

Synchronization of Boron Application Methods and Rates is Environmental Friendly Approach to Improve Quality Attributes of *Mangifera indica* L. on Sustainable Basis

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Abstract

Deficiency of micronutrients in soil is one of major cause for poor quality of mango fruit and yield. In addition, consumption of such diet also causes deficiency of micronutrients in humans. Among different micronutrients deficiency of boron is very common. It adversely affects flowering and pollen tube formation, thus played key role in decreasing the yield and quality attributes of mango. To overcome such problem, soil and foliar application of B is considered the efficacious methods. That's why under changing climatic condition, a field experiment was conducted to explore the most suitable method and application rate of B in mango under current climatic scenario. There were nine treatments applied in three replications. Results showed that application of T8=RD+Borax (75 g plant⁻¹ as basal application)+H₃BO₃ (0.8% as foliar spray) and T9=RD+Borax (150 g plant⁻¹ as basal application)+H₃BO₃ (0.8% as foliar spray) significantly enhanced nitrogen, potassium, proteins, ash, fats, fiber and total soluble solids in mango as compared to control. A significant decrease in sodium, total phenolics contents, antioxidant activity and acidity as citric acid also validated the efficacious functioning of T8=RD+Borax (75 g plant⁻¹ as basal application)+H₃BO₃ (0.8% as foliar spray) and T9=RD+Borax (150 g plant⁻¹ as basal application)+H₃BO₃ (0.8% as foliar spray) over control. In conclusion T8=RD+Borax (75 g plant⁻¹ as basal application)+H₃BO₃ (0.8% as foliar spray) and T9=RD+Borax (150 g plant⁻¹ as basal application)+H₃BO₃ (0.8% as foliar spray) is an effective strategy to improve quality attributes of mango under changing climatic situation.

Introduction

Micronutrients deficiency is a major concern in humans health globally especially among women and children's in under developed regions ¹. It is also required for optimum growth and regulation of metabolic processes in plants, in small quantity ². Unfortunately, a large number of environmental factors i.e., soil texture and structure, contents of calcium carbonate, soil pH, aluminum and iron oxides, nutritional status, organic matter, soil fauna and flora, bicarbonate and sulfur content, redox potential of soil, poor irrigation and management practices influence decreased micronutrients uptake by roots in plants. These factors also restrict the translocation and accumulation of micronutrient in consumable parts of crops thus adversely affect yield ^{3,4}.

To overcome the deficiency of micronutrients fertilizer application in soil is one of common method. These micronutrients can be added in soil via band placement, broadcasting or fertigation ⁵⁻⁷. On the other hand, foliar application of nutrients is also an important crop strategy to optimized crop yields and micronutrients in edible parts ^{3,8}. Several studies have shown that foliar application of nutrients ⁹ can increase growth and yield of crops ^{3,10}.

Among different micronutrients, boron (B) is an essential. It is required by all plants. Although B is component of cell walls, limited literature is documented on its biochemical functions. In maintenance of membrane function B played an imperative role ¹¹. It also supports metabolic activities in plants.

However, higher uptake of B in plants can also cause severe toxicity¹². Boron occurs as uncharged boric acid [B(OH)₃] in soil solution. Fruit setting and retention percentage of fruit are attributed to boron (B) concentration in fruit¹³.

Less availability of B in floral structure, resulted in less fruit setting from flowers. It also minimized percent fruit retention on panicle³. Balance B uptake increases thickness of cell wall thickness through specific complexes. In addition, increase in flower number and retention, germination, pollen tube elongation, seed and fruit development are other benefits associated with balance B uptake. Translocation of photosynthates and less IAA oxidation are also controlled by B¹⁴.

Mango (*Mangifera indica* L.) is a popular fruit crop of family Anacardiaceae. It is cultivated in tropical and subtropical areas of world. Due to excellent flavour, delicious taste and pleasant fragrance many people called it king of fruits. However, less fruit setting and retention is a serious problem in mango. During early development stages fruitlet abscission is complex physiological process. Role of micronutrients are very important in this regard. Their acute deficiencies some time causes lower fruit yield and quality of mango¹⁵. Among micronutrients, B plays a vital role in hormone movement, flowering, activate salt absorption, pollen germination fruiting process and pollen tube growth¹⁶. That's why current study was conducted with aim to explore the improvement in quality and yield attributes of mango amended with B fertilizer under B deficient conditions. It is hypothesized that combined application of B i.e., foliar and soil is a better approach than sole application for the improvement in quality and yield characteristics of mango in B deficiency conditions. Current study will help the farming community for management of B in mango trees for the achievement of better fruit quality and yield.

Methods

4.1. Treatment Plan

There were 9 treatments with 3 replication following randomized complete block design. The treatments includes: T₁: Recommended dose (RD) of NPK + Borax (0 g plant⁻¹ as basal application) + H₃BO₃ (0% as foliar spray), T₂: RD + Borax (75 g plant⁻¹ as basal application) + H₃BO₃ (0% as foliar spray), T₃: RD + Borax (150 g plant⁻¹ as basal application) + H₃BO₃ (0% as foliar spray), T₄: RD + Borax (0 g plant⁻¹ as basal application) + H₃BO₃ (0.4% as foliar spray), T₅: RD + Borax (75 g plant⁻¹ as basal application) + H₃BO₃ (0.4% as foliar spray), T₆: RD + Borax (150 g plant⁻¹ as basal application) + H₃BO₃ (0.4% as foliar spray), T₇: RD + Borax (0 g plant⁻¹ as basal application) + H₃BO₃ (0.8% as foliar spray), T₈: RD + Borax (75 g plant⁻¹ as basal application) + H₃BO₃ (0.8% as foliar spray) and T₉: RD + Borax (150 g plant⁻¹ as basal application) + H₃BO₃ (0.8% as foliar spray).

4.2. NPK application

Macronutrients application was done at the rate of 1.5 (N), 1(P), 1(K) kg/plant/ year respectively. All P amount (1kg) while half N (0.75kg) and K (0.50kg) were added at end of July. However, remaining half N and K were added before 1st week of February²⁷.

4.3. Boron application

Soil application will be done before flowering; Foliar spray will be done twice a year; first at inflorescence stage and second when fruit attained pea size. At the end of experiment, soil and leaf samples will be collected, stored and processed for analysis³.

4.4. Plants sampling

For collection of leaf samples, 15 healthy mango plants were randomly nominated from the orchard. About 20 developed leaves (4-6 months old) were collected randomly from all the sides of the canopy of mango plant from the fruit bearing and non-fruit bearing twigs. Samples were collected during the months of July/August. Then leaves were washed out with distilled water and dried in oven at temperature 70°C for 48 hours. Oven dried material was grind with the help of John Wiley mill and then passed through a 40-mesh screen.

4.5. Plant analyses

The leaf samples were digested in diacid mixture and the concentration of B²⁸. Zinc and iron were determined and analyzed using spectrophotometer /atomic absorption spectrophotometer²⁹. Leaf samples were digested and run with spectrophotometer for P³⁰ and flame photometer for K and Na³¹. Kjeldahl's method was used for nitrogen analysis³².

4.6. Fruit Retention

For assessment of fruit retention an area of 1.0 m² from all four sides of the tree was marked. Fruit retention was observed between mustard stages to the marble stage by adopting the standard protocol.

