ISSN 2175-6813

Revista Engenharia na Agricultura

Viçosa, MG, DEA/UFV - DOI: 10.13083/reveng.v32i1.16811 v.32, p.37-46, 2024

CHEMICAL ATTRIBUTES OF CORN UNDER THE PATH ANALYSIS IN AN AMAZON ECOSYSTEMIC DOMAIN

Luana da Silva Pinheiro[1], Mateus Monteles Vieira[2], Gabriel Gustavo Tavares Nunes[1], Claudete Rosa da Silva[1], Job Teixeira de Oliveira[3]*, Tulio Russino Castro[3], Cassiano Garcia Roque[3] & Priscilla Andrade Silva[1]

1 - Federal Rural University of the Amazon (UFRA), Parauapebas,PA, Brazil

2 - Federal University of Maranhão (UFMA), Chapadinha, MA, Brazil

3 - Federal University of Mato Grosso do Sul (UFMS), CPCS Campus, Chapadão do Sul, MS, Brazil

4 - Federal University of the Amazon (UFRA), Belém, PA, Brazil

Keywords:
Agroecology
Biotechnology
Precision Agriculture
Multicollinearity

ABSTRACT

The present study aims to expose information about the dynamics between the chemical attributes of corn and the direct and indirect influence of these attributes on the proteins of the grain. The attributes analyzed were grain mass, total soluble solids, pH, total titratable acidity, ashes, moisture content, lipids, proteins, and carbohydrates. A network of correlations was obtained and descriptive statistical results of the attributes were generated. Through a path analysis, in which protein content was the main variable, the direct and indirect correlation between the attributes was determined. The moisture level and ash content obtained for the corn were similar to those found in literature. The levels of protein, lipids, and carbohydrates were lower than those established in the Brazilian Table of Food Composition. It was concluded that lipids were the attributes that best determine corn proteins.

PALAVRAS-CHAVE:
Agroecologia
Biotecnologia
Agricultura de precisão
Multicolinearidade

ATRIBUTOS QUÍMICOS DO MILHO SOB ANÁLISE DE TRILHA EM UM DOMÍNIO ECOSSISTÊMICO DA AMAZÔNIA

RESUMO

O presente estudo tem como objetivo expor informações sobre a dinâmica entre os atributos químicos do milho e a influência direta e indireta desses atributos sobre as proteínas do grão. Os atributos analisados foram massa do grão, sólidos solúveis totais, pH, acidez total titulável, cinzas, teor de umidade, lipídios, proteínas e carboidratos. Foi obtida uma rede de correlações e gerados resultados estatísticos descritivos dos atributos. Por meio de uma análise de trilha, na qual o teor de proteína foi a variável principal, foi determinada a correlação direta e indireta entre os atributos. O teor de umidade e o teor de cinzas obtidos para o milho foram semelhantes aos encontrados na literatura. Os teores de proteína, lipídios e carboidratos foram inferiores aos estabelecidos na Tabela Brasileira de Composição de Alimentos. Concluiu-se que os lipídios foram os atributos que melhor determinam as proteínas do milho.

Received 10 Jul, 2023 • Accepted 18 Jul, 2024 • Published 23 Aug, 2024

Email (corresponding author)*: job.oliveira@hotmail.com

SECTION EDITOR IN CHARGE

Gabriel Araújo e Silva Ferraz

INTRODUCTION

Corn (*Zea mays L.*) has undeniable strategic importance to society, the economy, and agribusiness development. Globally, corn is the second most cropped grain, with a harvested area of around 202.92 million hectares and 1,227.86 production million metric tons in 2024 (USDA, 2024). It has high market potential (Chavan *et al*. 2020), being able to produce under different climates, soils, and management (Faostat, 2019). According to the National Supply Company Conab (2024), corn occupies the second position as the most relevant grain for agricultural production in Brazil. Food scarcity is a crescent problem (Arsyad and Sasunanda, 2020), according to studies for safe production, nutritional diversity, and food access.

The possibilities of corn use for various types of consumers and producers, make it a widely cultivated cereal (Singh *et al*. 2020). Also, according to Conab (2024), for the 2023/24 harvest, with the information obtained in the field research carried out in the last week of March, it was obtained a production volume of 294.1 million tons, 8% or 25.7 million tons below that obtained in 2022/23.

The results of corn production are consequences of the expression of genetic, environmental, and ecophysiological dynamics, in addition to various associations between the physical-chemical components. The direct and indirect correlation coefficient show the intrinsic dynamics and contributions of one characteristic to the final crop yield. Heritability is based on the total genetic variance – additive, dominant, and epistatic (Chavan *et al*. 2020).

