https://doi.org/10.71252/2177-34912025720039
ISSN: 2177-3491

Fruit characterization and genetic diversity among tamarind matrices

Francielly Rodrigues Gomes[1*], *Ângela Lopes Barros*[2], *Carla Gomes Machado*[2], *Simério Carlos Silva Cruz*[2], *Alejandro Hurtado Salazar*[3], *Danielle Fabíola Pereira da Silva*[2]

[1] Universidade Estadual Paulista "Júlio de Mesquita Filho", Jaboticabal, SP, Brazil. fram_rodgomes@hotmail.com

[2] Universidade Federal de Jataí, GO, Brazil. angelabarros951@gmail.com; carlagomesmachado@gmail.com; simerio_cruz@yahoo.com.br; daniellefpsilva@gmail.com

[3] Universidad de Caldas, Producción Agropecuaria - GIPPA, Manizales, Caldas, Colombia. alejandro.salazar@ucaldas.edu.co

*Corresponding author: fram_rodgomes@hotmail.com

Editors:
José Luis Nunes
Teogenes Senna de Oliveira

Submitted: June 30th, 2025.
Accepted: October 27th, 2025.

ABSTRACT

Tamarind is a tropical fruit highly cultivated in some countries. In Brazil, still there is a little exploitation of tamarind fruits, but its characterization can subsidize the commercial exploitation. Fruit characterization enables the study of genetic diversity between matrices or populations, allowing the identification of possible genitors, or even genotypes with superior characteristics. The aim of this study was to characterize and evaluate the genetic diversity of the physical characteristics of tamarind fruit, in order to provide subsidies for genetic improvement programs and conservation of the species. The fruits were evaluated by weight, diameter and length, color of epidermis and pulp. A completely randomized design was adopted, with 4 treatments (plants) and 7 replicates of 10 fruits, totaling 280 fruits. The data were subjected to analysis of variance, and the means were compared using the Duncan test. The matrix 4 presented higher values of weight, length and diameter, when compared to the others. There is genetic diversity among the tamarind matrices. Two groups were formed using the dendrogram generated by the UPGMA method. A strong correlation was observed between fruit length and weight, peel weight and fruit weight, and peel weight and length, which is crucial information for genetic improvement.

Keywords: *Tamarindus indica*, correlation, physical atributes, dendrogram.

INTRODUCTION

The tamarind tree (*Tamarindus indica* L.) belongs to the Fabaceae family and grows in tropical and subtropical regions, making it an ideal tree for semi-arid regions. Across the world, several regions were presumed as their center of origin. While some authors consider India as the center of origin, other authors considered it indigenous to the drier savannahs of tropical Africa, from Sudan, Ethiopia, Kenya, Tanzania, and Senegal. Currently, the region considered to be the center of origin is Madagascar and the trees are cultivated throughout semi-arid Africa and South Asia, Australian, Central American and South American countries.(1)

The adult plant is an evergreen tree that can reach up to 24 meters in height and 7 meters in circumference, producing light yellow or pink flowers. The fruit of the tamarind tree is an indehiscent pod up to 18 cm long with a velvety, brown skin and inside these pods is a viscous, edible pulp that covers the seeds.(2) The fruit has nutritional quality, a notable aroma and a sweet and sour taste, which is widely used in the manufacture of soft drinks, ice cream, pastes, sweets, liqueurs, jellies and as an ingredient in condiments and sauces, as well as being widely used in traditional medicine.(3) The pulp of ripe fruits has considerable export value in several countries across the world.(2)

Some countries like: Brazil, Bahamas, Costa Rica, Bangladesh, Cuba, Burma, Egypt, Cambodia, Guatemala, Dominican, Republic, India, Fiji, Indonesia, Gambia, Mexico, Kenya, Nicaragua, Pakistan, Puerto Rico, Senegal, Philippines, Tanzania, Sri Lanka, Vietnam, Thailand, Zambia, Venezuela and Zanzibar, are the major producers of tamarind, however, it is grown as a major plantation only in a few countries such as India and Thailand.(1)

In Brazil, the tamarind tree is well distributed and cultivated but is not organized into plantations(4) and is little explored, since there is little technological use of the edible part of the fruit and almost no studies aimed at its characterization. Biometry is an important tool for assessing genetic variability within populations of the same species and relationships with environmental factors.(5) Fruit characterization can help subsidize their commercial exploitation, since characterization enables the study of genetic diversity between matrices or populations, allowing the identification of possible genitors, or even genotypes with superior characteristics.(6) Information about these characteristics and the nutritional value of the fruit are basic tools for evaluating consumption and formulating new products.(7)