4.7. Acidity

Titrateable acidity as percent citric acid was assessed in fresh mango juice. Titration of sample at pH 8.2 was done with sodium hydroxide (0.1 N)³³.

$$\text{Acidity (\%)} = \left(\frac{\text{Volume of 0.1N NaOH (mL)} \times 0.067}{\text{Volume of Juice (mL)}} \right) \times 100$$

4.8. Total Soluble Solids (TSS)

For total soluble solids (Brix°) "Medline Scientific Ltd. digital hand refractometer model SELECT045" was used. From each fruit, 20 g pulp was collected. It was homogenized for 60 seconds in 80 mL distilled water. Finally, 1 ml of homogenate was placed on refractometer for TSS assesment³⁴.

4.9. Sugar Contents

Total sugar content of mango pulp was determined calorimetrically by the anthrone method³⁵.

4.10. Total Phenolic Contents and Vitamin C

The total phenolic content of the liqueurs was determined by the spectrophotometric method with Folin-Ciocalteu³⁶. Vitamin C was assessed in mango fruit by adopting the methodology of Spencer et al.³⁷.

4.11. Statistical analysis

Collected data was examined statistically by applying analysis of variance (ANOVA) and Tukey's test at $p \leq 0.05$. Statistical computer software package (Origin 2020b) was used for the statistical analysis³⁸.

Results

2.1. N, P and K of Mango

Effects of treatments was significant on nitrogen (N), phosphorus (P) and potassium (K) concentration of mango. Treatments T8 and T9 were significant for improvement in N of mango from control. Significant increase in N was also noted in T5 and T6 from control for N in mango. Application of T7, T3, T2 and T4 also remained significant for N improvement over control (Fig. 1). In case of phosphorus, a significant decrease was observed by the application of different levels of Zn. No significant change was observed in T3, T6 and T9 where highest level of Zn was applied. It was noted that phosphorus concentration was also significantly higher in T1, T4 and T7 over T2, T5 and T8 (Zn applied) (Fig. 2). Treatments T6, T8 and T9 remained significantly better than T1 for K concentration. Application of T3, T7 and T5 were also significantly different over T1 for K concentration (Fig. 3). Furthermore, for K concentration, T2 and T4 different significantly better from T1. Maximum increase in N, P and K was noted in T9, T1 and T9 as compared to T1, T9 and T1 respectively. Pearson correlation showed that N was positive and significant in correlation with K. However, negative significant correlation was noted between N and P. Principal component analysis showed that N and K were closely associated with T8 and T9. However, P was more closely associated with T1 and T4.

2.2. Na, Ca and Fe of Mango

Effects of treatments was significant on sodium (Na), calcium (Ca) and iron (Fe) concentration of mango. Treatments T1 and T4 were significant for improvement in Na of mango from control. Significant increase in Na was also noted in T2, T3 and T5 from control for Na in mango (Fig. 4). Application of T6, T7, T8 and T9 was non-significant for Na improvement with each other. In case of calcium, a significant decrease was also observed by the application of different levels of Zn. No significant change was observed among T6 and T8, however, minimum Ca was noted in T9 where highest level of Zn was applied (Fig. 5). Application of T2, T3, T4 and T5 were also significantly decrease Ca over T1. Furthermore, for Fe concentration, all the treatments showed significant decline as compared to T1 (Fig.

6). Maximum decrease in Zn, Ca and Fe was noted in T9 as compared to T1. Pearson correlation showed that Ca was positive and significant in correlation with Fe and Na. Similarly, positive significant correlation was noted between Na and Fe. Principal component analysis showed that Na, Fe and Ca were closely associated with T2.

2.3. Protein, Fats, Ash and Fiber contents of Mango

Effects of treatments was significant on protein, fats, ash and fiber contents of mango. Treatments T9 were significant for improvement in protein contents of mango from T1 control. Significant increase in protein was also observed in T7 and T8 from control for protein contents in mango. Application of T2 to T5 was significant as well for protein contents improvement with T1 (Fig. 7). In case of ash content, a significant increase was noted in T9 and T8 over T1. No significant change was observed among T8 and T7, for ash contents with each other. However, T5 and T6 also differed significantly for ash contents over T1 control. Statistical analyses also confirmed that T2 and T4 were non-significant over control T1 for ash contents in mango (Fig. 8). Treatments T6 and T9 remained significantly better than T1 for fat contents. Application of T6, T5 and T8 were also significantly increase fat contents over T1. It was observed that T2 did not differ significantly for fat contents in mango over T1 (Fig. 9). For fiber contents of mango, T5, T7, T8 and T9 were statistically alike with each other but were significantly different over control T1. Application of T3, T4 and T6 also remained significant for improvement in fiber contents over T1. However, T2 remained non-significant for fiber contents over T1 control (Fig. 10). Maximum increase in protein, fats, ash and fiber contents was noted in T9 as compared to T1. Pearson correlation showed that protein, fats, ash and fiber contents were positive and significant in correlation with each other. Principal component analysis showed that protein, fats, ash and fiber contents were closely associated with T8.

2.4. Moisture, TSS, TPC and antioxidant activity in Mango

Effects of treatments was significant on moisture, TSS, TPC and antioxidant activity in mango. Treatments T9, T8, T6 were significant for improvement in moisture contents of mango from T1 control. Significant increase in protein was also observed in T7 and T8 from control for protein contents in mango. Application of T3, T4 and T5 was significant as well for moisture contents improvement from T1. Application of T2 and T7 were statistically alike with each other but differed significantly from T6 control for moisture contents (Fig. 11). In case of total soluble solids (TSS), a significant increase was noted in T6 and T9 over T1. No significant change was observed among T2 and T1, for TSS with each other (Fig. 12). However, T3, T4 and T5 also differed significantly for TSS over T1 control. Statistical analyses also confirmed that T8 and T9 were non-significant with each other but significant over control T1 for total phenolic contents (TPC) in mango (Fig. 13). Treatments T6 and T7 cause significant decrease in TPC than T1. Application of T4 and T5 were also significantly decrease TPC over T1. No significant change in

TPC among T1, T2 and T3. Furthermore, for antioxidants activity, all the treatments showed significant decline as compared to T1, T4 and T7 (Fig. 14). Maximum increase in moisture, TSS, TPC and antioxidant activity was noted in T9 as compared to T1. Pearson correlation showed that moisture and TSS were positive and significant in correlation with each other. However, antioxidant activity and TPC showed negative significant correlation with moisture, TSS. Principal component analysis showed that moisture, TSS and antioxidant activity were closely associated with T6, T8 and T9, T8 and T1 and T7 respectively.

2.5. Acidity, SC and Vitamin C in Mango

Effects of treatments was significant on acidity, sugar content (SC) and vitamin C in mango. All the treatments significantly decreased acidity of mango from T1 control except T4 and T7 (Fig. 15). In case of SC a significant increase was noted in T9 over T1. No significant change was observed among T5, T6 and T8 but differed significantly from T1, for SC. In addition, T2, T3 and T4 also differed significantly for SC over T1 control (Fig. 16). Statistical analyses also confirmed that T2, T4 and T7 were non-significant with each other and T1 control for vitamin C in mango (Fig. 17). Treatments T3, T5, T6, T8 and T9 significantly decreased vitamin C than T1. Maximum increase in sugar content (SC) was noted in T9 as compared to T1. However, T9 gave maximum decrease in acidity and vitamin C in mango as compared to T1. Pearson correlation showed that sugar content showed negative significant correlation with acidity and vitamin C (Fig. 18). Principal component analysis showed that acidity, sugar content (SC) and vitamin C were closely associated with T4, T6 and T7 respectively (Fig. 19).

