good predictability, showing great potential to be new cultivars to the Brazilian semiarid region.

KEYWORDS: *Cajanus cajan,* Breeding, Genotype × Environment Interaction, Protein Content.

RESUMO: O feijão guandu (*Cajanus cajan* (L.) Millspaugh) é uma leguminosa de múltiplos usos, podendo ser utilizado como produtora de grãos, forragens e melhorador de solos. Sua composição nutricional apresenta elevado teor de proteína, em média 22%, o caracterizando como uma espécie relevante economicamente em diversos países emergentes. Embora seja uma cultura importante em regiões semiáridas de outros países, no Brasil tem sido pouco utilizada e estudada, de modo que ainda é considerada cultura de subsistência. Desta forma, o presente trabalho buscou avaliar, nos anos de 2019, 2020 e 2021, em Barbalha/CE, Petrolina/PE e Juazeiro/BA, o teor de proteína em 21 linhagens de feijão guandu desenvolvidas pelo programa de melhoramento de guandu da Embrapa Semiárido, mais a variedade controle ‘guandu Petrolina’ distribuídas em quatro ambientes, três sob cultivo irrigado e um sob cultivo de sequeiro. Os experimentos foram dispostos em parcelas com duas linhas de plantio 2,4m x 2,5m, espaçado entre linhas por 1,2m e entre plantas por 0,5m, com duas plantas por cova, usando delineamento em blocos casualizados com três repetições. Os tratos culturais consistiram de capinas manuais, não se efetuando qualquer tipo de adubação na área experimental. A determinação do nitrogênio total e proteína bruta foi realizada através do método de Kjeldahl. A interação genótipo x ambiente foi altamente significativa (p<0,01) para o teor de proteína. Não houve diferença significativa entre os teores de proteína sob cultivo irrigado e sequeiro. Após análise de variância conjunta entre quatro ambientes, a cultivar controle 'guandu Petrolina', apresentou a maior média, com 24,60%. A menor média, foi apresentada pelo tratamento 17 (ICPL 900053 x Anagé), indicando 20,12%. As linhagens 12 (ICPL 90053 x D2 Type), 9 (ICPL 90045 x ICPL 89027) e 19 (ICPL 89027 x D3 Type) expressaram valores aceitáveis para teor de proteína, 22,35, 21,99 e 22,72%, respectivamente, associados à produtividade alta, ampla adaptabilidade e boa previsibilidade, apresentando grande potencial para lançamento como cultivar e recomendação para cultivo de guandu na região semiárida brasileira.

PALAVRAS-CHAVE: *Cajanus cajan*, Melhoramento, Interação Genótipo × Ambiente, Teor de Proteína.

RESUMEN: Guisante (Cajanus cajan (L.) Millspaugh) es una leguminosa multipropósito, que puede ser utilizada como productor de granos, forraje y mejorador del suelo. Su composición nutricional tiene un alto contenido proteico, en promedio del 22%, que caracteriza a una especie relevante en varios países emergentes. Aunque es un cultivo importante en regiones semiáridas de otros países, en Brasil ha sido poco utilizado y estudiado, por lo que todavía se considera una cultura de subsistencia. El objetivo del presente estudio fue evaluar el contenido proteico en 21 líneas de guisante de paloma, del programa de mejoramiento de Embrapa Semiárido, incluyendo la variedad control 'guandu Petrolina'. Los experimentos se realizaron en Barbalha/CE, Petrolina/PE y Juazeiro/BA, años de 2019, 2020 y 2021, distribuidos en cuatro ambientes, tres bajo cultivo de regadío y uno bajo cultivo de secano. Los experimentos se organizaron en parcelas con dos líneas de siembra que miden 2.4m x 2.5m, espaciadas entre filas por 1.2m y entre plantas por 0.5m, con dos plantas por hoyo, utilizando un diseño de bloques aleatorios con tres repeticiones. Los tratamientos culturales consistieron en el deshierbe manual, sin ningún tipo de fertilización en el área experimental. La determinación de nitrógeno total y proteína cruda se realizó utilizando el método de Kjeldahl. La interacción genotipo × ambiente fue altamente significativa (p<0,01) para el contenido de proteínas. No hubo diferencias significativas entre los niveles de proteína en el cultivo de regadío y de secano. Tras el análisis conjunto de la varianza entre los cuatro ambientes, el cultivar control 'Petrolina presentó el promedio más alto, con un 24,60%. El promedio proteico más bajo se presentó por tratamiento 17 (ICPL 900053 x Anagé), 20,12%. Las líneas 12 (ICPL 90053 x D2 Type), 9 (ICPL 90045 x ICPL 89027) y 19 (ICPL 89027 x D3 Type) expresaron valores aceptables para el contenido de proteínas, 22.35, 21.99 y 22.72%, respectivamente, asociados con alta productividad, amplia adaptabilidad y buena previsibilidad, mostrando un gran potencial para ser nuevos cultivares en la región semiárida brasileña.