The study of genetic diversity can be carried out through the relationship between various characteristics, and the use of dissimilarity measures is recommended.(8) These measures can be obtained through grouping analysis, which aims to group individuals in such a way that there is maximum homogeneity within the group and maximum heterogeneity between the groups.(9)

There are various clustering methods, which differ in the type of result and the different ways of defining the proximity between individuals or groups formed. In all cases, the number of groups to be established is not known a priori and different methods provide different results.(10)

Among the characteristics that can be used to assess fruit quality are the external appearance, taste, smell, fiber content, texture, nutritional value, size, mass and shape of the fruit. These characteristics can vary greatly depending on the variety and the place where it is grown, and there are also sensitive changes during the ripening process.(11)

Therefore, knowledge of the genetic diversity among the tamarind genotypes grown in Brazil is of great importance for directing studies that allow for the conservation and use of the intraspecific genetic resource. Since the exploitation of a plant species depends on technical knowledge, which is fundamental for defining rational use technologies.(12)

There are reports of the evaluation of the genetic variability of tamarind fruits in some countries using different methodologies,(13-19) however, the evaluation with fruits produced in Brazil lacks further studies. The aim of this study was to characterize and evaluate the genetic diversity of the physical characteristics of tamarind fruit, with a view to providing subsidies for genetic improvement programs and conservation of the species.

MATERIAL AND METHODS

The tamarind fruits were harvested from four mother plants in the municipality of Cascalho Rico - MG, in July 2020. A completely randomized experimental design (DIC) was adopted, with 4 plants (matrices 1, 2, 3 and 4) and seven repetitions of 10 fruits, resulting in 70 fruits for each matrix and 280 fruits in total.

The fruits were taken in polyethylene packaging in a refrigerated vehicle to the Fruit Growing Laboratory at the Federal University of Jataí, where they were selected for their lack of mechanical damage. Subsequently, the physical characteristics were assessed: fruit weight, fruit length and diameter, peel weight, and epidermal and flesh color parameters.

Fruit weight was obtained by weighing each fruit individually on a 0.001 g precision digital scale. Fruit length and diameter were obtained by measuring the transverse and longitudinal directions of each fruit using a digital caliper.

The pulp of the fruit was removed manually from the pods for subsequent evaluations. The peels obtained after extracting the pulp were weighed on a precision scale to determine the weight of the peels.

The color parameters of the fruit epidermis and pulp were determined using the CIELAB color system, which expresses color by the coordinates C* (chroma), h* (hue angle) and L* (luminosity). Two readings were taken on opposite sides of the fruit and pulp using a Konica Minolta® CR-10 colorimeter. The L* parameter represents the luminosity of the sample, with values ranging from 0 (lowest luminosity) to 100 (highest luminosity), the C* coordinate represents color saturation and h° represents the hue angle, which ranges from 0 to 360° and indicates the quadrant of the sample color.[20]

The data was subjected to analysis of variance and the means of each matrix were evaluated using Duncan's test. Multivariate analysis was carried out by estimating the average Euclidean distance obtained from the characteristics analyzed. The similarity and grouping of the accessions were measured using the UPGMA dendrogram (Unweighted Pair Group Method using Arithmetic averages).

The cut-off criterion used to determine the number of groups in the UPGMA method was based on the relative size of the 27 levels of fusions (distances). The cophenetic correlation coefficient (CCC) between the genetic dissimilarity matrix and the matrix of cophenetic values was calculated in order to verify the consistency of the grouping.

The data was analyzed using the GENES computer program.[8] The dendrogram was made using the statistical software SAS version 5.0.

RESULTS AND DISCUSSION

In terms of fruit weight, there was a statistical difference between matrix 4 and the other matrices, where matrix 4 produced fruit with a higher weight. Similarly, the weight of the fruit peel varied between the matrices, with matrix 4 also producing fruit with heavier peels and matrices 1 and 2 producing fruit with lighter peels, which did not differ (Table 1).