Discussion

Optimum uptake of B is important not only for normal growth but also for enhancement of quality attributes in fruiting plants². A large number of studies indicated that B played an immense role in better uptake of nitrogen. Plants showed minimum nitrate reductase (NR) activity. It is also sensitive towards accumulation of nitrate when there is severe deficiency of B¹⁷. In addition of N, better uptake of B also facilitates the better P and K intake in plants. It increases the permeability of roots, which facilitate the P and K uptake. However, application of B as treatment also decrease the uptake of Ca^{18,19}. Our findings also justified these arguments. Results showed that increasing level of B also enhanced the N, P and K concentration of Mango. It also decreases the Ca uptake in mango might be due to its antagonistic relationship with B. It plays a key role in pollen germination, pollen tube formation and anther development. Hence, limited number of flowers, poor fruit quality and yield are major drawbacks of B deficiency²⁰. Application of boron as foliar, become the part of plants through superiority of phloem filter plates in the basipetal flow of sucrose. It stabilizes the nuclear membrane and ribonucleic acid metabolism, thus played imperative role in assimilation of sugar contents². Results of current study also

in agreement with these findings. Foliar application of micronutrient B and Zn as T9 significantly enhanced the sugar contents of mango. It has been observed that B has key role in phenolic metabolism. It activates enzyme phenylalanine ammonium-lyase (PAL) under deficiency conditions which significantly increased phenolic. Higher accumulation phenolic are catalytic oxidized by activity of polyphenoloxidase (PPO) enzyme. Such oxidation resulted in the production of quinones that decrease the integrity of cell membrane²¹. Findings of current study also signifies that phenolics contents were decreased by increasing soil and foliar application of B. The reduction in phenolic was might be due to better uptake of B and alleviation of B deficiency in mango plants. In plant cell wall growth deficiency of B also decrease glycoproteins. Most of surface proteins bind with membrane through glycosylphosphatidylinositol anchor such as arabinogalactan proteins (AGP). These glycosylphosphatidylinositol anchor such as arabinogalactan proteins (AGP) provide bindings sites for putative B-binding structures^{22,23}. Same kind of changes are also observed in pollen tubes where cell wall is made up of pectins. Results of current study are also in line with above arguments. Highest application rate of B significantly increases the proteins in mango. This increase in proteins contents was due to significant enhancement in the uptake of nitrogen which is key part of amino acids and protein synthesis. Marschner² documented that deficiency of B enhanced the formation of reactive oxygen species (ROS). Higher ROS restrict the glutathione and ascorbic acid metabolism through oxidative damage. To overcome such situation, a significant quantity of antioxidants are produced in the plants to alleviate the oxidative damages²⁴. Low antioxidants detection in T9 and higher in T1 signifies that T9 alleviate the deficiency of B in plants more efficaciously as compared to other treatments. Higher permeability of roots where facilitate the uptake of P and K also enhance the uptake of water. Both P and K are widely uptake in the plants through soil solution^{18,19}. Thus improvement in moisture contents of mango in current study also justified the better uptake of P and K. Thomidis et al.²⁵ argued that better uptake of K by application of B, promotes the firmness of fruit and total soluble solids. This optimum uptake of K decrease the acidity of fruit juice regulated by balance application of B as a foliar and soil application²⁶. The findings regarding improvement in total soluble solids and decrease in acidity of mango fruit juice in T9 validated the efficacious functioning of B when applied as foliar application in combination with soil application.

Conclusion

It is concluded that application of boron has potential to improve the quality attributes and nutrients contents of mango. Both soil and foliar application are important for the uptake of B in mango plants. However, more and efficacious results can be obtained through combined application of B as foliar and soil application. It is recommended to apply B 150 g plant⁻¹ as a basal dose +0.8% as foliar in combination to achieve the alleviation of B deficiency and improvement in quality and nutrients contents of mango in B deficient soils. More investigations are suggested on different mango varieties to establish and declare a narrow range of B application rates for mango.

Declarations

Author Contributions: Conceptualization, M.M.H.K.; N.A.; M.A.A.; methodology, M.M.H.K.; N.A.; M.A.A.; software, M.M.H.K.; N.A.; M.A.A.; validation, M.M.H.K.; N.A.; M.A.A.; formal analysis, M.M.H.K.; N.A.; M.A.A.; investigation, M.M.H.K.; N.A.; M.A.A.; resources, M.M.H.K.; N.A.; M.A.A.; data curation, M.M.H.K.; N.A.; M.A.A.; writing—original draft preparation, S.D.; S.F.; R.D.; M.M.H.; M.B.; A.E.S. M.S.; writing—review and editing, S.D.; S.F.; R.D.; M.M.H.; M.B.; A.E.S. visualization, S.D.; S.F.; R.D.; M.M.H.; M.B.; A.E.S. supervision, N.A.; project administration, M.M.H.; M.B.; A.E.S.; funding acquisition, M.M.H.; M.B.; A.E.S.;

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Figures

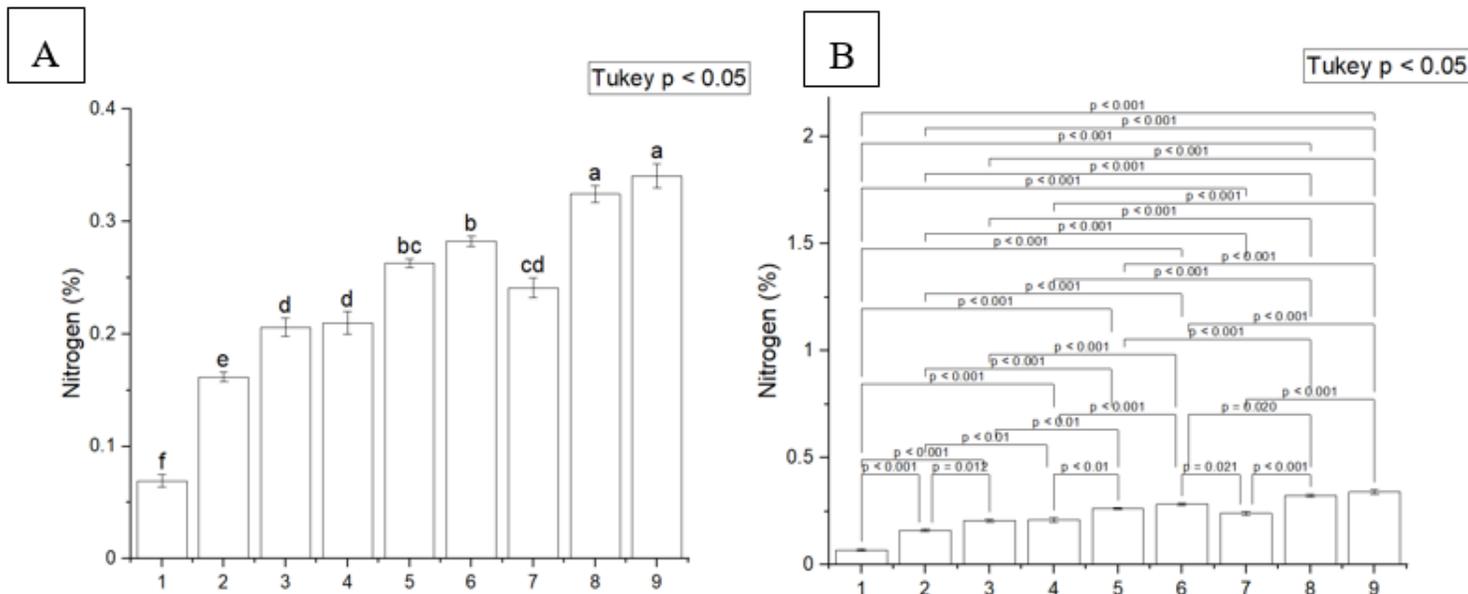


Figure 1

Effect of treatments on nitrogen concentration of mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in nitrogen concentration.