PALABRAS CLAVE: *Cajanus cajan*, Crianza, Interacción Genotipo × Medio Ambiente, Contenido Proteico.

1. Introduction

Pigeon pea (*Cajanus cajan* (L.) Millspaugh), commonly known in Brazil as *andu, ervilha-de-angola, ervilha-do-congo,* and *feijão-da-árvore*, is part of a wide variety of legume species belonging to the family Fabaceae (REMANANDAN, 1990), of which the genus Phaseolus contains the most cultivated and consumed species worldwide (FRANCISCO et al., 2016). Segundo FULLER; HARVEY (2006). Based on archaeological studies, pigeon pea originated in Meridional Asia, specifically in northern India, from where it advanced to other parts of the Asian continent until reaching Africa. Around the middle of the 16th century, pigeon pea was introduced into the American continent through slave ships (GODOY et al., 2013).

These dry grain legume species are a good option for people who do not have sufficient resources to consume protein of animal origin. According KRAEMER & ZIMMERMANN (2007), the shortage of proteins and minerals in food contributes negatively to public health, affecting approximately half of the world's population, especially children, teenagers, and pregnant women.

These circumstances characterize cowpea as a socioeconomically relevant species in several emerging countries in Africa and Asia, given that, among its nutrient composition, on average 23.1% corresponds to crude (TEIXEIRA et al., 1985). However, as commonly occurs with other legume species with regard to the amino acid content, there is a lack of the sulfur amino acids cystine, methionine and tryptophane (ICRISAT, 1976).

In addition to being used as human food, pigeon pea also has foraging attributes due to its high leaf retention rate during the dry period and high yield, with the potential to be used as silage, direct pasture, and hay, increasing the quality of protein supplementation for animals, as stated by COSTA et al. (2001).

Data from FAOSAT (2020) show that the worldwide production of pigeon pea reached the mark of 5 million tons. India is the largest producer, representing 76.6%, followed by Malawi (8,4%) and Myanmar (6,7%). In Brazil, although it is a plant with characteristics that make it extremely qualified to be spread into production systems in tropical, subtropical, and especially semi-arid regions, given its ability to withstand climate change, tolerate water stress, soils with poor nutrient availability (VARSHNEY et al., 2017), and the ability to fix air nitrogen through symbiotic association with microorganisms (SAXENA, 2008), the crop is still largely neglected and little spread in such a way that there are no current data regarding its production in the country in the databases of Brazilian and international government agencies.

However, following the example of other legume species with agricultural importance, e.g., common bean and especially soybean, for which research in the fields of genetic resources, plant breeding, and management programs have contributed to spreading and solidifying the crop through the release of new superior cultivars (RAMALHO et al. 2012), this case of success is already adopted and well established for pigeon pea in countries such as India and Malawi, with the implementation of early and very productive hybrids (KAONEKA et al. 2016).

In Brazil, the Brazilian Agricultural Research Corporation (EMBRAPA) has conducted studies aimed at pigeon pea breeding for more than 30 years, with long interruption periods. These studies began with the collection of accessions from different traditional producing regions in Northeastern Brazil, in addition to the introduction of germplasm from FAO Latin America and the Caribbean (Food and Agriculture Organization of the United Nations) and ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), giving origin to a collection with more than 200 accessions (SANTOS et al. 2000). The evaluations carried out by this institution have resulted in the registration of the foraging pigeon pea cultivar Taipeiro and in the recommendation of the grain pigeon pea cultivar Petrolina (SANTOS et al., 2005).