It is estimated that at least half the weight of tamarind fruit comes from the pulp and the discovery of matrices with higher fruit weight is an important selection criterion for new materials with the potential to produce fruit with a greater amount of pulp.[18] Variation in fruit peel weight between matrices is due to genotypic differences and can also be attributed to differences in fruit size.[21]

Fruit diameter and length varied widely, with matrices 1, 2 and 3 producing fruit with smaller diameters and lengths, and matrix 4 producing fruit with superior characteristics compared to the other matrices (Table 1).

Despite the variability that occurred between the tamarind matrices, the results obtained in this study are similar to those obtained by Sanches[22] for fruit length and diameter. According to the authors, the variability can be attributed to the soil and climate conditions of each growing site and can also be influenced by the availability of water and nutrients at the time of fruit formation. According to Algabal[23] fruit that are longer tend to have a greater number of seeds and the high variability in this trait indicates great potential for improvement, noting that this trait is significantly affected by cross-pollination and the availability of resources.

Table 1. Fruit characterization of Tamarind (*Tamarindus indica* L.) matrices collected in Cascalho Rico-MG

Matrices	Fruit weight (g)	Diameter (mm)	Length (mm)	Shell weight (g)
1	4.43 b	25.03 bc	40.34 bc	0.98 c
2	4.34 b	24.69 c	38.92 c	0.94 c
3	4.95 b	25.63 b	42.44 b	1.12 b
4	8.63 a	27.04 a	69.79 a	1.81 a
F	71.61**	11.20**	193.03**	83.18**
CV (%)	47.91	10.66	32.42	48.19

** Significant at 5% probability by the F test, ns not significant. Averages followed by the same letter in the column are not significantly different at the 5% probability level by the Duncan test.

Regarding the color of the peel and pulp of the fruit, matrix 4 produced fruit with lower luminosity (L*), which indicates that this fruit has a darker tone in the peel and pulp, as well as lower color intensity (C*) and higher hue angle. The luminosity of the peel did not differ between the other matrices and in the pulp, matrices 1 and 2 had the highest values. Chroma was higher in the peel of fruit from matrix 1 and in the pulp of matrices 2 and 3. The hue angle of the peel and pulp of the fruit ranged from approximately 50 to 70°, indicating that the color of the samples is close to brown, and the lowest values were observed in the peel and pulp of the fruit from matrix 2 (Table 2).

Table 2. Color parameters of the peel and pulp of fruit from Tamarind (*Tamarindus indica* L.) matrices collected in Cascalho Rico-MG

	Shell color		
Matrices	L/1	C	h (°)
1	40.52 a	25.99 a	63.71 b
2	40.33 a	24.69 b	54.60 c
3	40.11 a	23.36 c	65.68 b
4	36.72 b	22.08 d	73.60 a
F	20.75**	15.93**	41.55**
CV (%)	9.31	15.84	18.67
	Pulp color		
Matrices	L	C	h (°)
1	34.54 a	25.27 a	61.56 b
2	35.65 a	24.46 a	57.11 c
3	33.76 ab	22.63 b	59.22 bc
4	31.69 b	20.26 c	71.64 a
F	4.80**	15.83**	22.54**
CV (%)	15.59	21.86	20.25

** Significant at 5% probability by the F test, ns not significant. Averages followed by the same letter in the column are not significantly different at the 5% probability level by the Duncan test. /1L: Luminosity, C: Chroma, h: Hue angle.

In studies evaluating the color of tamarind pulp, Canuto[24] found similar results to the present study, with luminosity values of 33.8 ± 0.5 and hue angle of 63.1° ± 0.2. Towards the end of ripening, there is a drastic reduction in the brightness of tamarind fruit, especially in the pulp, since there is a high rate of browning and the pulp becomes dark brown or black.[25] Variability in fruit color, among other characteristics, can be used as a selection criterion in breeding programs using methods such as mass selection.[26]

Clustering using the UPGMA method showed a cophenetic correlation coefficient of 0.80. With the cut-off point set at 10% on the abscissa axis, two main groups were formed based on the 10 fruit characteristics. The groups are made up of matrices with similar characteristics. Matrix 1 was the most divergent, making up group I, and matrices 2, 3 and 4 were the most similar, making up group II (Figure 1).

