**Correlation Analysis of Quality Characteristics in 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 analysed the correlation among tamarind quality parameters, uncovering several statistically significant relationships that offer valuable insights into the biochemical and physiological factors influencing fruit quality and yield. TSS exhibited a strong positive correlation with both reducing sugars (r = 0.73, p < 0.01) and total sugars (r = 0.75, p < 0.01), indicating that an increase in TSS is associated with a higher sugar concentration in tamarind fruits. The pH displayed a moderate positive correlation with total sugars (r = 0.47, p < 0.05). A significant inverse relationship was observed between non-reducing sugars and reducing sugars (r = -0.64, p < 0.01). This indicates that during tamarind fruit ripening, non-reducing sugars like sucrose are biochemically converted into reducing sugars such as glucose and fructose, a common process observed in many ripening fruits. Total sugars exhibited a significant positive correlation with reducing sugars (r = 0.7, p < 0.01). Tartaric acid, the primary organic acid in tamarind, showed a significant negative correlation with total sugar (r = -0.51, p < 0.05) while as Pod yield per tree showed low negative correlations with key quality traits such as TSS (r = -0.293), pH (r = -0.37) and reducing sugars (r = -0.22), suggesting that trees with higher yields might produce fruits with marginally reduced sugar content and acidity.

**Keywords:** Correlation, Quality characteristics, Biochemical characteristics, Yield, *Tamarindus indica*,

**1 Introduction**

Tamarind (*Tamarindus indica* L.) is a multipurpose tropical fruit tree used primarily for its fruits, which can be consumed fresh, processed into seasonings or spices, or utilized, along with the seeds, for various non-food applications. Tamarind is widely distributed across the subtropical and semi-arid tropical regions and is cultivated extensively in various areas (Chitra *et al.,* 2023).

In India, tamarind is predominantly cultivated in states like Tamil Nadu, Karnataka, Kerala, Telangana, Maharashtra, and Tripura. The total area under tamarind cultivation across the country encompasses approximately 43,010 hectares with an annual production of ~~about~~ around 172,910 tonnes. In Telangana alone, tamarind is cultivated on 2,020 hectares, contributing about 12,690 tonnes annually (FAOSTAT, 2022-23).

Tamarind belongs to the dicotyledonous family Fabaceae (Leguminosae) and has a somatic chromosome number of 2n=24. It is believed that Linnaeus assigned the specific epithet *indicus* because the name “tamarind” originated from Arabic word, *Tamar*, meaning ‘date’, with Hindi, meaning ‘of India’. The full Arabic name was Tamar-u’ l-Hind, with ‘date’ includedto reference the brown appearance of tamarind pulp (El-Siddig *et al*., 2006). Although tamarind is an ancient domesticated species, little attempt has been made ~~to~~ in its genetic improvement due to the time-intensive nature of the process and the relatively nascent stage of its large-scale cultivation. Indigenous farmers have ~~however~~ traditionally selected planting materials from natural populations based on desirable and observable ~~characteristics~~ traits; ~~but such~~ however, this phenotypic selection has resulted in cultivation stocks that remain nearly wild. (El-Siddig *et al*., 2006). Since the variation in pod length and pod width was genotypically consistent with other traits, the potential for improvement depends on harnessing the genetic variability ~~available~~ present within and between populations. Therefore, understanding the genetic variation, population structure of a species, and the genetic parameters of key traits is crucial for formulating effective strategies for improvement and conservation.

The genetic improvement goals are clear given the available resources: to identify faster-growing and higher-yielding lines suited for various purposes. As conventional crossing methods ~~is~~ are not feasible, greater international collaboration is required to conduct provenance trials. These trials would enable the selection of genotypes that combine desirable characters, leading to the development of cultivars tailored to diverse land-use systems of agroforestry, orchards and plantations. Additionally, these cultivars should be designed to thrive under challenging conditions, including those found in wastelands requiring rehabilitation.

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

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 and qualitaive traits. 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 on 20 tamarind genotypes aged 25 - 40 years, located at the 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 the experiment was designed 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 total soluble solids in tamarind pulp were 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 sugars were 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, and it was completed when a brick-red precipitate formed, indicating the endpoint. The results were expressed as a percentage of reducing sugar.

 Reducing Sugars (%)$=\frac{Factor value x dilution x 100}{Titre value x Weight of sample (g)}$ x 100

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

Non-reducing sugars in samples were obtained by subtracting reducing sugars from total sugars.

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

**2.2.5 Total sugars (%)**

Total sugars were 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 hours. 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 (%)=$\frac{FactorvaluexDilution 1 xDilution 2}{TitervaluexWeightofsample\left(g\right)xAliquottaken (ml)}$ x 100

**2.2.6 Tartaric acid (%)**

The 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) = $\frac{T x E x N}{1000 x W}$ x 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 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) = $\frac{Titrate value x Dye factor x volume made up }{Aliquot taken x weight of sample taken }$ x 100

**3 Results and Discussion**

The correlation analysis of tamarind quality parameters revealed several statistically significant relationships ~~provide~~ offering valuable insights 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 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 an increase in TSS is associated with a higher sugar concentration in tamarind fruits. (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 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 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 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 sugars and reducing sugars (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), The breakdown of sucrose enhances sweetness and is a key indicator of fruit maturation (Shahood *et al*., 2020 and). 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**

Total sugars exhibited a significant positive correlation with reducing sugars (r = 0.7, p < 0.01), demonstrating that reducing sugars contribute substantially to the overall sugar content of tamarind (Fig.1). Similar findings are observed in fruits like apples and citrus, where reducing sugars are predominant in shaping the sweetness profile. 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**

Tartaric acid, the primary organic acid in tamarind, showed a significant negative correlation with 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 and 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. Similarly no correlation between vitamin C and the other fruit quality parameters was noted in other crops (Fenech *et al*., 2019 and).

**3.6 Pod Yield and Quality Traits**

Pod yield per tree showed weak negative correlations with key quality traits such as 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 (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.

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**

TSS exhibited a strong positive correlation with both reducing sugars. The pH displayed a moderate positive correlation with total sugars. A significant inverse relationship was observed between non-reducing sugars and reducing sugars. Total sugars exhibited a significant positive correlation with reducing sugars. Tartaric acid showed a significant negative correlation with total sugar. Pod yield per tree showed weak negative correlations with key quality traits such as TSS and reducing sugars 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.

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