It is necessary to evaluate the properties under the interconnected multiple regression coefficients (Cruz, 2013). Thus, there is the partitioning of the correlation coefficient between direct and indirect consequences (path coefficient). The relevance of the technical applicability is expressed in the critical analysis of the genetic variability present in the germplasm of the crop and its estimative is a prerequisite to the beginning of any crop breeding program and adoption of the proper selection techniques (Sravanti *et al*. 2017).

Physiology of the corn is governed by pH as a growth promoter, moisture, and biochemical appropriation behavior, ashes, and inorganic residual content, and proteins with nutritional value with essential amino acids for human health (Régis *et al*., 2019). Similar to the lipids that protect the grain from excess moisture and insects, carbohydrates are responsible for chemical energy, as well as total energy value that guarantees physical-chemical quality, and influence the crop conception (Sukumar *et al*. 2019).

Using the path technique is possible to analyze the variables and postulate correlations about the chemical attributes of corn. The technique enables the partitioning of the correlation coefficient into direct and indirect effects applied to the data (path coefficient). The effectivity of the path analysis is found in the dynamic of cause-effect between variables, as stated by Olawamide and Fayeun (2020).

Therefore, this article aimed to outline, through path analysis, the variables that best explain corn productivity under the direct and indirect dynamics of the chemical attributes of one cultivar in an Amazonian ecosystem.

MATERIAL AND METHODS

The present study was conducted in the Technological Center of Family-Farming (CEFAT), in the Parauapebas–PA municipality. One corn cultivar was analyzed. The layout in the experimental area situated in the southeast mesoregion of Pará State (06º 03’ 30’’ N, 49º 55’ 15’’ W) was 0.2 m between plants and 0.7 between rows.

The local soil was a red-yellow argisol (Embrapa, 2018). The climate, according to Köppen and Geiger’s (1930) classification is super humid equatorial situated at the transition to a tropical wet and dry or seasonal climate (Aw). The local temperature is 26 ºC, on the average with maximum and minimum of 33 ºC and 22 ºC respectively. The total rainfall is 1827 millimeters each year.

Planting was completed under conventional farming. For that, there were two plows and one harrow. Sowing was carried out in March 2019 using a seeding machine with a fertilizer attachment. For fertilization, 350 kg of NPK were used, in the following amounts: 110 kg of nitrogen, 150 kg of phosphorus, 90 kg of potassium and 50 kg of micronutrients.

Nine corn cultivars were analyzed with a layout of 0.2 m between plants and 0.7 m between rows. The evaluated cultivars were: C1-7742, C2-EXP.61, C3-6520, C4-713265, C5-EXP.83, C6-7641, C7-7132, C8-EXP.88, C9-774265. A strip design was adopted, with nine treatments and five repetitions. Sampling was done by collecting a hundred corn ears of each parcel of the cultivar for characterization. The corn ears were selected manually, the kernels were detached and stored in polyethylene plastic bags. Finally, they were stored and frozen at -20ºC until the chemical analysis was performed.

The following analyses were performed for characterization and analysis of corn kernels: the pH (PH) was determined with a potentiometer (Model HI9321; Hanna Instruments, Rhode Island, USA) calibrated according to the method 981.12 of the AOAC (2000); the Total Titratable Acidity (TTA) was performed by titrating with 0.1N sodium hydroxide solution until the first pink color persisted for 30 seconds (AOAC, 2000). The measurements of soluble solids content (BRX) was carried out using the bench refractometer method according to AOAC (2000); the moisture content (UMI) was determined by gravimetric method in an oven (TE – 395; Tecnal, São Paulo, Brazil), according to the 920.151 standards of the AOAC (2000).

The incineration to obtain the ashes (CIN) was performed in a muffle furnace at 550 ºC according to the 930.05 method of the AOAC (2000); the determination of protein content (PRO) was conducted according to the calorimetric method of the biuret described by Layne (1957), obtaining compounds with maximum absorption at 540nm – examined in a UV-Vis spectrophotometer (SP-220; Bioespectro, Curitiba, Brazil). The lipid (LIP) determination was performed by cold extraction with a mixture of solvents by the method of Bligh and Dyer (1959). The carbohydrates were calculated by the difference, according to the resolution nº 360 from December 23, 2003 (Anvisa, 2003). Carbohydrates (%): 100 – (% moisture + % protein + lipids + ashes).