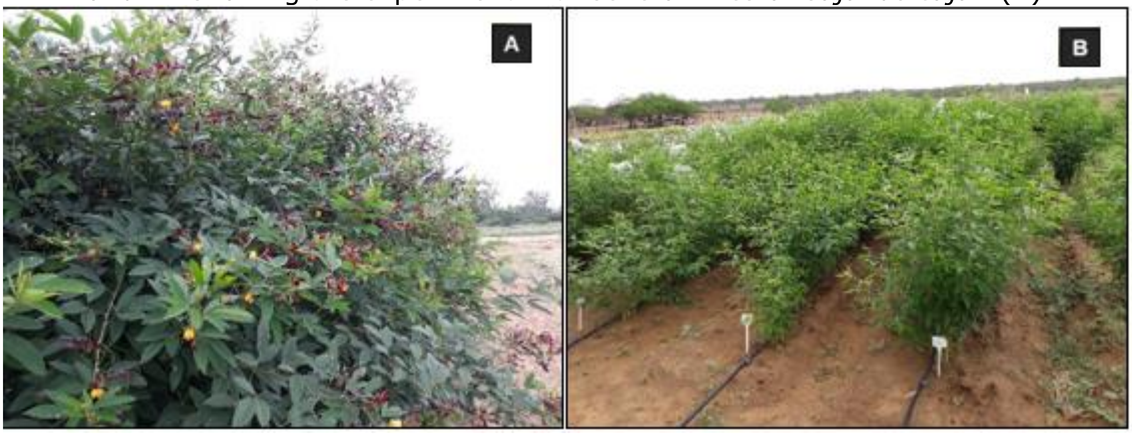
It is common sense that a plant breeding program aims to select desirable traits of a cultivar for a given region. Therefore, according to SANTOS et al. (2000), the variables of interest for the grain pigeon pea crop are: earliness, small plant size, a determined growth habit with a rapid growth rate, high yield, larger grain sizes, and more grains per pod. With that in mind, Embrapa Semiárido conducted studies aimed at identifying accessions with the potential for use as parents in manual hybridizations to select lines recommended for local cultivation conditions (GODOY et al. 2013). As a result, new lines were developed for possible registration and recommendation, with the potential to contribute directly to the consolidation of pigeon pea as a crop in the semi-arid region of Brazil.

From this perspective, this study aimed to evaluate the variability for the crude protein content in different grain pigeon pea lines, to promote the breeding program of this species in the semi-arid region of Brazil, aiming at grain production for human consumption.

2. Material and Methods

Twenty-two pigeon pea genotypes were analyzed, consisting of 21 lines developed by the plant breeding program at Embrapa Semiárido and the control cultivar 'guandu Petrolina', recommended by the same corporation. Four experiments were evaluated, two in Petrolina/PE and one in Juazeiro/BA, in the experimental fields Caatinga (09º04'15,7''S, 40º,19'30,5''W), at 376m of elevation above sea level, and Mandacaru (09º23'34''S, 40º24'58''W), at 379m of elevation above sea level, with two in an area irrigated by dripping and planting in the second semester of 2019 and 2021, and one in a rainfed area, with planting in the first semester of 2020 (Figure 1). The region has air temperature means above 24ºC, with a climate classified as *BSwh'*, according to the Köppen classification, corresponding to a region with a semi-arid climate (TEIXEIRA, 2010).

Figure 1. Pigeon pea plants, with picture 1A highlighting the flower of *Cajanus cajan* (A) and 2B showing the experiment with several lines of *Cajanus cajan* (B).



Source: Carlos Antônio da Silva, 2021.

The fourth experiment was conducted at the experimental field of Embrapa Algodão in Barbalha/CE (07º17'46''S, 39º16'11''W) at 402m of elevation above sea level, with sowing in the second semester of 2019 under a drip irrigation system. The region has annual air temperature means above

25.7 ºC, with a maximum of 27.4 °C in November and a minimum of 23.3 ºC occurring in June and July, with a BSwh’ climate (MATOS et al., 2014).

The experiments were arranged in plots with two planting rows measuring 2.4 m x 2.5 m, spaced 1.2 m between rows and 0.5 m between plants, with two plants per hole, under a randomized block design with three replications. Throughout the experiments, the plants were eventually sprayed for the initial control of sucking pests, and no fertilizers were used in any of the areas.

Grain harvest was performed manually after maturity was perceived in at least 50% of the pods, when they expressed a standard brown color typical of mature pods. The harvested grains were stored in a cold chamber of Embrapa Semiárido, to be processed and ground until reaching a mealy form.

Total nitrogen and crude protein were determined using the Kjeldahl method, by placing a 0.1g sample of ground pigeon pea to a test tube, which then received 3mL of 96% sulfuric acid (H2SO4). In order to make the solution more efficient, 1g of a catalytic mix of potassium sulfate (K2SO4) and copper sulfate (CuSO4) was added in a proportion of 10:1. The K2SO4 increased the boiling point of the acid, whereas CuSO4 accelerated the reaction (DIAS & PEREIRA, 2006). The digestion of the sample was performed in a block digester by gradually increasing temperature up to 400ºC to completely fix the protein nitrogen into ammonium, in the form of ammonium sulfate ((NH4)2SO4). The nitrogen was then subjected to reaction with 20mL sodium hydroxide (NaCl) 40%, to steam distillation, and then retrieved in the form of ammonia (NH3) in 25mL of a 2.5% boric acid solution (H3BO3), forming borate ions, which were then titrated with 0.05 mol/L^{-1} hydrochloric acid (HCl) standardized for the quantification of protein nitrogen and subsequent conversion into the crude protein content.

In total, 265 samples were analyzed for the total crude protein content, expressed in percentage (%). The experimental data were subjected to joint analysis of variance and the "Student-Newman-Keuls" means comparison test using the "GLM" procedure of the SAS software.

