**CORRELATION STUDIES AMONG QUALITY TRAITS OF TAMARIND (*Tamarindus indica* L.) GENOTYPES**

**ABSTRACT**

Tamarind (*Tamarindus indica* L.) is a tropical fruit tree belonging to the Leguminosae family, renowned for its unique sweet and tangy flavour. This study aimed to examine the correlation analysis of the tamarind quality parameters. It revealed several statistically significant relationships that provided insight into the biochemical and physiological factors governing fruit quality and yield. The amount of Total Soluble Solids (TSS) in tamarind fruit pulp TSS exhibited a strong positive correlation with that of both reducing sugars (r = 0.73, *p* < 0.01) and total sugars (r = 0.75, *p* < 0.01), suggesting that as the amount of TSS in tamarind fruit pulp increased, the sugar concentration rose. The pH of fruit pulp displayed a moderate positive correlation with the amount of total sugars (r = 0.47, p < 0.05). A significant inverse relationship was observed between the amount of non-reducing sugars and reducing sugars in fruit pulp (r = -0.64, p < 0.01). This suggests that as tamarind fruits ripen, there is a biochemical conversion of non-reducing sugars (such as sucrose) into reducing sugars (glucose and fructose). The amount of total sugars exhibited a significant positive correlation with that of reducing sugars (r = 0.7, p < 0.01). The amount of tartaric acid in fruit pulp showed a significant negative correlation with that of total sugar (r = -0.51, p < 0.05). Pod yield per tree showed low negative correlations with key quality traits such as the amount of TSS (r = -0.293), pH (r = -0.37) and reducing sugars (r = -0.22), indicating that higher-yielding trees may produce fruits with slightly lower sugar content and acidity.

**Keywords:** Quality characteristics, *Tamarindus indica*, Correlation.

**1 Introduction**

Tamarind (*Tamarindus indica* L.) is a multipurpose tropical fruit tree used primarily for its fruits, which are eaten fresh or processed, used as a seasoning or spice, or the fruits and seeds are processed for non-food uses. The species has a wide geographical distribution in the subtropics and semi-arid tropics and is cultivated in numerous regions (El-Siddig *et al*., 2006).

In India, tamarind is predominantly cultivated in states like Tamil Nadu, Karnataka, Kerala, Telangana, Maharashtra, and Tripura. The total area dedicated to tamarind cultivation across the country encompasses approximately 43,010 hectares and a production of about 172,910 tons annually. Specifically, in Telangana, tamarind is grown on an area of 2,020 ha, contributing an annual production of around 12,690 tons (Anonymous, 2022-2023).

Tamarind belongs to the dicotyledonous family Fabaceae (Leguminosae) and has a somatic chromosome number of 2n=24. Although tamarind is an ancient domesticate, little attempt has been directed at its genetic improvement because it is time-consuming and the large-scale cultivation of tamarind is still in its early stages. Indigenous farmers have however selected planting materials from natural populations based on desirable and observable characteristics but such phenotypic selection means the growing stocks are virtually wild (El-Siddig *et al*., 2006). Since the variation in pod length and pod width was found to be genotypically similar for other traits the potential for improvement depends on sampling the genetic variability available within and between populations. Hence, knowledge of genetic variation and structure of a species and genetic parameters of important traits are essential to developing effective improvement and conservation strategies.

The genetic improvement goals are straightforward based on the available material. They are faster-growing and higher-yielding lines for selection for different uses. Since normal crossing is not an option, more transpacific work is needed so that provenance trials can lead to selections that combine the desirable characters and then to cultivars developed from them. These should be developed to fit the different land-use systems of agroforestry, orchards/plantations as well as certain stress conditions inherent in several wastelands that need to be rehabilitated (El-Siddig *et al*., 2006).

Tamarind was recorded over a century ago as a variable species, especially for pulp colour and sweetness. Since there is such extensive variation in characteristics such as foliage, flower and pod production, and timber quality, there is a considerable scope to improve the species. Improvement holds the key to boosting the productivity and yield of the orchards and involves the development of genotypes possessing desirable characteristics like fast growth, good tree form, high yield, and resistance or tolerance to major pests, diseases and drought (Radhamani et al., 1998).