The analysis was performed by the computational program in genetics and experimental statistics GENES (Cruz, 2013). After data partitioning, values were acquired for the direct and indirect effects of the chemical attributes highlighted by the path analysis. Such application is indispensable to recognize the nature of linear submission existing between the characters, finding those that contributed to the determination of the principal variable, which in our study was the protein content (PRO) in the corn kernel.

RESULTS AND DISCUSSION

Descriptive statistics are presented in Table 1, where it is possible to evaluate the variation in corn attributes.

The average pH contents ranged from 4.7 to 5.6 among the nine cultivars, having an acid character. Due to the decrease in pH, an increase in titratable acidity was observed between cultivars up to the maximum value found from 3.25 for the C1 cultivar. Pinho *et al*. (2003) evaluated the physical and chemical characteristics of corn cultivars for the production of mini-corn, and found the pH average values of 6.42 to 6.95. Mamede *et al*.

Table 1. Descriptive statistics of the chemical attributes of the nine corn cultivars

Chemical attributes	Minimum	Mean	Maximum	Standard Deviation
Kernel mass (g)	43.68	76.93	94.83	16.15
Soluble Solids (°Brix)	3.50	4.41	6.00	0.66
pH	4.70	5.08	5.60	0.32
Total Titratable Acidity	1.50	2.24	3.40	0.55
Moisture (g $100g^{-1}$)	44.60	52.14	98.40	9.51
Ashes (g $100g^{-1}$)	0.50	0.71	0.90	0.11
Lipids (g $100g^{-1}$)	2.10	3.34	5.40	0.94
Proteins (g $100g^{-1}$)	0.21	0.33	0.54	0.09
Carbohydrates (g $100g^{-1}$)	40.82	45.17	49.62	2.46

(2014) also observed pH of 7.15, 7.11, and 7.61 in sweet corn kernels.

It is worth mentioning the influence of acidity addressed in studies of compound determination, as well as the presence of organic acids, helping to maintain the flavor, odor, color, and expiration date. An effect was observed by Ubi *et al*. (2019), also applying to corn physiology - conditioned by complex interactions throughout the life cycle. Furthermore, the development is influenced worldwide under varying agro-climatic conditions (Dash *et al*. 2020).

The variation of soluble solids (Table 1) of corn cultivars compared in this research ranges from 3.5 to 6.0 °Brix. These values differ from those found in the literature; for instance, according to Mamede *et al*. (2014), analyzing physical-chemical parameters of sweet corn cultivars, they observed an average soluble solids content of 15.49 °Brix. This difference, according to Perfeito *et al*. (2017), was influenced by the cultivar factor, which can be explained by the fact that the corn has a different composition of sugars in the kernels, which give them different levels of soluble solids.

Sugars are particularly important for the taste of corn and vary according to the cultivar and climatic conditions. The concentration of total sugars in corn increases during the development of the corn cobs, until the beginning of ripening (Pinho *et al*. 2003). The soluble solids content is usually obtained from °Brix evaluations. The °Brix value indirectly measures the “sugar content”, being an important quality parameter for “in nature” consumption and processing of green corn (Perfeito *et al*. 2017).

According to Pinheiro *et al*. (2021), the corn ears must be harvested with adequate moisture content. This parameter was shown, through chemical analysis, as slightly below the range indicated for harvest; the lowest moisture content was for cultivar C4 with 44.6 g 100 g^{-1}, and the highest value found was for Cultivar C6 with 98.4 g 100 g^{-1}. The reduction of moisture content and starch accumulation is dynamic during the development of the crop. The harvest period is quite narrow and is determined between the milky and the pasty stages of the kernels. The harvest period for this study occurred late in phase R5.

The division of these stages is done by the so-called starch dividing line or milk line. This line appears shortly after the formation of the kernel and, with maturation, advances towards the base of the grain. Due to the accumulation of starch, the grain is hard above the line and soft below the line while the kernels in this stage are about 55% moisture content.

Minerals or ash is the inorganic residue that remains after burning organic matter, which is transformed into CO_2, H_2O, and NO_2. The mineral elements are present in the ashes, depending on the conditions of incineration and the composition of the food. As for the ash content, the values found were 0.50 to 0.90 g 100 g^{-1}. When compared to studies by Pinho *et al*. (2008), the average ash content found was 0.60 g 100 g^{-1}, within the range found in this study. According to the Brazilian Food Composition Table (Taco, 2011), the average ash values found for raw green corn must be 0.70 g 100 g^{-1}. The lipid content was relatively higher than that of cereals in general, whose average range is 2%. The average protein content of the cultivars ranged from 0.21 to 0.54 g 100 g^{-1}, and were below those found by Pinho *et al*. (2003) from 1.23 to 0.86 g 100 g^{-1} for protein.