3. Results and Discussion

The lines (T), environments (A), and the interaction between them (TxA) were highly significant by the F-test ($p<0.01$) and significant for the blocks ($p<0.05$) in the joint analysis of variance for data referring to the protein content (Table 1). The relationships between the mean squares of the residuals found in all experiments were less than seven, demonstrating homogeneity of residual variances, a premise for the joint analysis of experiments (CRUZ E REGAZZI, 1994).

In the Mandacaru experimental field, treatment 19 (ICPL 89027 x D3 Type) showed the highest mean protein content, with 23.96%, whereas treatment 15 (ICPL 89027 x D3 Type), with the same parents, expressed only 19.32%. These values may be related to the possibility of a soil patch being present in the area or even the action of microorganisms on the roots, preventing nutrient uptake by the plant since, according to a study carried out by WOLFSON & SHEAVER (1981), plants grown under high nitrogen fertilization produce seeds with higher protein contents than those produced under low nitrogen availability.

Table 1. Joint analysis of variance for the protein content in 21 lines plus the control pigeon pea variety 'guandu Petrolina', evaluated in four environments: Experimental Field Mandacaru, Experimental Field Barbalha, and Experimental Field Caatinga (2), under irrigated and rainfed conditions (2019-2021).

Treatments	Parents	Protein content (%)
Guandu Petrolina	UW 10	24.60
2	ICPL 89027 x D3 Type	23.10
5	ICPL 90045 x UW 10	23.07
4	ICPL 89027 x UW 10	22.89
13	ICPL 89027 x UW 10	22.81
19	ICPL 89027 x D3 Type	22.72
14	ICPL 89027 x UW 10	22.63
7	ICPL 90045 x UW 10	22.45

8	ICPL 900053 x Anagé	22.41
12	ICPL 90053 x D2 Type	22.35
11	ICPL 90045 x ICPL 89027	22.05
9	ICPL 90045 x ICPL 89027	21.99
20	ICPL 90045 x ICPL 89027	21.95
3	UW10 x D3 Type	21.95
6	ICPL 900053 x Anagé	21.95
1	ICPL 900053 x Anagé	21.73
15	ICPL 89027 x D3 Type	21.28
21	ICPL 89020 x D3 Type	21.15
10	ICPL 900053 x Anagé	20.79
18	ICPL 900053 x Anagé	20.21
16	ICPL 90053 x D3 Type	20.18
17	ICPL 900053 x Anagé	20.12
Mean		22.02
CV (%)		7.00
QMB		8.71*
QMTr (T)		14.31**
QMA (A)		78.83**
QM (T x A)		1.72**
QMR		2.38

*, ** and NS: significant at 5%, 1%, and non-significant, respectively, by the F-test. Coefficient of variation (CV); Mean square of the block (QMB); Mean square of the treatment (QMTr); Mean square of the environment (QMA); Mean square of the residual (QMR). Means followed by the same letter in the column do not differ significantly at 5% probability.
Source: self-authored.

The highest protein content, considering the joint analysis in all environments, was observed in the control treatment 'guandu Petrolina' with 24.60%, whereas the lowest content was observed in treatment 17 (ICPL 900053 x Anagé), with 20.12% (Table 1). The mean protein content of the lines was 22.02%, ranging from 20.69% in the irrigated environment in the Experimental Field Caatinga with planting in 2021 (Table 4) to 23.30% in irrigated cultivation in the Experimental Field Barbalha with planting in 2019 (Table 2).

Table 2. “SNK” test of means for the protein content in 21 lines plus the control pigeon pea variety ‘guandu Petrolina’, evaluated at the Experimental Field Barbalha, CE,under rainfed cultivation (2019).

Treatment	Parents	Protein content (%)
Guandu Petrolina	UW 10	27.13 a
11	ICPL 90045 x ICPL 89027	26.09 ab
5	ICPL 90045 x UW 10	25.70 ab
14	ICPL 89027 x UW 10	24.71 abc
8	ICPL 900053 x Anagé	24.44 abcd
20	ICPL 90045 x ICPL 89027	24.11 abcd
15	ICPL 89027 x D3 Type	24.08 abcd
13	ICPL 89027 x UW 10	24.05 abcd
4	ICPL 89027 x UW 10	23.93 abcd
7	ICPL 90045 x UW 10	23.90 abcd
6	ICPL 900053 x Anagé	23.87 abcd
2	ICPL 89027 x D3 Type	23.78 abcd
21	ICPL 89020 x D3 Type	23.72 abcd
9	ICPL 90045 x ICPL 89027	23.48 abcd
19	ICPL 89027 x D3 Type	23.27 abcd
1	ICPL 900053 x Anagé	22.22 bcd
12	ICPL 90053 x D2 Type	22.16 bcd
3	UW10 x D3 Type	21.56 bcd
17	ICPL 900053 x Anagé	20.39 cd
10	ICPL 900053 x Anagé	20.33 cd
16	ICPL 90053 x D3 Type	19.92 d
18	ICPL 900053 x Anagé	19.89 d
Mean		23.30
CV (%)		6.15
QMB		30.33**
QMTr		10.56**
QMR		2.05