The present study aims to assess genetic variability in tamarind based on yield and quality traits across 20 genotypes. This understanding is crucial for conserving valuable germplasm and protecting it from potential loss while also supporting future efforts in tamarind improvement programs. Understanding the inheritance patterns of various traits is essential for determining the most suitable breeding strategies for any crop. A breeder's selection of material for improvement largely depends on the level of genetic variability present. It is important to note that phenotype alone may not accurately reflect genotype; thus, the variation observed in natural populations represents phenotypic variability, which is ultimately influenced by underlying genotypic factors.

Genetic variation in tamarind plays a significant role in both quantitative traits and those contributing to fruit quality. Key yield-related characteristics, such as fruit size (including length and weight), are influenced by genetic factors. Meanwhile, the pulp content and fiber levels are important determinants of fruit quality. Additionally, the interaction between genotype and environment can further affect these traits.

**2 Materials and Methods**

**2.1 Location and plant material**

Characterization and variability studies were conducted with 20 tamarind genotypes of 25 - 40 years available at Fruit Research Station, Sangareddy, Telangana, India (15° 46' N to 19° 47' N altitude - 77° 16' E to 81° 43' E latitude, 496 mMSL) and these 20 genotypes are planted in Randomized Block Design (RBD) with three replications (Table.1).

**Table 1: The list of genotypes used for the study are given in the table below**

|  |  |  |  |
| --- | --- | --- | --- |
| **S. No** | **Accession name** | **S. No** | **Accession name** |
|  | SRDTi-01 |  | SRDTi-27 |
|  | SRDTi-03 |  | SRDTi-28 |
|  | SRDTi-04 |  | SRDTi-30 |
|  | SRDTi-05 |  | SRDTi-31 |
|  | SRDTi-06 |  | SRDTi-32 |
|  | SRDTi-11 |  | SRDTi-33 |
|  | SRDTi-12 |  | SRDTi-34 |
|  | SRDTi-16 |  | SRDTi-35 |
|  | SRDTi-21 |  | SRDTi-36 |
|  | SRDTi-22 |  | SRDTi-37 |

**2.2 Biochemical Analysis of the Pulp:**

**2.2.1 Total soluble solids (°Brix)**

The amount of total soluble solids in tamarind pulp was measured using an ERMA Hand Refractometer with a range of (0-32 °Brix). For each genotype, three readings were taken, and the average value was calculated and expressed in °Brix (Ranganna, 1979).

**2.2.2 pH of the pulp**

The pH of the pulp was measured using a digital U-365 pH meter. The meter was calibrated with standard buffer solutions, and the pH was assessed by directly inserting the electrodes into a 25 ml beaker containing the fruit pulp.

**2.2.3 Reducing sugar (%)**

Reducing sugar content was measured using the Lane and Eynon method (AOAC, 1965). Ten grams of fruit pulp were finely ground and transferred to a 250 ml volumetric flask, to which 100 ml of water was added. Two ml of 45% lead acetate solution was mixed in and allowed to stand for 10 minutes to precipitate colloidal matter. Following this, 2 ml of 22% potassium oxalate was added to remove excess lead, and the volume was adjusted to 250 ml. The solution was then filtered through the Whatman number 4 filter paper. The lead-free filtrate was transferred into a burette and titrated against 10 ml of standard Fehling’s solution (A and B mixed in a 1:1 ratio), using methylene blue as the indicator. The titration, conducted with Fehling’s solution kept boiling on a heating mantle, was completed when a brick-red precipitate formed, indicating the endpoint. The results were expressed as a percentage of reducing sugar.

Reducing Sugars (%) × 100

**2.2.4 Non-reducing sugars (%)**

Non-reducing sugar content in samples was obtained by subtracting reducing sugars from total sugars.