Carbohydrates are the most abundant biochemical constituents in vegetables, reaching 50 to 80% of their total dry weight. The carbohydrate contents obtained in this study were above the average of 28.60 g as recommended by Taco (2011). The cultivars presented average values of 40.82 to 49.62 g. It is important to highlight that kernels produced in the conventional system had an average carbohydrate value higher than that produced in an organic cultivation system. These values were different from those observed by Pinho *et al*. (2008) between varieties of corn produced in conventional and organic systems that were, respectively, 12.97 and 16.77 g 100 g^{-1} of carbohydrates.

Figure 1 presents the correlation network between the studied attributes.

Through the Pearson linear correlation network,

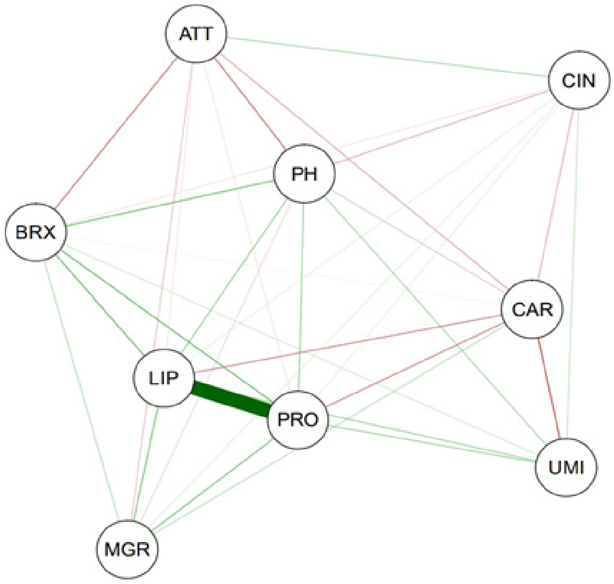

Figure 1. Pearson correlation network between the studied attributes. The attributes studied were: total titratable acidity (ATT), pH (PH), ashes (CIN), total soluble solids (BRX), lipids (LIP), kernel mass (MGR), carbohydrates (CAR), moisture content (UMI), and proteins (PRO)

it is demonstrated a significant positive and direct correlation between the values referring to the lipid attributes (LIP) and proteins (PRO). The link between the grain mass values (MGR) is expressed positively; however, with a less expressive direct relationship with soluble solids (BRX), lipids (LIP), proteins (PRO), and carbohydrates (CAR). The pH (PH) is positively related to lipids (LIP), proteins (PRO), and moisture (UMI).

There is insufficient evidence as highlighted by Dash *et al*. (2020), to elucidate real association for the cause-effect relationship to be understood effectively. Thus, it is necessary to configure a network that mutually exerts direct and more expressive positive influences on the final design. The association of expressions, according to Dash *et al*. (2020), helps to analyze the interdependence between connecting components and the final product from such correlations, as they can present an inherent degree of association, governed mostly by genetic factors.

The intermediate dynamic consists of the link between total titratable acidity (ATT) and kernel mass (MGR), proteins (PRO), and carbohydrates (CAR). Mutually, there is a less direct, but positive, relationship between ash (CIN) and soluble solids (BRX), not different from pH (PH) and grain mass (MGR). In a negative spectrum, there is an expressive and direct relationship between the data of moisture (UMI) and carbohydrates (CAR), as well as those related to total titratable acidity (ATT), soluble solids (BRX), and pH (PH). Similarly, there is a slight negative relationship in the bilateral links between carbohydrates (CAR) and lipids (LIP), proteins (PRO), ash (CIN), and pH (PH).

The approach shows that it occurs in a network of correlations, most of the time, multicollinearity. Certainly, it is known that different variables are exercising mutual influences, which can potentially lead to data interpretation errors. Therefore, it is necessary to apply the path analysis by inserting a k = 0.05 factor to eradicate this possibility. Consequently, data will have no interference from any attributes.

The data obtained with the path analysis technique are shown in Figure 2. For this purpose, the variables previously expressed in Pearson's linear correlation regarding the chemical attributes of corn were used.