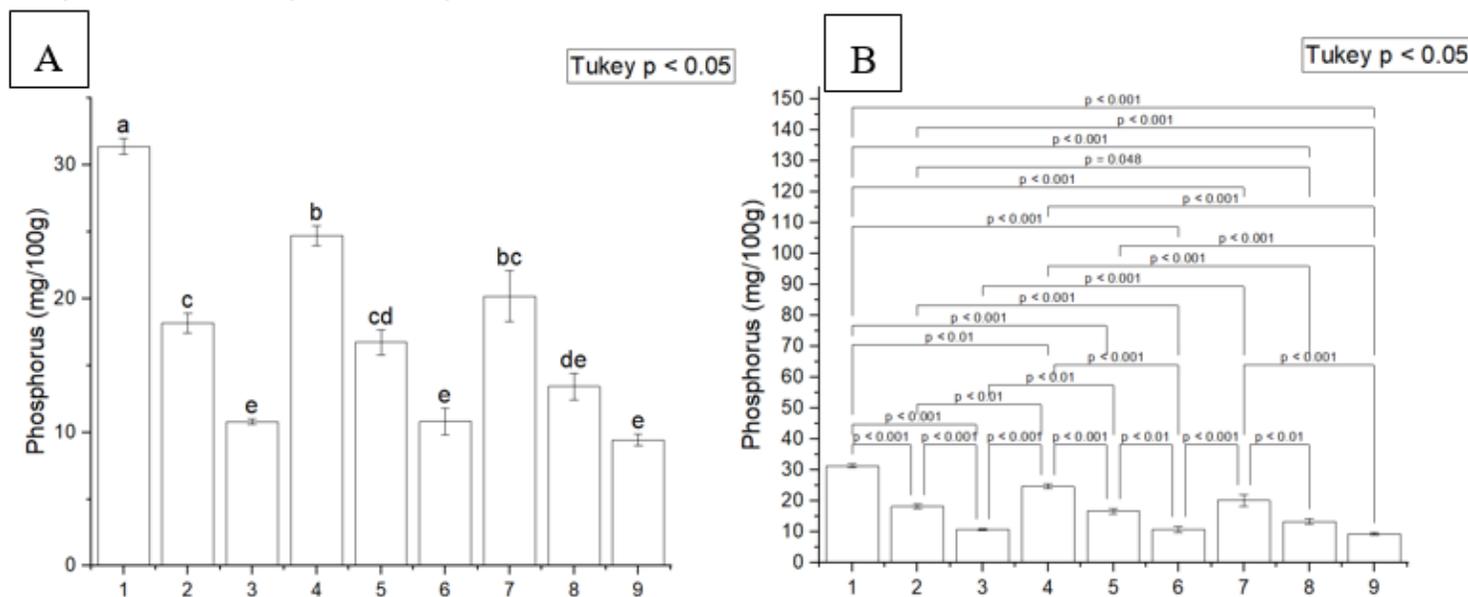


Figure 2

Effect of treatments on phosphorus concentration of mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in phosphorus concentration.

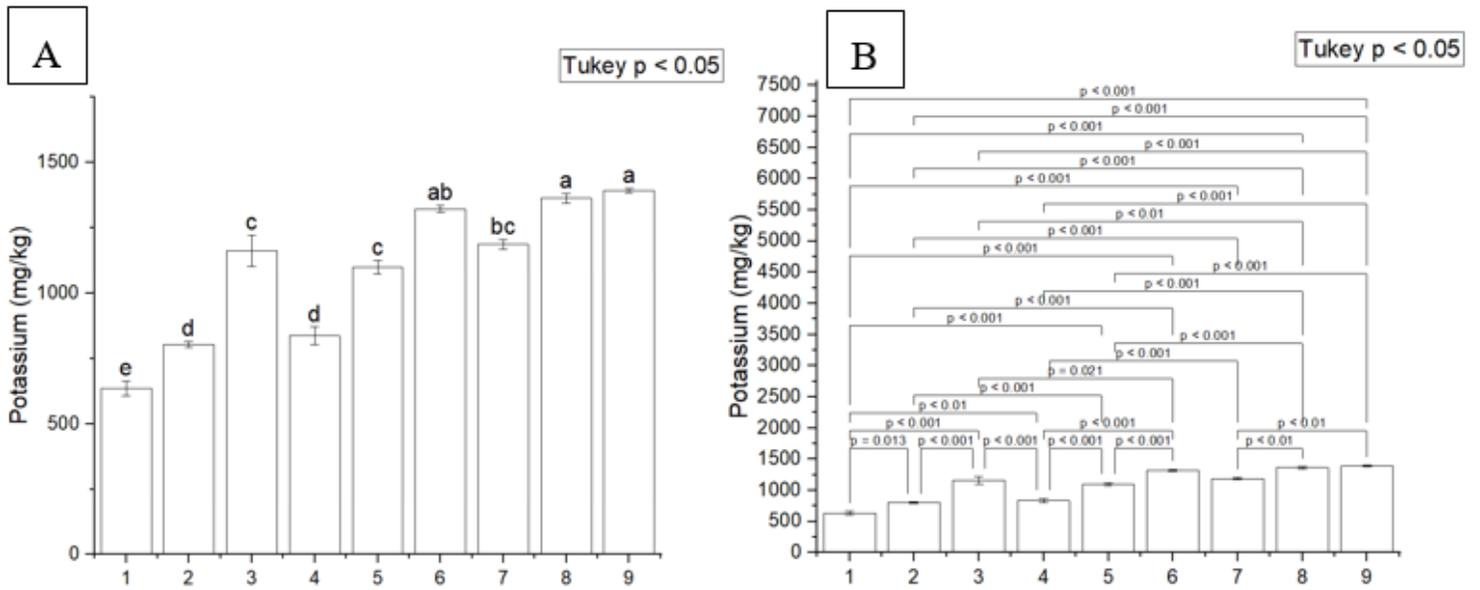


Figure 3

Effect of treatments on potassium concentration of mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in potassium concentration.