*, ** and NS: significant at 5%, 1%, and non-significant, respectively, by the F-test. Coefficient of variation (CV); Mean square of the block (QMB); Mean square of the treatment (QMTr); Mean square of the environment (QMA); Mean square of the residual (QMR). Means followed by the same letter in the column do not differ significantly at 5% probability.
Source: self-authored.

The experiments in the Experimental Field Caatinga under irrigated and rainfed cultivation, in general, showed similar protein content values, varying only by 1.79% (Table 3 and 4), thus corroborating the results reported by ANTONIEL (2016) and DA SILVA (2018), who also found little or no difference between mean protein content values, regardless of the management adopted, with or without irrigation.

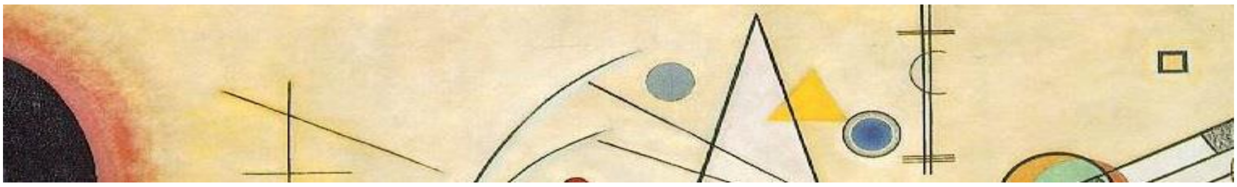


Table 3. "SNK" test of means for the protein content in 21 lines plus the control pigeon pea variety 'guandu Petrolina', evaluated in the Experimental Field Caatinga in Petrolina, PE, under rainfed cultivation (2020).

Treatments	Parents	Protein content (%)
Guandu Petrolina	UW 10	25.49 a
12	ICPL 90053 x D2 Type	25.11 ab
2	ICPL 89027 x D3 Type	24.14 ab
14	ICPL 89027 x UW 10	23.90 ab
4	ICPL 89027 x UW 10	23.66 ab
1	ICPL 900053 x Anagé	23.30 ab
7	ICPL 90045 x UW 10	23.00 ab
20	ICPL 90045 x ICPL 89027	22.96 ab
8	ICPL 900053 x Anagé	22.46 ab
3	UW10 x D3 Type	22.46 ab
19	ICPL 89027 x D3 Type	22.40 ab
18	ICPL 900053 x Anagé	22.25 ab
10	ICPL 900053 x Anagé	21.89 ab
13	ICPL 89027 x UW 10	21.89 ab
9	ICPL 90045 x ICPL 89027	21.79 ab
11	ICPL 90045 x ICPL 89027	21.79 ab
15	ICPL 89027 x D3 Type	21.68 ab
17	ICPL 900053 x Anagé	21.32 ab
21	ICPL 89020 x D3 Type	20.75 ab
5	ICPL 90045 x UW 10	20.69 ab
6	ICPL 900053 x Anagé	20.62 ab
16	ICPL 90053 x D3 Type	20.42 b
Mean		22.48
CV (%)		6.50
QMB		6.90^{NS}
QMTr		4.92*
QMR		2.16

*, ** and NS: significant at 5%, 1%, and non-significant, respectively, by the F-test. Coefficient of variation (CV); Mean square of the block (QMB); Mean square of the treatment (QMTr); Mean square of the environment (QMA); Mean square of the residual (QMR). Means followed by the same letter in the column do not differ significantly at 5% probability.
Source: self-authored.

The environment of Experimental Field Barbalha, in addition to showing the highest overall mean for the protein content, also expressed the highest individual mean value for the control treatment 'guandu Petrolina,' with 27.13% (Table 2). These values may be associated with soil fertility or even the presence of nitrogen-fixing bacteria, as indicated by MARINHO et al. (2014).