Following the explanatory correlations applied

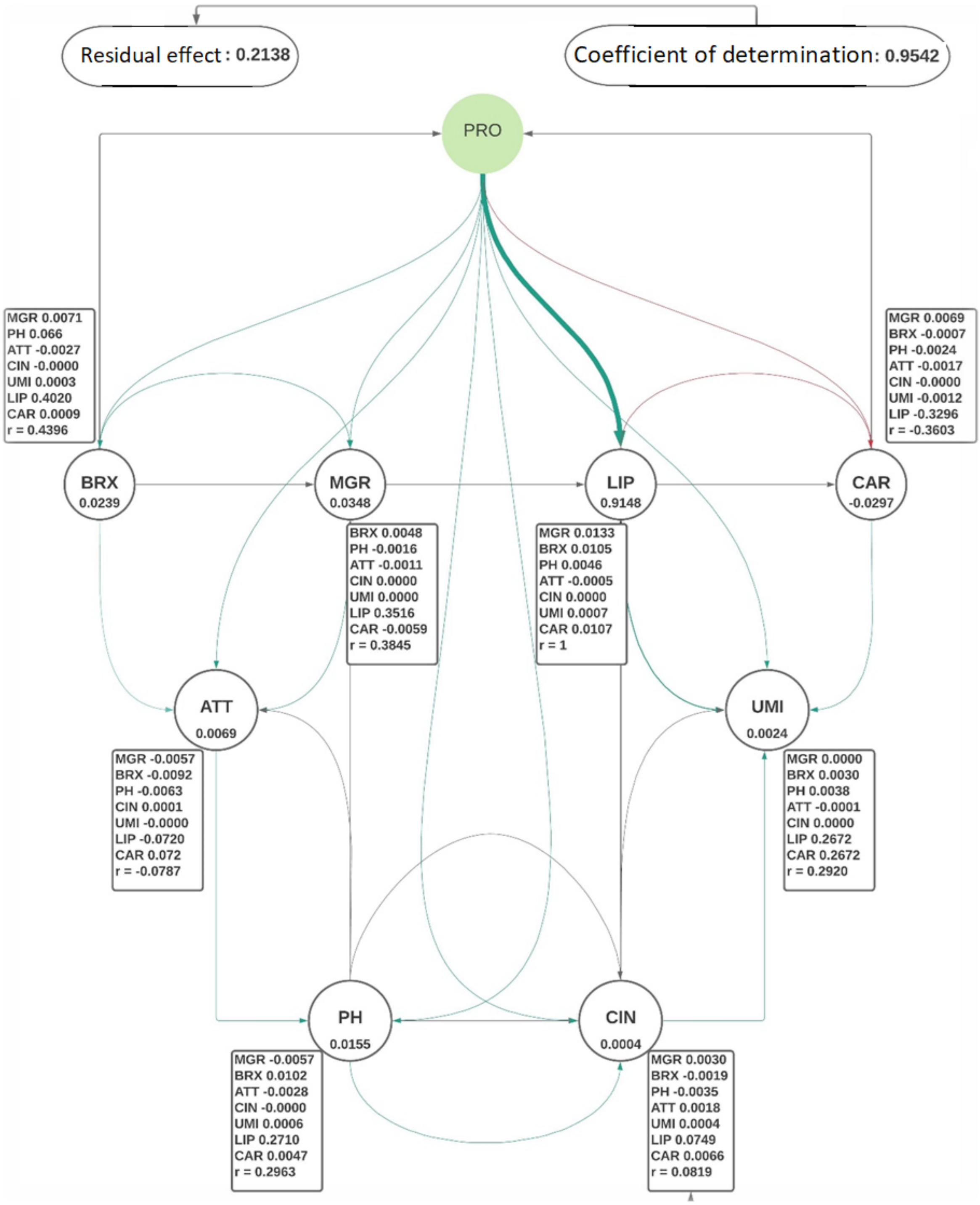

Figure 2. Results from the path analysis in which the corn protein is the principal variable

to the basic variable Protein (PRO), a significant positive relationship (0.9148) was observed with the lipid (LIP) variable. Regarding the other attributes, the correlations found were: total soluble solids (BRX), 0.0239; pH (PH), 0.0155; total titratable acidity (ATT), 0.0069; ashes (CIN), 0.0004 and moisture (UMI), 0.0024. The negative relationship was expressed in carbohydrates (CAR), -0.0297. Diversity was noted in the indirect expressions of the different attributes.