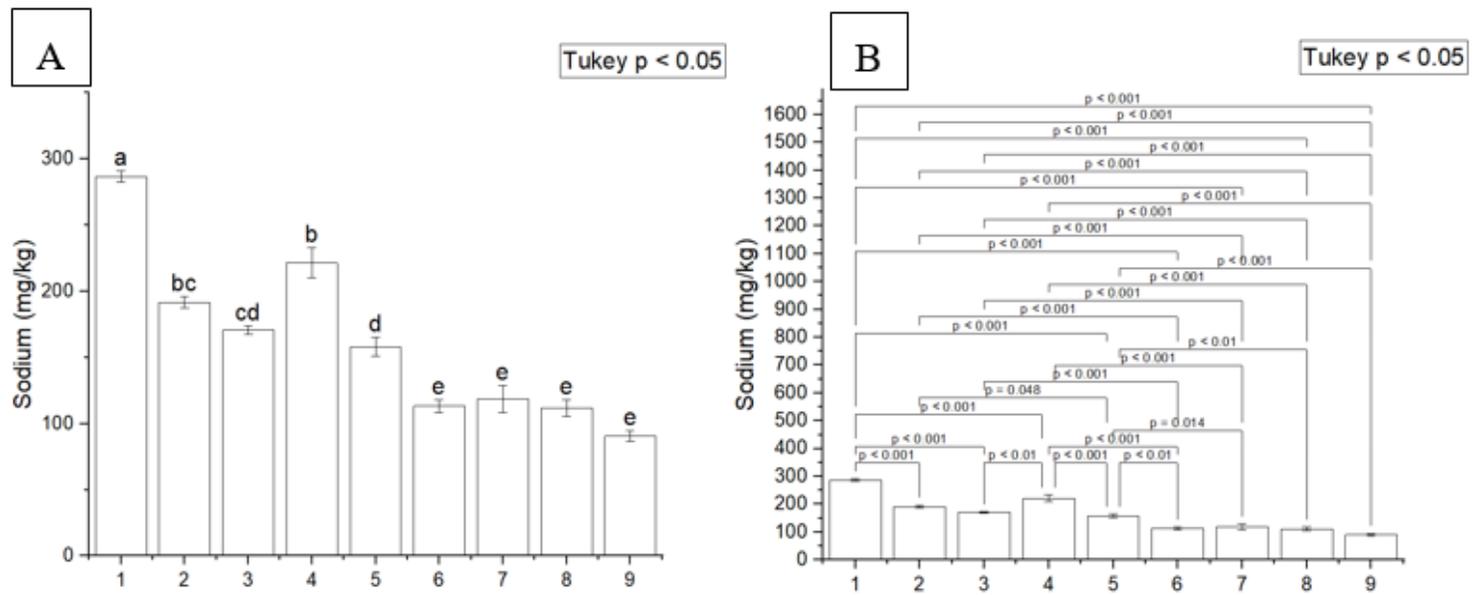


Figure 4

Effect of treatments on sodium concentration of mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in sodium concentration.

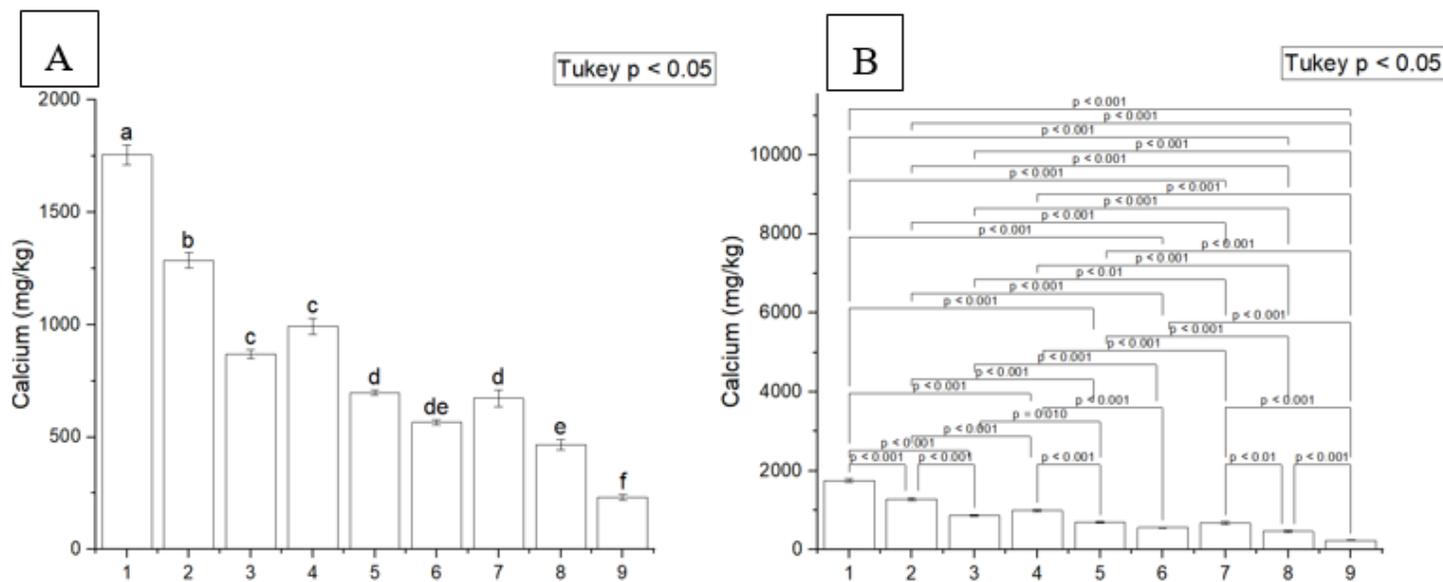


Figure 5

Effect of treatments on calcium concentration of mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in calcium concentration.

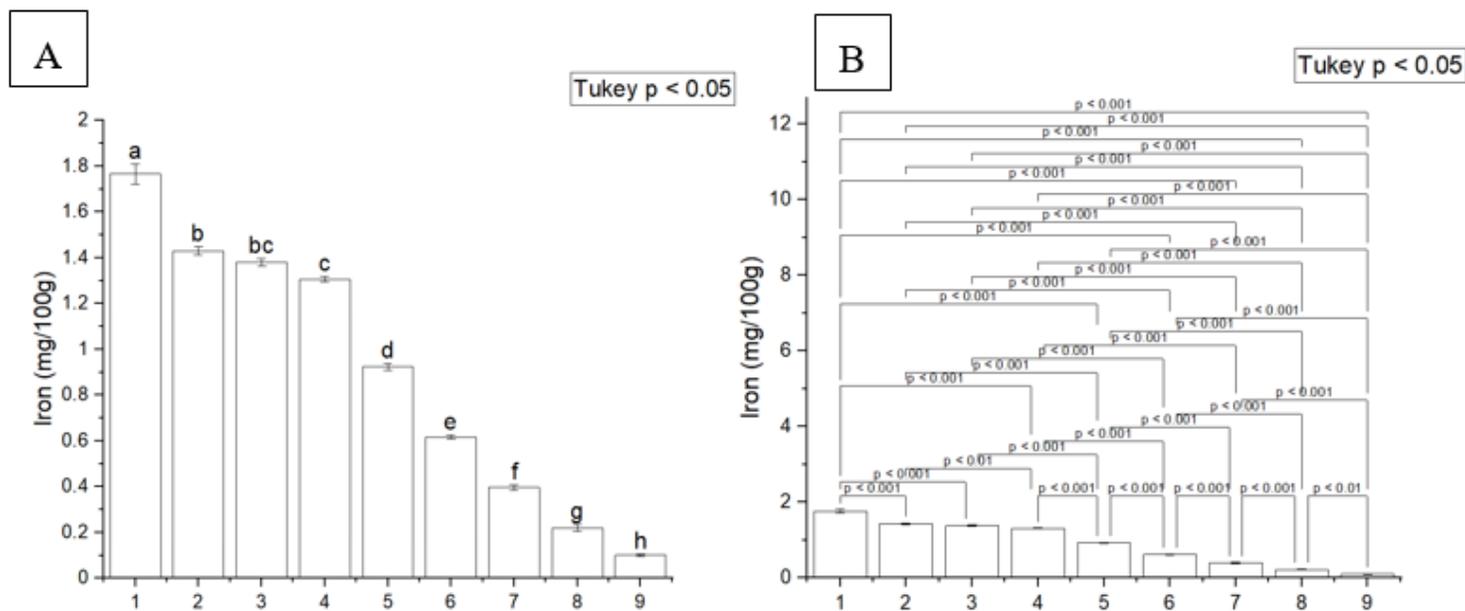


Figure 6

Effect of treatments on iron concentration of mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in iron concentration.