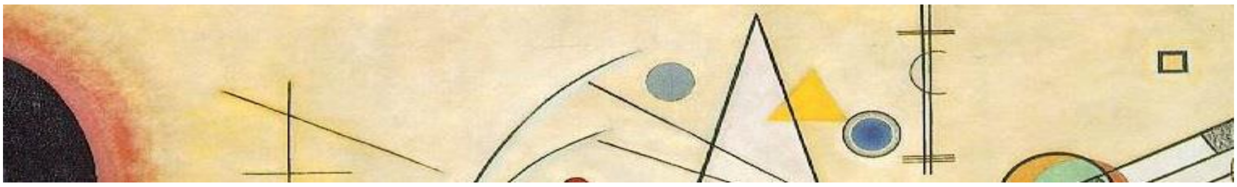
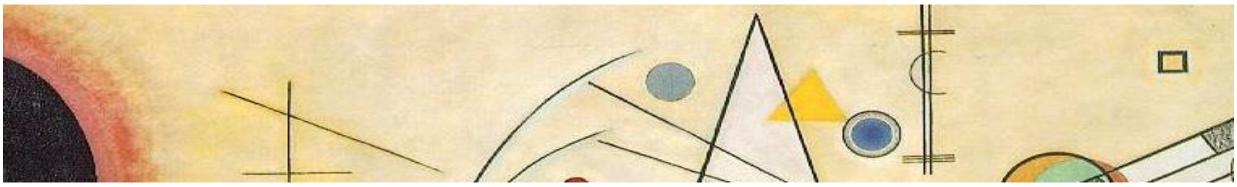


Table 4. "SNK" test of means for the protein content in 21 lines plus the control pigeon pea variety 'guandu Petrolina', evalauted in the Caatinga Experimental Field in Petrolina, PE, under irrigated cultivation (2021).

Treatments	Parents	Protein content (%)
13	ICPL 89027 x UW 10	23.12 a
Guandu Petrolina	UW 10	23.06 ab
5	ICPL 90045 x UW 10	22.91 ab
8	ICPL 900053 x Anagé	22.07 ab
6	ICPL 900053 x Anagé	21.59 ab
3	UW10 x D3 Type	21.47 ab
19	ICPL 89027 x D3 Type	21.47 ab
4	ICPL 89027 x UW 10	21.02 ab
10	ICPL 900053 x Anagé	20.75 ab
9	ICPL 90045 x ICPL 89027	20.72 ab
1	ICPL 900053 x Anagé	20.57 ab
14	ICPL 89027 x UW 10	20.51 ab
20	ICPL 90045 x ICPL 89027	20.45 ab
7	ICPL 90045 x UW 10	20.30 ab
2	ICPL 89027 x D3 Type	20.30 ab
12	ICPL 90053 x D2 Type	20.03 ab
16	ICPL 90053 x D3 Type	19.71 ab
18	ICPL 900053 x Anagé	19.41 ab
15	ICPL 89027 x D3 Type	19.38 ab
21	ICPL 89020 x D3 Type	18.81 ab
17	ICPL 900053 x Anagé	18.72 ab
11	ICPL 90045 x ICPL 89027	18.57 b
Mean		20.69
CV (%)		6.92
QMB		4.20^{NS}
QMTr		5.36**
QMR		2.05

*, ** and NS: significant at 5%, 1%, and non-significant, respectively, by the F-test. Coefficient of variation (CV); Mean square of the block (QMB); Mean square of the treatment (QMTr); Mean square of the environment (QMA); Mean square of the residual (QMR). Means followed by the same letter in the column do not differ significantly at 5% probability.
Source: self-authored.

Although the 'guandu Petrolina' variety reached the highest individual mean, a study carried out by COSTA (2021) with these same lines showed that its productivity was lower than all others, totaling 1015.65 kg ha^{-1}, while the average was 1516.31 kg ha^{-1}. These results indicate difficulties in selecting lines that present the highest protein contents associated with high grain production. One possibility to overcome this challenge is to perform selection for intermediate values or above the mean of the experiments for grain and protein production. According to SANTOS & BOITEUX (2013),



phenotypic correlations were not significant between these two variables in cowpea, demonstrating that it is possible to select lines with high grain production and high protein content (Table 5).

Tabela 5. SNK" test of means for the protein content in 21 lines plus the control pigeon pea variety 'guandu Petrolina', evalauted at the Mandacaru Experimental Field in Juazeiro, BA, under irrigated cultivation (2021).

Treatments	Parents	Protein content (%)
19	ICPL 89027 x D3 Type	23.96 a
Guandu Petrolina	UW 10	23.57 ab
2	ICPL 89027 x D3 Type	23.24 abc
12	ICPL 90053 x D2 Type	23.00 abc
5	ICPL 90045 x UW 10	22.97 abc
4	ICPL 89027 x UW 10	22.94 abc
7	ICPL 90045 x UW 10	22.58 abc
3	UW10 x D3 Type	22.22 abc
13	ICPL 89027 x UW 10	22.19 abc
9	ICPL 90045 x ICPL 89027	21.89 abc
11	ICPL 90045 x ICPL 89027	21.68 abc
14	ICPL 89027 x UW 10	21.41 abc
6	ICPL 900053 x Anagé	21.26 abc
21	ICPL 89020 x D3 Type	21.17 abc
1	ICPL 900053 x Anagé	20.84 abc
8	ICPL 900053 x Anagé	20.66 abc
16	ICPL 90053 x D3 Type	20.66 abc
20	ICPL 90045 x ICPL 89027	20.63 abc
10	ICPL 900053 x Anagé	20.18 abc
17	ICPL 900053 x Anagé	20.06 abc
15	ICPL 89027 x D3 Type	19.32 bc
18	ICPL 900053 x Anagé	18.87 c
Mean		21.69
CV (%)		6.40
QMB		0.33^{NS}
QMTr		5.14**
QMR		1.92