Total soluble solids (BRX) had an average content higher than that presented by Chavan *et al*. (2020) when evaluating genetic parameters and correlation of characteristics of yield attributes in sweet corn – obtaining an index of 0.0039 – registering high estimates of heritability in a broad sense. In this approach, this variable had an average of 4.40 – these different levels occur due to dissimilar sugar compositions in the kernels. Values are subject to improvement, according to Chavan *et al*. (2020), through the simultaneous selection of other characteristics.

The mean for the pH (PH) variable showed a result close to that exposed by Sukumar *et al*. (2019) in the analysis of characteristics and associations in path analysis for yield and protein quality of corn. According to the Brazilian Food Composition Table (TBCA, 2020), this variable has a common average of 0.70 g 100 g^{-1}, diverging from the value presented in this study.

The moisture content (UMI) found for the corn cultivars had an average value of 0.71 g 100 g^{-1}, below that required by the Brazilian Food Composition Table, (TBCA, 2020). The average content for carbohydrates (CAR) was lower than that described by the Tbca (2020), produced under conventional systems – 86.3 g. Diversity was noted in the indirect expressions of the different attributes.

When comparing the other mean values (g .100 g^{-1}) obtained by the path analysis with those available in the database of the Tbca (2020), there is a categorical gap between the values. The carbohydrate value (CAR) obtained through the path analysis – 45.17 g .100 g^{-1} – was lower than that presented by the TBCA (86.30). The other values for ashes (CIN), moisture content (UMI), lipids (LIP), and proteins (PRO) resulted in values higher than those of TBCA: 0.71, 52.14, 3.34, 0.33 g .100 g^{-1}, respectively (Tbca 2020).

The direct and indirect results of each attribute and its role in the final framing, are responsible for the productivity and profitability of the crop. Furthermore, corn is among the most cultivated cereals in the world, points out Dash *et al*. (2020).

Production under the Amazon ecosystem domain requires possession of information and tools to understand the conservation of the area. Furthermore, the interrelationships with the environment is also important, as observed by Holanda *et al*. (2017) when evaluating corn and its nutrients. The author also considers the dynamics of biogeochemical cycling in forest ecosystems, providing improvement in chemical attributes. These factors, under intrinsic interference from biotic and abiotic factors, have direct effects on the nutrient cycling process (Figure 3).

The coefficient of determination of the path analysis performed was 95% valid, expressing that the results found in the present study were very well evaluated. Oliveira *et al*. (2018) also found a correlation coefficient with the same level when performing path analysis on bean attributes. The results emphasize that the selection could be more effective through indirect character selection (Chavan *et al*. 2020).

This type of study, as corroborated by Ubi *et al*. (2019), allow us to observe correlations and simplifies the analysis of associative measures between income and other characteristics. While analyzing the expression of the path coefficient, the possibility of segregating coefficients in direct and indirect effects is ensured. Consequently, according to Embrapa (2019), such applicability, by combining genetic resources and plant breeding, contributes to agribusiness.

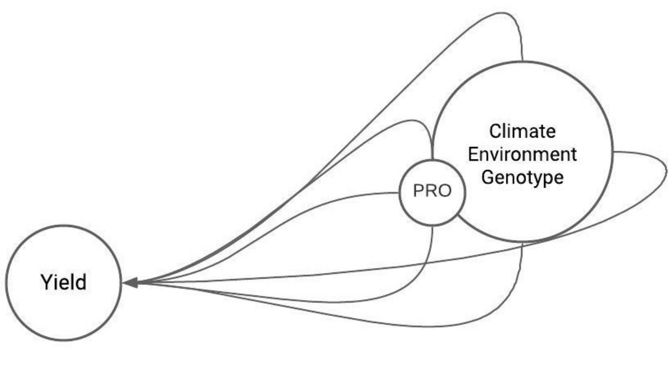

Figure 3. Yield derived from proteins (PRO) under ecophysiological interactions

CONCLUSION

- Lipids are the chemical attributes that best determine the protein in corn kernels in a direct and significant way among the studied parameters. Lipids contribute indirectly, significantly, and positively to the pH, grain weight, Brix, and moisture content of the corn grain.
- As for chemical characterization, the average pH value for all cultivars analyzed was below the specified value for sweet corn, having an acid character. The moisture values were below what is stipulated in the literature for green corn, as the harvest was performed late when the corn buds were in the reproductive phenological stage R5. The average values of ash found in corn kernels were close to those stipulated by the Brazilian Food Composition Table. Regarding the carbohydrate content, the average values verified were above that described by the Brazilian Food Composition Table for green corn. However, for protein and lipid contents, the averages observed were lower than those stipulated in the literature.