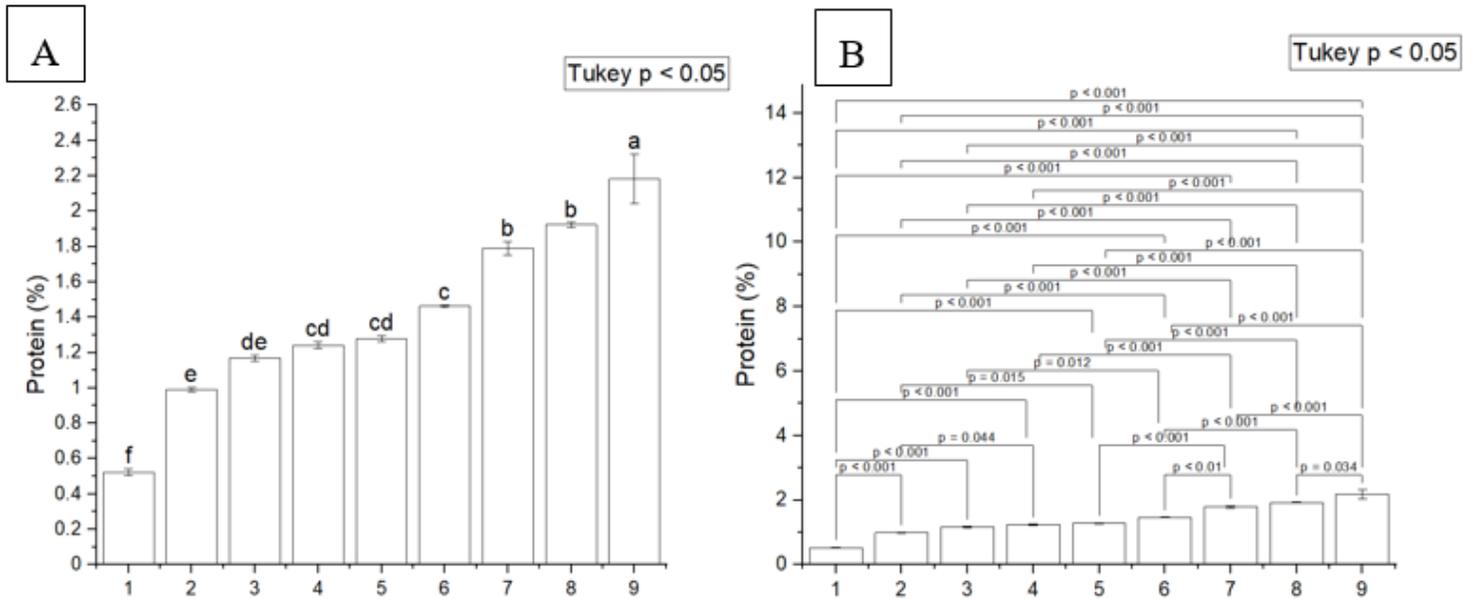


Figure 7

Effect of treatments on protein contents of mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in protein concentration.

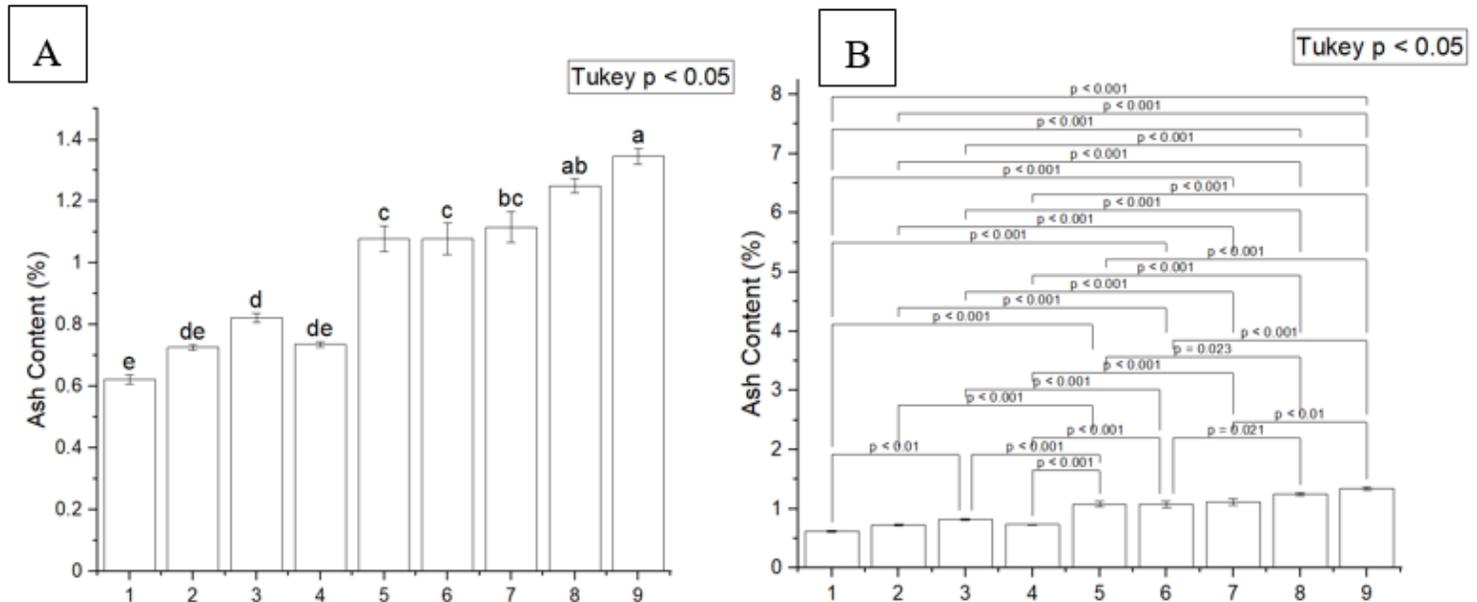


Figure 8

Effect of treatments on ash contents of mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in ash contents.