Non-reducing sugars (%) = Total sugars (%) - Reducing sugars (%)

**2.2.5 Total sugars (%)**

Total sugar content was determined using the Lane and Eynon method (AOAC, 1965). Fifty ml of the clarified lead-free solution was transferred to a 250 ml volumetric flask, to which 10 ml of HCl was added. The mixture was well combined and allowed to stand at room temperature for 24 h. After this period, the solution was neutralized with NaOH, with a drop of phenolphthalein used as an indicator, and the volume was adjusted to 250 ml. The solution was then placed in a burette and titrated against standard Fehling’s solution (A and B mixed in a 1:1 ratio), using methylene blue to indicate the endpoint.

Total sugars (%)= × 100

**2.2.6 Tartaric acid (%)**

The amount of tartaric acid was determined using the formula mentioned below, as per the procedure suggested by Praveena kumar et al., 2020.

Organic acid (as tartaric acid) = 100

Where,

T = Titre value (ml)

E = Equivalent weight of the tartaric acid

N = Normality of NaOH

W = Weight of the pulp sample taken

**2.2.7 Ascorbic acid (mg/100g)**

Ascorbic acid content was measured using the method described by Ranganna (1986). Ten grams of fruit tissue were blended with 3% meta-phosphoric acid, and the volume was adjusted to 100 ml with H3PO4. The mixture was then filtered through Whatman No. 1 filter paper. An aliquot of 10 ml from the filtered solution was titrated with a standard dye solution (2, 6-dichlorophenol-indophenol dye) until a pink endpoint was reached. The ascorbic acid content was reported as mg of ascorbic acid per 100 grams.

Ascorbic acid (mg/100g) = x 100

**3 Results and Discussion**

The correlation analysis of the tamarind quality parameters revealed several statistically significant relationships that provided insight into the biochemical and physiological factors governing fruit quality and yield. Understanding the interdependence of traits such as Total Soluble Solids (TSS), pH, sugars, and organic acids is crucial for breeding programs aimed at improving tamarind fruit quality.

**3.1 Total Soluble Solids (TSS) and Sugars**

TSS content in tamarind fruit pulp exhibited a strong positive correlation with both reducing sugars (r = 0.73, p < 0.01) and total sugars (r = 0.75, p < 0.01), suggesting that as TSS increased, the sugar concentration in tamarind fruits also rose (Fig.1). This is an essential quality trait since higher sugar content directly influences consumer acceptability, especially in fresh consumption and processed products. TSS is often used as a predictor of fruit sweetness, which is consistent with observations in other tropical fruits like mango (Malundo *et al*., 2001) and strawberry (Basak *et al*., 2024) where TSS positively correlates with sugar content Selecting for higher TSS levels could therefore improve the sweetness profile of tamarind fruits.

**3.2 pH and Sugars**

The pH of tamarind fruit pulp displayed a moderate positive correlation with total sugars (r = 0.47, p < 0.05), indicating that fruits with higher sugar content tend to have a slightly lower acidity. However, the relationship between pH and reducing sugars (r = 0.43) was weaker and not statistically significant (Fig.1). This suggests that while the pH of fruit influences the general flavour perception by moderating acidity, it does not directly affect specific sugar types such as reducing sugars (Anthon *et al*., 2011). This trend is similar to other fruit crops where the balance between sweetness and acidity defines the overall flavour profile. In tamarind, achieving the right balance between sugars and acids is critical, especially for processing into sauces and concentrates where both flavour components are vital.

**3.3 Non-reducing Sugars and Reducing Sugars**

A significant inverse relationship was observed between non-reducing sugar content and reducing sugar content (r = -0.64, p < 0.01) (Fig.1). This suggests that as tamarind fruits ripen, there is a biochemical conversion of non-reducing sugars (such as sucrose) into reducing sugars (glucose and fructose), a process typical in many fruits during ripening. The breakdown of sucrose enhances sweetness and is a key indicator of fruit maturation (Basson *et al*., 2010; Shahood *et al*., 2020; ). This finding highlights the importance of harvest timing, as it influences both the sweetness and textural quality of tamarind fruit.