ACKNOWLEDGMENTS

The authors would like to thank the Universidade Federal do Maranhão (UFMA), Universidade Federal de Mato Grosso do Sul (UFMS), Universidade Federal Rural da Amazônia (UFRA) and Fundação de Apoio ao Desenvolvimento do Ensino, Ciência e Tecnologia do Estado de Mato Grosso do Sul - FUNDECT.

AUTHORSHIP CONTRIBUTION STATEMENT

PINHEIRO, L. S.: Conceptualization, Data curation, Methodology, Supervision, Writing – review & editing; **VIEIRA, M. M:** Data curation, Supervision; **NUNES, G. G. T.:** Data curation, Project administration, Writing – review & editing; **SILVA, C. R.:** Formal Analysis, Software, Writing – review & editing; **OLIVEIRA, J. T.:** Funding acquisition, Methodology, Visualization, Writing – review & editing; **CASTRO, T. R.:** Formal Analysis, Funding acquisition, Writing – review & editing; **ROQUE, C. G.:** Data curation, Visualization, Writing – review & editing; **SILVA, P. A.:** Conceptualization, Formal Analysis, Methodology, Writing – original draft.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

ANVISA –Agência Nacional de Vigilância Sanitária. Resolução RDC n° 360; de 23 de dezembro de 2003. **Regulamento Técnico sobre rotulagem nutricional de alimentos embalados.** DOU. Brasilia; p. 4. 2003.

AOAC –Association of Official Analytical Chemists. Official Methods of Analysis of AOAC International. 17 th etd; **AOAC International**; Arlington; 2000.

ARSYAD, F.; & BASUNANDA, P. Identification of agronomic traits that affect the ear weight of families BTP1-X purple sweet corn (*Zea mays* L. Saccharata Sturt) using path analysis. IOP Conference Series: **Earth and Environmental Science**: Sleman. 484 012011. 2020.

BLIGH, E.C.; & DYER, W.J. A rapid method of total lipid extraction and purification. **Canadian Journal Biochemistry Physiology**; Ottawa; 37; p. 911-917; 1959. D

BRAZ, R.D.S.; LACERDA, C.F.D.; ASSIS JÚNIOR, R.N.D.; FERREIRA, J.F.D.S.; OLIVEIRA, A.C.D.; & RIBEIRO, A.D.A. Crescimento e fisiologia do milho sob salinidade da água e adubação nitrogenada em dois solos. **Revista Brasileira de Engenharia Agricola e Ambiental**; 23(12):907-913. 2019.

CHAVAN, S.; BHADRU, D.; SWARNALATHA, V.; & MALLAIAH, B. Studies of genetic parameters; correlation analysis and path to yield and characteristics of Income allocations for sweet corn (*Zea mays* EU. Saccharata). **International Journal of Current Microbiology and Applied Sciences**: Hyderabad. V. 9. Number 7. 1725-1734. 2020.

Conab. Acompanhamento da safra brasileira de grãos: Brasília, DF, v. 11, safra 2023/24, n. 7 sétimo levantamento, abril 2024.

CRUZ, J.C.; ALVARENGA, R.C.; NOVOTNY, E.H.; PEREIRA FILHO, I.A.; SANTANA, D.P.; PEREIRA, F.T.F.; & HERNANI, L.C. **Cultivo do milho. Sistema plantio direto**. Ministério da Agricultura; Pecuária e Abastecimento (Ed.). Sete Lagoas; MG. Vol 51. 2002.

CRUZ, C.D. Genes: A Software Package for Analysis in Experimental Statistics and Quantitative Genetics. **Acta Scientiarum: Agronomy**. 35; p. 271 - 276. 2013.

DASH, P.A.; LENKA, D.; TRIPATHY, S.K.; & SWAIN, D. Character association and grain yield path analysis and their Components in corn (*Zea mays* L.) under heat stress. **International Journal of Current Microbiology and Applied Science**: Bhubaneswar. 9(3). 2020.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. **Sistema Brasileiro de classificação de solos**: Brasília; DF: Embrapa. 5. ed. rev. e ampl. 355 p. 2018. ISBN 978-85-7035-800-4.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. Embrapa Agrossilvipastoril: **Primeiras contribuições para o desenvolvimento de uma Agropecuária Sustentável**. Brasília. 823 p. 2019. ISBN: 978-85-7035-905-6.

FAOSTAT. Alimentos e Agricultura Organização das Nações Unidas (FAO): FAO **Statistical Database. Florestal**; 27(2):621–633. 2017.