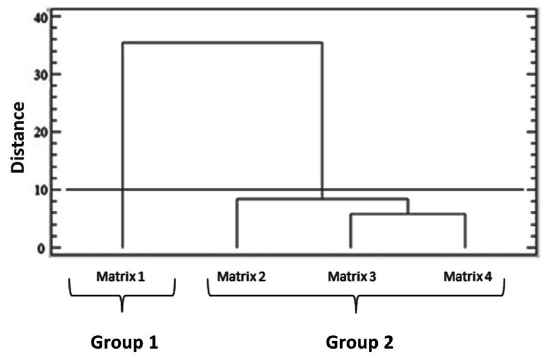

Figure 1. Dendrogram, generated by the UPGMA method, of the dissimilarities between the average Euclidean distance among 10 characteristics of the fruit of 4 tamarind matrices collected in Cascalho Rico - MG.

Through cluster analysis it is possible to identify genetically dissimilar genotypes, reducing the number of combinations needed in breeding studies.[27] The cophenetic correlation coefficient observed in this study indicates that the fit of the graph was satisfactory in representing the Gower distances, confirming Rohlf's hypothesis[28] that phenotypic correlation values greater than 0.80 indicate good fits between the original matrices and the derivatives of the graphical distances.

Strong positive and significant correlations were observed between fruit weight and peel weight, as well as between fruit weight and fruit length, fruit weight and fruit diameter, between peel weight and fruit diameter and between peel weight and fruit length (Table 3), indicating that these characteristics are directly related.

The weight of tamarind fruits shows a positive and significant association with their size, highlighting that knowledge of correlations and the relative contribution of independent characters to dependent variables allows breeders to apply appropriate selection procedures in breeding programs.[29]

Regarding the color of the peel and pulp of the fruit, there was a weak significant correlation (±0.31 to ±0.50)

Table 3. Pearson's correlation matrix between the physical variables of tamarind matrix fruit collected in the municipality of Cascalho Rico-MG

	FW$^{/1}$	D	L	S*L	S*C	h°S	PW	P*B	P*C
D	0.782^{**}	-							
L	0.843^{**}	0.662^{**}	-						
S*L	-0.327^{**}	-0.200^{**}	-0.443^{**}	-					
S*C	-0.289^{**}	-0.135^{*}	-0.343^{**}	0.158^{ns}	-				
h°S	0.441^{**}	0.252^{**}	0.478^{**}	-0.104^{ns}	-0.496^{**}	-			
PW	0.902^{**}	0.712^{**}	0.855^{**}	-0.321^{**}	-0.348^{**}	0.444^{**}	-		
P*B	-0.346^{**}	-0.296^{**}	-0.297^{**}	0.101^{ns}	0.040^{ns}	-0.127^{ns}	-0.397^{**}	-	
P*C	-0.288^{**}	-0.226^{**}	-0.317^{**}	0.128^{*}	0.253^{**}	-0.259^{**}	-0.348^{**}	0.614^{**}	-
h°P	0.224^{**}	0.034^{ns}	0.343^{**}	-0.273^{**}	-0.392^{**}	0.547^{**}	0.212^{**}	0.192^{**}	-0.843^{**}

* $p < 0.05$; ** $p < 0.01$; ^{ns} not significant at $p < 0.05$. /1 FW: Fruit weight, D: Fruit diameter, L: Fruit length, S*L: Shell luminosity, S*C: Shell chroma, h°S: Hue angle of the shell, PW: Peel weight, P*B: Pulp brightness, P*C: Pulp chroma, h°P: Pulp hue angle.

between the chroma of the pulp and the chroma of the peel and between the chroma of the pulp and the luminosity of the peel. A positive correlation was also observed between the luminosity and chroma of the pulp and between the hue angle of the pulp and peel, indicating that the characteristics increase or decrease at the same rate. Negative correlations were observed between the chroma and the hue angle of the pulp, between the chroma and the hue angle of the peel, between the hue angle of the peel and the chroma of the pulp, between the chroma of the peel and the hue angle of the pulp, and the luminosity of the peel and the hue angle of the pulp (Table 3).

Fruit pulp color is strongly influenced by the genetic composition of the parent plant.[30] Correlation studies specify the degree of interaction between traits for the selection of attributes in breeding programs, so assigning correlations between traits is vitally important for effective selection.[6]

The characterization of plants based on their morphological characteristics is of great importance for the selection of individuals with superior characters, thus, the characteristics evaluated in this study can be useful to identify promising genotypes. It is important to mention that the evaluation of such characteristics can be complemented with other technologies, like molecular markers, which can be combined with morphological traits to evaluate the dissimilarity between and among populations.[31]

CONCLUSIONS

There is genetic diversity among the tamarind matrices, two groups were formed by the UPGMA method based on the physical characteristics of the tamarind fruit, which facilitates subsequent selection and contributes to the conservation of the species. The strong correlations between fruit length and weight, peel weight and fruit weight, peel weight and length, indicate that fruit weight, peel weight and fruit length are directly related, which is crucial information for genetic improvement.