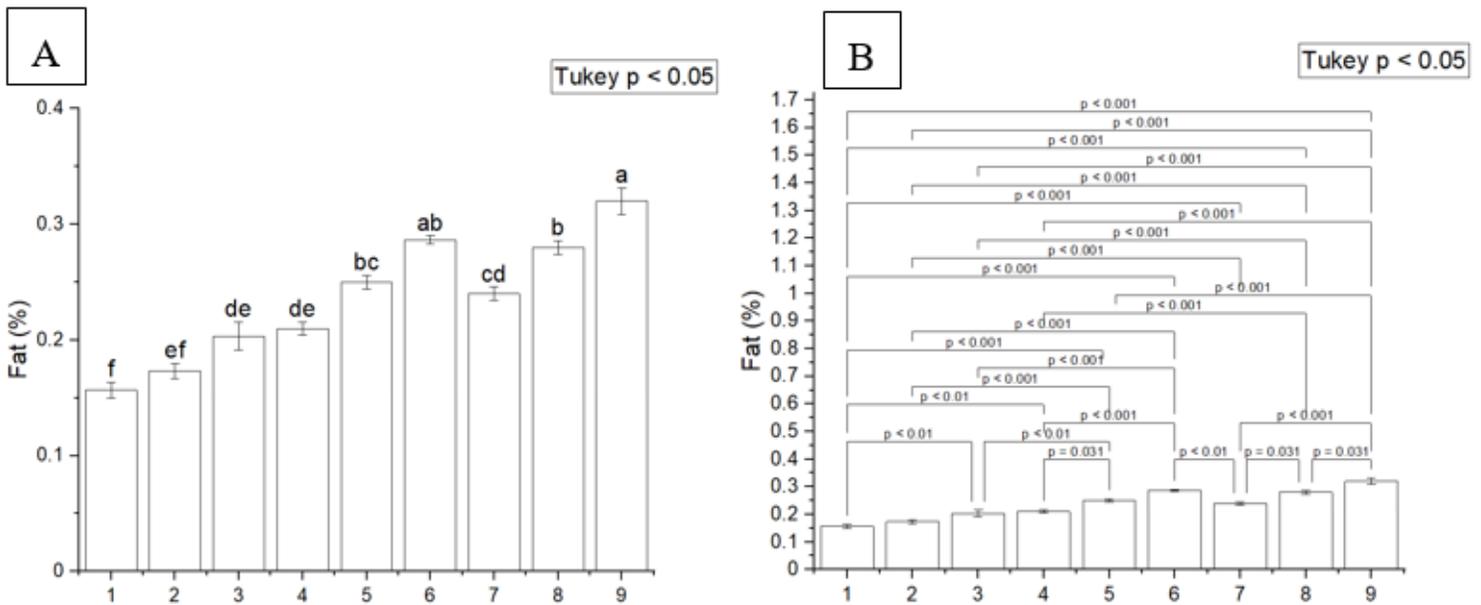


Figure 9

Effect of treatments on fats contents of mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in fat contents.

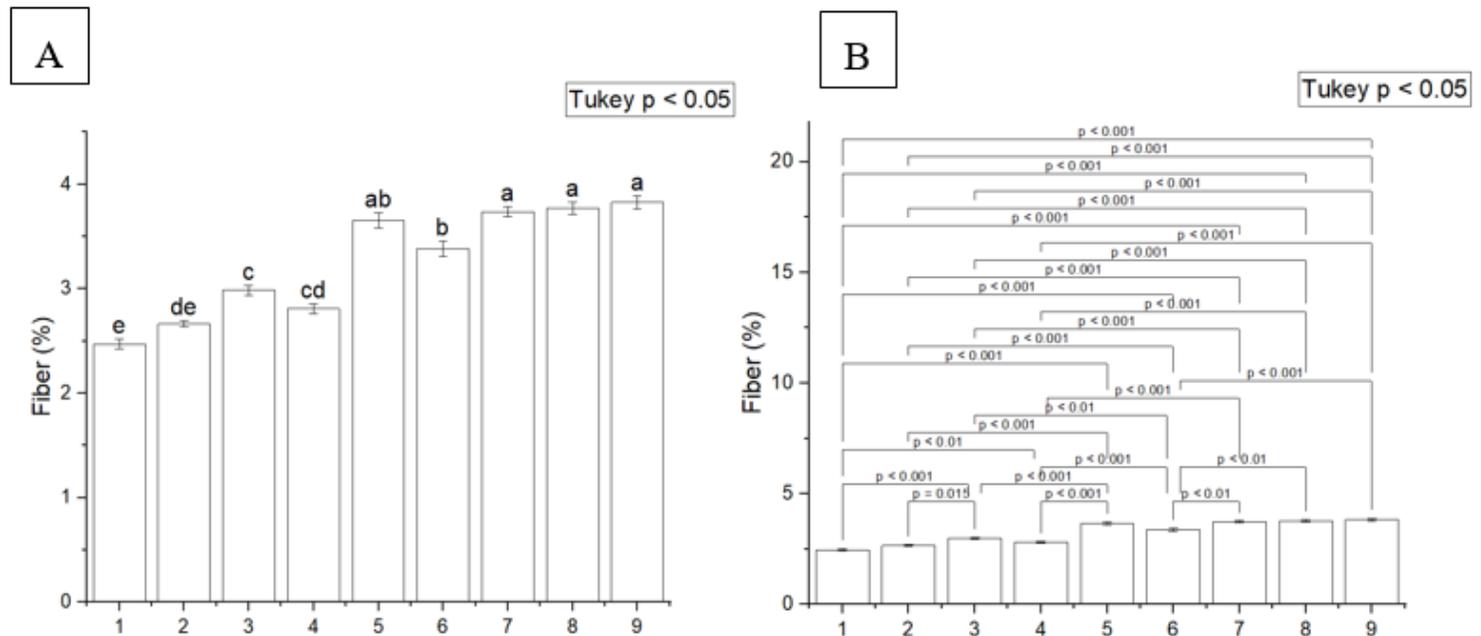


Figure 10

Effect of treatments on fiber contents of mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in nitrogen concentration.