HOLANDA, A.C.; FELICIANO, A.L.P.; FREIRE, F.J.; SOUSA, F.Q.; FREIRE, S.R.O.; & ALVES, A.R. Aporte de serapilheira e nutrientes em uma área de caatinga. **Ciência Florestal**; 27(2):621-633. 2017.

Köppen, W., & Geiger, R. (Eds.). **Handbuch der klimatologie** (Vol. 1). Berlin: Gebrüder Borntraeger. 44p. Vol. 1. 1930.

LAYNE, E. Spectrophotometric and turbidimetric methods of measuring proteins. In: Colowick SP; Kaplan NO. eds. **Methods in enzymology**; New York; Academic Press; New York; 3; p. 447 - 454; 1957.

MAMEDE, A.M.G.N.; CHITARRA, A.B.; FONSECA, M.J.O.; ANTONIO, G.S.; & PEREIRA, I.A.F. Qualidade do milho doce minimamente processado conservado sob diferentes atmosferas. **Engenharia na Agricultura**; 22(6):520-534. 2014.

OLAWAMIDE, D.O.; & FAYEUN, L.S. Correlation and path coefficient analysis for yield and yield components in late maturing pro-vitamin A synthetic maize (*Zea mays* L.) breeding lines. **Journal of Experimental Agriculture International**; p. 64 - 72. 2020.

OLIVEIRA, J.T.; RIBEIRO, I.S.; ROQUE, C.G.; MONTANARI, R.; GAVA, R.; & TEODORO, P.E. Contribution of morphological traits for grain yield in common bean. **Bioscience Journal**; 34: p. 951-956. 2018.

PERFEITO, D.G.A.; LOPES, M.C.M.; SALOMÃO, L.C.; SOUZA, M.L.C.; BENETT, C.G.S.; & LIMA, B.P. Caracterização pós-colheita de milho doce submetido ao parcelamento de fertirrigação nitrogenada. **Braz. J. Food Technol**; 20 e 2016140. 2017.

PINHEIRO, L.S.; VIEIRA, R.C.; BARATA, H.S.; MOTA, R.S.; SOUSA, R.F.; VIEIRA, M.M.; & SILVA, P.A. Análise de trilha da massa da espiga de milho e seus atributos físicos. **Research; Society and Development**; 10(1):e41510111912-e41510111912. 2021.

PINHO, L.; PAES, M.C.D.; ALMEDA, A.C.; & COSTA, C.A. **Características físicas e físico-químicas de cultivares de milho-verde produzidos em sistemas de cultivo orgânico e convencional**. Embrapa Milho e Sorgo em Sete Lagoas/MG. p. 4; 2008.

PINHO, R.G.; CARVALHO, G.S.; RODRIGUES, V.N.; PEREIRA, J. Características físicas e químicas de cultivares de milho para produção de minimilho. **Ciência e Agrotecnologia**; Lavras - MG; 27(6):1419-1425. 2003.

SINGH, D.; KUMAR, A.; KUMAR, R.; SINGH, S.K.; KUSHWAHA, N.; & MOHANTY, T.A. Correlation and Path Coefficient Analysis for 'Yield Contributing'Traits in Quality Protein Maize (*Zea mays* L.). **Current Journal of Applied Science and Technology**; p. 91 - 99. 2020.

SRAVANTI, K.; SWARNALATHA, I.; SUDARSHAN, M.R.; & SUPRIYA, K. Evaluation of maize (*Zea mays* L.) genotypes for variability; heritability and genetic advancement. **International Journal of Current Microbiology and Applied Sc**. 6(10): 2227-2232. 2017.

SUKUMAR, K.; HEMALATHA, V.; REDDY, N.V.; & REDDY, N.S. Association of Character and Path Analysis for Performance and Quality Characteristics in Quality protein corn (*Zea mays* EU.). **International Journal of Current Microbiology and Applied Sciences**: Telangana. 08(08). 2019.

TACO - **Tabela Brasileira de Composição de Alimentos**: versão 4ª edição revisada e ampliada. Campinas; 28 p. UNICAMP/NEPA. 2011.

TBCA - **Tabela Brasileira de Composição de Alimentos**. 56p. 2020.

UBI, M.G.; ONABE, B.M.; & KALU, E. Path coefficient analysis; character association and Variability Studies in Selected Maize (*Zea mays* L.) Genotypes grown in southern Nigeria. **Annual biology research and review**: Veracruz. 33(3):1-6. 2019.

USDA - United States Department of Agriculture - World Agricultural Production. Circular Series WAP 4-24. 34p. April 2024.