DATA AVAILABILITY STATEMENT

All datasets supporting the results of this study were used in this article.

ACKOWLEDGEMENTS, FINANCIAL SUPPORT AND FULL DISCLOSURE

The authors acknowledge the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (CAPES) and the *Conselho Nacional de Desenvolvimento Científico e Tecnológico* (CNPq) for financial support.

AUTHOR CONTRIBUTIONS

Conceptualization: Danielle Fabíola Pereira da Silva, Francielly Rodrigues Gomes, Ângela Lopes Barros.

Data curation: Alejandro Hurtado Salazar, Carla Gomes Machado, Simério Carlos Silva Cruz.

Formal analysis: Danielle Fabíola Pereira da Silva, Francielly Rodrigues Gomes, Ângela Lopes Barros.

Software: Alejandro Hurtado Salazar, Carla Gomes Machado, Simério Carlos Silva Cruz.

Writing – original draft: Danielle Fabíola Pereira da Silva, Francielly Rodrigues Gomes, Ângela Lopes Barros.

Writing – review & editing: Alejandro Hurtado Salazar, Carla Gomes Machado, Danielle Fabíola Pereira

da Silva, Simério Carlos Silva Cruz.

REFERENCES

1. Rao YS, Mathew KM. Tamarind. In: Peter KV, editor. Handbook of herbs and spices. 2nd ed. Cambridge: Woodhead Publishing; 2012. p. 512-33.
2. Singh S, Naruka IS, Singh AK. Tamarind (Tamarindus indica L.). In: Singh RS, Singh AK, Maheshwari SK, Bhargava R, Saroj PL, editors. Underutilized fruit of India. New Delhi: Brillion Publishing; 2021. p. 439-56.
3. Kuru P. Tamarindus indica and its health related effects. Asian Pac J Trop Biomed. 2014;4(9):676-81.
4. Silva MS, Castro RS, Cavalcanti CJ, Azevedo LC. Produtos do tamarindo (Tamarindus indica L.) no sertão pernambucano: uma experiência de extensão tecnológica. Rev Semiárido De Visu. 2020;8:105-16.
5. Amir A, Sharangi AB, Bal S, Upadhyay TK, Khan MS, Ahmad I, et al. Genetic variability and diversity in red onion (Allium cepa L.) genotypes: elucidating morpho-horticultural and quality perspectives. Horticulturae. 2023;9(8):1005.
6. Gomes BH, Faria MV, Mendes MG, Bonetti AM, Oliveira RJ Júnior, Nogueira AP. Genetic diversity and correlation between morphological traits of pequi fruits (Caryocar brasiliense Camb.) with and without thorns at the endocarp. An Acad Bras Cienc. 2022;94:e20210016.
7. Bailão EF, Oliveira MG, Almeida LM, Amaral VC, Chen LC, Caramori SS, Borges LL. Food composition data: edible plants in Cerrado. In: Jacob MC, Albuquerque UP, editors. Local food plants of Brazil: ethnobiology. Cham: Springer International Publishing; 2021. p. 179-224.
8. Cruz CD. Genes – a software package for analysis in experimental statistics and quantitative genetics. Acta Sci Agron. 2013;35(3):271-6.
9. Faria PN, Cecon PR, Finger FL. Métodos de agrupamento em estudo de divergência genética de pimentas. Hortic Bras. 2012;30(3):428-32.
10. Rodrigues HC, Carvalho SP, Carvalho AA. Avaliação da diversidade genética entre acessos de mamoneira (Ricinus communis L.) por meio de caracteres morfoagronômicos. Rev Ceres. 2010;57(6):773-7.
11. Silva DF, Siqueira DL, Pereira CS. Caracterização de frutos de 15 cultivares de mangueira na Zona da Mata Mineira. Rev Ceres. 2009;56(6):783-9.
12. Priyanka GP, Biradar IB, Satish D. Character association and path analysis studies in tamarind (Tamarindus indica L.) genotypes. J Pharmacogn Phytochem. 2021;10(3):606-9.
13. Diallo BO, Joly HI, McKey D. Genetic diversity of Tamarindus indica populations: any clues on the origin from its current distribution? Afr J Biotechnol. 2007;6(7):853-60.