*, ** and NS: significant at 5%, 1%, and non-significant, respectively, by the F-test. Coefficient of variation (CV); Mean square of the block (QMB); Mean square of the treatment (QMTr); Mean square of the environment (QMA); Mean square of the residual (QMR). Means followed by the same letter in the column do not differ significantly at 5% probability.
Source: self-authored.

The genotype x environment interaction is an event that constitutes one of the main complications in plant breeding, as well as for the selection phase and the recommendation of cultivars, with adaptability and stability studies being alternatives to minimize or take advantage of the effects of this interaction (CRUZ et al. 2014). Recommending cultivars with good adaptability and stability is essential in countries that have diverse agroecological areas with different crops and defined climates. Therefore, understanding the G×E interaction is essential to estimate the different responses of genotypes to a wide range of environmental conditions. (BECKER & LEON, 1988; SIMMONDS, 1991; CRUZ & REGAZZI, 1994).

Research on the genotype x environment interaction for protein content is scarce for relevant commodities such as soybeans and common beans, and has not been observed for pigeon pea, making this study a precursor for this species. Studies that associate pigeon pea genotypes with high grain yields and high protein levels are of great importance, as they enable the recommendation of genotypes with good performance, in different cultivation locations, or genotypes that respond to improved management, e.g., the use of irrigation, which had no significant difference in the presnet study.

According to COSTA (2021), in study with these same pigeon pea lines, treatments 12, 9, and 19 expressed high grain yields, higher than the general mean of the experiments, 1516.31 kg ha^{-1}, good stability, and wide adaptability in the locations evaluated. These lines have a cycle shorter than the general average, with 128 days to harvest from planting, and with harvesting possible after 127 and 124 days, respectively, indicating earliness, an attribute of interest especially to producers in rainfed areas, due to short rainy periods. The results observed in this study showed acceptable values for the protein content of these treatments, with 22.35, 21.99, and 22.72%, respectively, indicating possible releases as new pigeon pea cultivars for the semi-arid region of Brazil.

4. Conclusions

A highly significant genotype × environment interaction was observed for the protein content of 21 pigeon pea lines plus the ‘guandu Petrolina’ control variety evaluated in four environments in the semi-arid region of northeastern Brazil.

Lines 12, 9, and 19 expressed adequate protein content, associated with high yield, broad adaptability, and good predictability, indicating their launch as a new pigeon pea cultivar for the Brazilian semi-arid region.

References

ANTONIEL, L. S. Irrigação no teor de proteína bruta de duas espécies de pastagens. Irriga, v. 1, n. 1, p. 248-248, 2016.

BECKER H. C.; LEON J. Stability analysis in plant breeding. Plant Breeding 101: 1–23, 1998.

COSTA, A. E. S. Diversidade molecular de acessos, estimativas de parâmetros genéticos e de adaptabilidade e estabilidade em linhagens de guandu (Cajanus cajan (L.) Millspaugh). Universidade Federal Rural de Pernambuco, 2021.

COSTA, N.L.; TOWNSEND, C.R.; MAGALHÃES, J.A.; PEREIRA, R.G.A. Formação e manejo de pastagens de guandu em Rondônia. 2p. Recomendações Técnicas, 23. Porto Velho: Embrapa Rondônia, 2001.

CRUZ C. D.; CARNEIRO P. C. S. & REGAZZI A. J. Modelos biométricos aplicados ao melhoramento genético. rev. e ampl. Ed. da UFV, Viçosa, 2, 668p, 2014.

CRUZ C. D.; REGAZZI A. J. Biometrical model applied to genetic improvement. Imprensa Universitaria, Vicosa, Brazil, 1994.

DA SILVA, D. O. M. Parâmetros de adaptabilidade e estabilidade para produção de grãos, teores de proteínas e minerais em feijão-caupi (vigna unguiculata (l.) walp.) no semiárido brasileiro. Universidade Estadual de Feira de Santana, 2018.