**3.4 Total Sugars and Reducing Sugars**

The amount of total sugars exhibited a significant positive correlation with that of reducing sugars (r = 0.7, p < 0.01), demonstrating that reducing sugar content contributed substantially to the overall sugar content of tamarind (Fig.1). This mirrors findings in fruits like apples and citrus, where reducing sugars are predominant in shaping the sweetness profile (Drewnowski *et al*., 2012 and Yıldız *et al*., 2015). In tamarind, these sugars are particularly important as they define the palatability of the fruit, which is crucial for both direct consumption and product development such as jams and candies.

**3.5 Organic Acids: Tartaric Acid and Ascorbic Acid**

The amount of tartaric acid, the primary organic acid in tamarind, showed a significant negative correlation with that of total sugar (r = -0.51, p < 0.05) (Fig.1). This inverse relationship between sugar content and acidity is typical of ripening fruit, where increasing sugar levels are associated with decreasing acidity (Mahmood *et al*., 2012; Batista *et al*., 2018). In tamarind, a reduction in tartaric acid enhances sweetness perception, making the fruit more appealing for consumption and further processing. In contrast, ascorbic acid (vitamin C) did not exhibit significant correlations with the other measured traits, indicating that its content is relatively independent of the sugar and acid levels in tamarind (Fig.1). This suggests that breeding for higher ascorbic acid content in tamarind would require targeted selection, as variations in sweetness or acidity are unlikely to influence vitamin C levels. A similar lack of correlation between vitamin C and other fruit quality parameters has been noted in other crops (Lee *et al*., 2012; Fenech *et al*., 2019 ).

**3.6 Pod Yield and Quality Traits**

Pod yield per tree showed weak negative correlations with key quality traits such as TSS content (r = -0.293), pH (r = -0.37), and reducing sugar content (r = -0.22), indicating that higher-yielding trees may produce fruits with slightly lower sugar content and acidity (Fig.1). This negative relationship between yield and quality is a common challenge in fruit breeding, where an increase in fruit quantity often comes at the expense of specific quality attributes like flavours and sweetness (Rossi *et al*., 2015 and Nimisha *et al*., 2013).

In tamarind, balancing high yields with superior fruit quality will require careful selection strategies, especially in breeding programs aimed at improving both production efficiency and consumer desirability.

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**Fig.1: Correlation between quality traits of 20 tamarind genotypes**

**Note:** RS= reducing sugars; NRS= non-reducing sugars; TS= total sugars; TA= tartaric acid; AC= ascorbic acid; PY= pod yield; TSS= Total Soluble Solids

**Conclusion**

The amount of TSS in tamarind fruit pulp exhibited a strong positive correlation with that of both reducing sugars. The pH of pulp displayed a moderate positive correlation with total sugar content. A significant inverse relationship was observed between non-reducing sugar content and reducing sugar content. Total sugar content exhibited a significant positive correlation with reducing sugar content. The amount of tartaric acid showed a significant negative correlation with total sugar content. Pod yield per tree showed weak negative correlations with key quality traits such as TSS content and reducing sugar content indicating that higher-yielding trees may produce fruits with slightly lower sugar content and acidity.

**Conflicts of interest**

The authors declare that they have no conflict of interest.

**References**

Anonymous, (2022-2023). Ministry of agriculture and farmers welfare, government of India, third advance estimation.

Anthon, G.E., LeStrange, M. and Barrett, D.M. (2011). Changes in pH, acids, sugars and other quality parameters during extended vine holding of ripe processing tomatoes. *Journal of the Science of Food and Agriculture*. 91(7): 1175-1181.

Basak, J.K., Madhavi, B.G.K., Paudel, B., Kim, N.E. and Kim, H.T. (2024). Prediction of total soluble solids and pH of strawberry fruits using RGB, HSV and HSL colour spaces and machine learning models. *Foods*. 11(14): 2086.