14. Algabal AQ, Papanna N, Simon L. Estimation of genetic variability in tamarind (Tamarindus indica L.) using RAPD markers. Int J Plant Breed. 2011;5(1):10-6.
15. Gangaprasad SR, Ravikumar RL, Savitha MH. Genetic diversity analysis in tamarind (Tamarindus indica L.). J Spices Aromat Crops. 2013;22(1):55-61.
16. Singh TR, Nandini R. Genetic variability, character association and path analysis in the tamarind (Tamarindus indica L.) population of Nallur tamarind grove. SAARC J Agric. 2014;12(2):20-5.
17. Kumar M, Ponnuswami V, Rajamanickam C. Assessment of genetic diversity in tamarind (Tamarindus indica L.) using random amplified polymorphic DNA markers. SAARC J Agric. 2015;13(2):27-36.
18. Sharma DK, Aklade AS, Virdia HM. Genetic variability in tamarind (Tamarindus indica L.) from south Gujarat. Curr Hortic. 2015;3(1):43-6.
19. Raut UA, Jadhav SB, Pawar YD. Genetic variability studies in tamarind (Tamarindus indica L.). Pharma Innov J. 2022;11(10):2731-40.
20. Gomes FR, Rodrigues CD, Ragagnin AL, Salazar AH, Silva DF. Genetic diversity and characterization of sweet lemon (Citrus limetta) fruits. J Agric Sci. 2020;12(10):181-90.
21. Hoque AK, Chowdhury HT, Maya MA, Ahmed QA, Hossain A. Assessing the genetic diversity of twenty one Colombo limon L. genotypes through multivariate and covariance matrix analysis. Acta Fytotech Zootech. 2021;24(3):110-6.
22. Divakara BN, Upadhyaya HD, Fandohan B. Identification and divergence studies of genotypes of Tamarindus indica (Fabaceae) with superior pod traits. Int J Biol Chem Sci. 2012;5(2):509-14.
23. Sanches LA, Camargo AB, Garlet J. Aspectos biométricos de frutos e de sementes de Tamarindus indica L. Rev Verde Agroecol Desenvolv Sustentável. 2019;14(3):156-60.
24. Algabal AQ, Papanna N, Ajay BC. Studies on genetic parameters and interrelationships for pulp yield and its attributes in tamarind (Tamarindus indica L.). Int J Plant Breed. 2012;6(2):65-9.
25. Canuto GA, Xavier AA, Neves LC. Caracterização físico-química de polpas de frutos da Amazônia e sua correlação com a atividade anti-radical livre. Rev Bras Frutic. 2010;32(4):1196-205.
26. Lee YC, Yu MC, Yen CY, Tsay JS, Hou CY, Li PH, et al. Exploitation of post-ripening treatment for improving cold tolerance and storage period of Jin Huang mango. Horticulturae. 2024;10(2):103.
27. Heinrich AG, Ferraz RM, Ragassi CF. Caracterização e avaliação de progênies autofecundadas de pimenta biquinho salmão. Hortic Bras. 2015;33(4):465-70.
28. Tesfaye A. Genetic divergence and cluster analysis for bulb yield and related traits in garlic (Allium sativum) accessions at Dorze, southern Ethiopia. Agrosyst Geosci Environ. 2022;5:e20269.
29. Rohlf FJ. Adaptive hierarchical clustering schemes. Syst Zool. 1970;18(1):58-82.
30. Mayavel A, Nagarajan B, Muthuraj K. Correlation and path coefficient analysis of selected red tamarind (Tamarindus indica var. rhodocarpha) genetic resources. Int J Curr Microbiol Appl Sci. 2018;7(3):794-802.
31. Kidaha ML, Kariuki W, Rimberia FK. Evaluation of morphological diversity of tamarind (Tamarindus indica) accessions from Eastern parts of Kenya. J Hortic For. 2019;11(1):1-7.
32. Bruno MH, Castanho MF, Araújo L, Carvalho S. Caracterização morfológica e molecular de biótipos de Conyza spp. Cienc Agric (Londrina). 2021;19(1):61-9.