DIAS, J. C. R; PEREIRA, C. M. Tratamento de resíduos de cobre da análise de nitrogênio pelo método de Kjeldahl. In: Embrapa Florestas-Resumo em anais de congresso (ALICE). In: Evento de iniciativas e melhorias das atividades de apoio técnico da Embrapa Florestas, 1., 2006, Colombo. Anais. Colombo: Embrapa Florestas, 2006., 2007.

FAOSTAT. FaoStat. Rome, 2022. Disponível em: http://www.fao.org/faostat/en/#data/QC. Acesso em: 20 fev. 2022.

FRANCISCO, P. R. M. et al. Aptidão climática da cultura do feijão comum (Phaseolus vulgaris) para o estado da Paraíba. Revista Brasileira de Climatologia, v. 19, 2016.

FULLER, D. Q.; HARVEY, E. L. The archeobotany of Indian pulses: identification, processing and evidence for cultivation. Environmental Archeology, v. 11, n. 2, p. 219-246, 2006.

GODOY R.; SOUZA F. H. D.; SANTOS P. M. Pigeonpea selection and breeding. In Jank L, Chiari L, Valle CB, Simeão RM (eds) Forage breeding and biotechnology, Embrapa, Brasília, p. 107-118, 2013.

GUEDES, F. L.; PONTE FILHO, F. A. M.; GAMA, L. D. S.; SOUZA, H. A.; POMPEU, R. Metodologia para determinação do estresse hídrico em feijão guandu em solos com diferente textura no Semiárido cearense. Embrapa Caprinos e Ovinos-Comunicado Técnico. 2017.

ICRISAT (Patancheru, India). The pulses. In: ICRISAT (Patancheru, India). Annual Report 1975-1976. Hyderabad, 1976. p.87-139

KAONEKA S. R. et. al. Pigeonpea breeding in eastern and southern Africa: challenges and opportunities. Plant Breeding 135(2): 148-154, 2016.

KRAEMER, K.; ZIMMERMANN, M. B. Nutritional anemia. Sight and Life Press. Basel, Switzerland, p. 45-58, 2007.

MARINHO R. C. N. et. al. Field performance of new cowpea cultivars inoculated with efficient nitrogen-fixing rhizobial strains in the Brazilian semiarid. Pesqui Agropecu Bras. 49:395-402, 2014.

MOTEETEE A.; VAN WYK B. E. A revision of the genus Bolusafra (tribe Phaseoleae, Fabaceae). South African Journal of Botany 72: 604-608, 2006.
RAMALHO M. A. P.; DIAS L. A. S.; CARVALHO B. L. Contributions of plant breeding in Brazil: progress and perspectives. Crop Breeding and Applied Biotechnology 12(SPE): 111-120, 2012.

SANTOS C. A. F.; ARAUJO F. P.; MENEZES E. A. Avaliação de genótipos de guandu de diferentes ciclos e portes no Sertão pernambucano. Magistra 12: 31-40, 2000.

SANTOS C. A. F.; BOITEUX L. S. Breeding biofortified cowpea lines for semi-arid tropical areas by combining higher seed protein and mineral levels. Genet Mol Res. 12:6782-6789, 2013.

SANTOS C. A. F.; DE ARAÚJO F. P.; MENEZES E. A.; CAVALCANTI J. Guandu Petrolina. Embrapa Semi-Árido. Instruções Técnicas. 2001.

SANTOS, C. A. F.; ARAÚJO, F. P.; MENEZES, E. A. Guandu. In: KIILL, L. H. P.; MENEZES, E. A. (ed.). Espécies vegetais exóticas com potencialidades para o Semi-Árido brasileiro. Petrolina: Embrapa Semi-Árido; Brasília, DF: Embrapa Informação Tecnológica, cap. 7, p. 227-250, 2005.

SAXENA K. B. Genetic improvement of pigeon pea—a review. Tropical plant biology 1: 159-178, 2008.

TEIXEIRA, A. H. C. Informações agrometeorológicas do Polo Petrolina, PE/Juazeiro, BA - 1963 a 2009. Petrolina: Embrapa Semiárido, 2010.

VARSHNEY R.K.; SAXENA R.K.; JACKSON S.A. The Pigeonpea Genome: An Overview. In Varshney RK, Saxena RK e Jackson S (eds) The Pigeonpea Genome. Compendium of Plant Genomes A book series (CPG) Springer, Cham, p. 1-4, 2017.

WOLFSON & SHEAVER. Amino acid composition of grain protein of maize grown with and without pesticides and stranded commercial fertilizers (Organic farming). Agronomy-Journal (USA). v. 73(4) p. 611-613, 1981.

YASUHARA, T.; NOKIHARA, K. High-throughput analysis of total nitrogen content that replaces the classic Kjeldahl method. Journal of agricultural and food chemistry, v. 49, p. 4581-4583, 2001.