Basson, C.E., Groenewald, J.H., Kossmann, J., Cronjé, C. and Bauer, R. (2010). Sugar and acid-related quality attributes and enzyme activities in strawberry fruits: Invertase is the main sucrose hydrolysing enzyme. *Food Chemistry*. 121(4): 1156-1162.

Batista-Silva, W., Nascimento, V.L., Medeiros, D.B., Nunes-Nesi, A., Ribeiro, D.M., Zsögön, A. and Araújo, W.L. (2018). Modifications in organic acid profiles during fruit development and ripening: correlation or causation. *Frontiers in Plant Science*. 9: 1689.

Drewnowski, A., Mennella, J.A., Johnson, S.L. and Bellisle, F. (2012). Sweetness and food preference. *The Journal of nutrition*, *142*(6), pp.1142S-1148S.

El-Siddig, K., Gunesana, H.P.M., Prasad, B.A., Pushpukumara, D.K.N.G., Ramana, K.VR., Vijayananand, P and Williams, J.T. (2006). Fruits for the future 1 – tamarind (*Tamarindus indica* L.) (Revised). Southampton Centre for Underutilized Crops. Southampton, United Kingdom. 9-12.

Lane, J. H and Eynon, L. (1965). The determination of reducing sugars by the Lane and Eynon method. *In Official Methods of Analysis*. Association of Official Analytical Chemists. Washington. D.C, United States of America. 490-510.

Fenech, M., Amaya, I., Valpuesta, V. and Botella, M.A. (2019). Vitamin C content in fruits: Biosynthesis and regulation. *Frontiers in plant science*, *9*, p.2006.

Lee, M.Y., Yoo, M.S., Whang, Y.J., Jin, Y.J., Hong, M.H. and Pyo, Y.H. (2012). Vitamin C, total polyphenol, flavonoid contents and antioxidant capacity of several fruit peels. *Korean Journal of Food Science and Technology*, *44*(5), pp.540-544.

Mahmood, T., Anwar, F., Abbas, M., Boyce, M.C. and Saari, N. (2012). Compositional variation in sugars and organic acids at different maturity stages in selected small fruits from Pakistan. *International journal of molecular sciences*, *13*(2), pp.1380-1392.

Praveenakumar, R., Gopinath, G., Shyamalamma, S., Ramesh, S., Vasundhara, M and Chandre Gowda, M. (2020). Studies on phytochemical evaluation of tamarind (*Tamarindus indica* L.) genotypes prevailing in Eastern Dry Zone of Karnataka. *Indian Journal of Pure and Applied Biosciences*. 8(5): 320-324.

Ranganna, S. (1986). *Handbook of analysis and quality control for fruits and vegetable products*. Tata Mc Graw Hill Publishing Company Limited, New Delhi.

Malundo, T.M.M., Shewfelt, R.L., Ware, G.O. and Baldwin, E.A. (2001). Sugars and acids influence flavour properties of mango (*Mangifera indica*). *Journal of the American Society for Horticultural Science*, *126*(1), pp.115-121.

Nimisha, S., Kherwar, D., Ajay, K.M., Singh, B. and Usha, K. (2013). Molecular breeding to improve guava (*Psidium guajava* L.): current status and future prospective. *Scientia Horticulturae*, *164*, pp.578-588.

Rossi, M., Bermudez, L. and Carrari, F. (2015). Crop yield: challenges from a metabolic perspective. *Current Opinion in Plant Biology*, *25*, pp.79-89.

Shahood, R., Torregrosa, L., Savoi, S. and Romieu, C. (2020). First quantitative assessment of growth, sugar accumulation and malate breakdown in a single ripening berry. *Oeno One*. 54(4): 1077-1092.

Yıldız, G., İzli, N., Ünal, H. and Uylaşer, V. (2015). Physical and chemical characteristics of golden berry fruit (*Physalis peruviana* L.). *Journal of Food Science and Technology*. 52: 2320-2327.