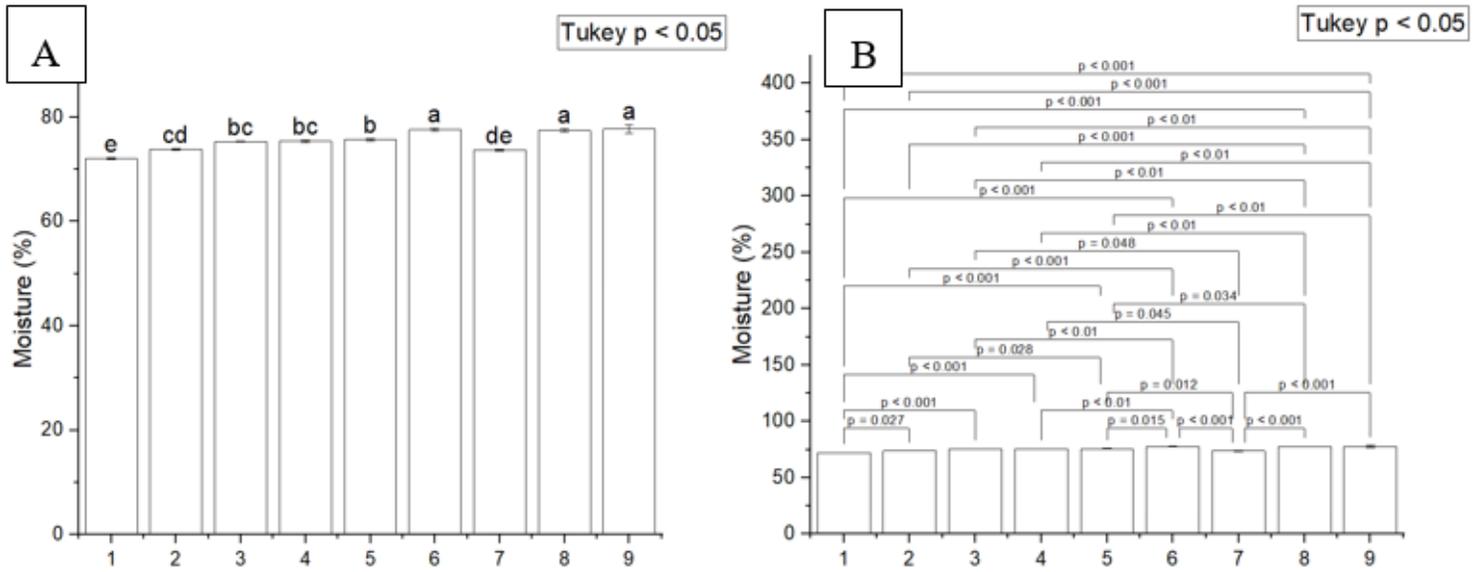


Figure 11

Effect of treatments on moisture contents of mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in moisture contents concentration.

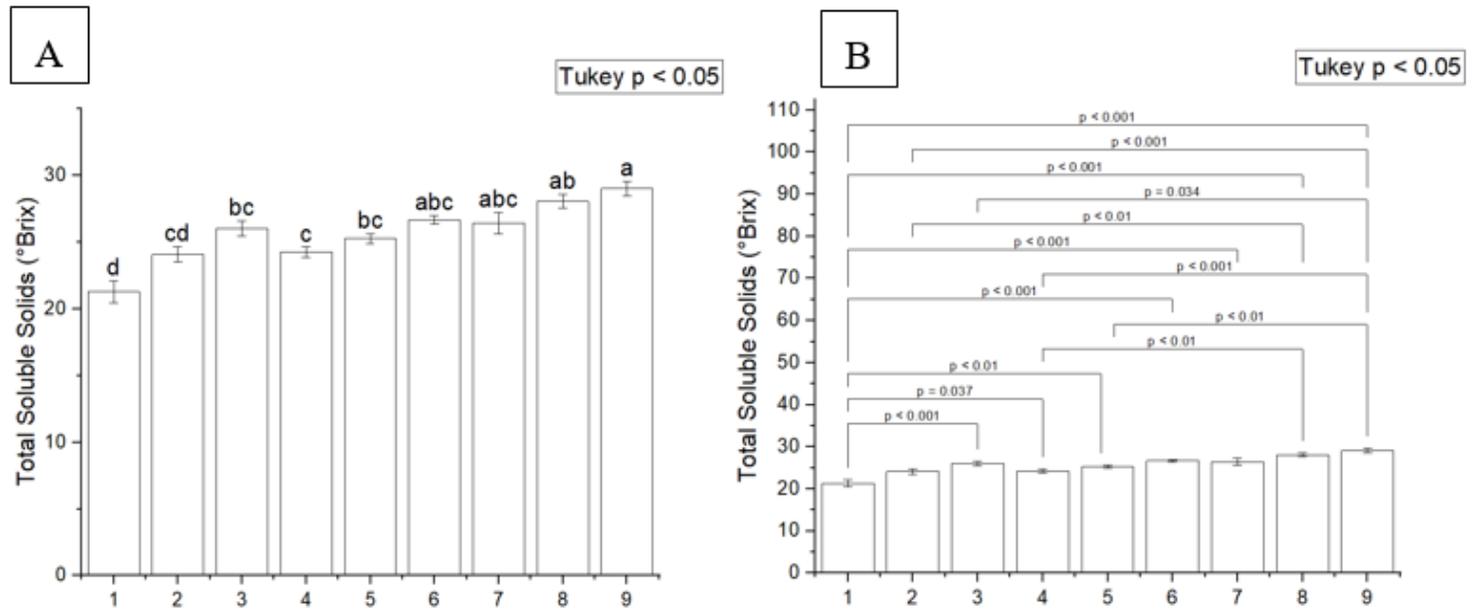


Figure 12

Effect of treatments on total soluble solids of mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in total soluble solids concentration.

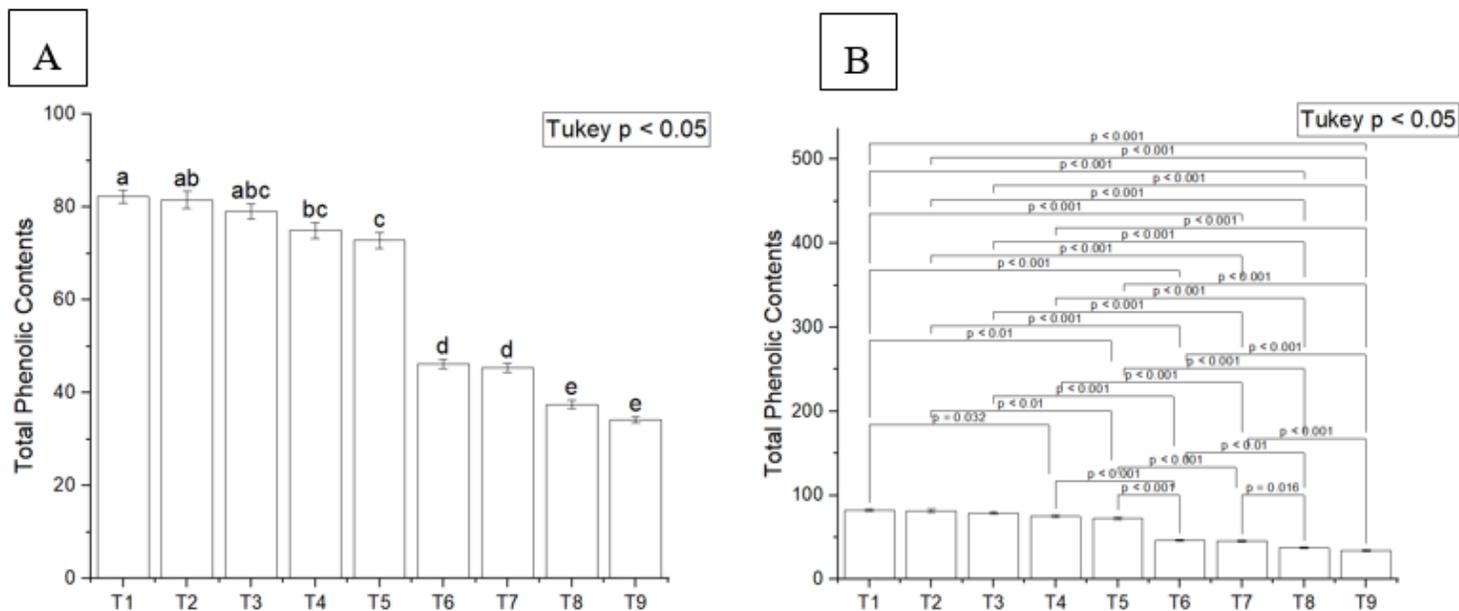


Figure 13

Effect of treatments on total phenolic contents of mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in total phenolic contents.

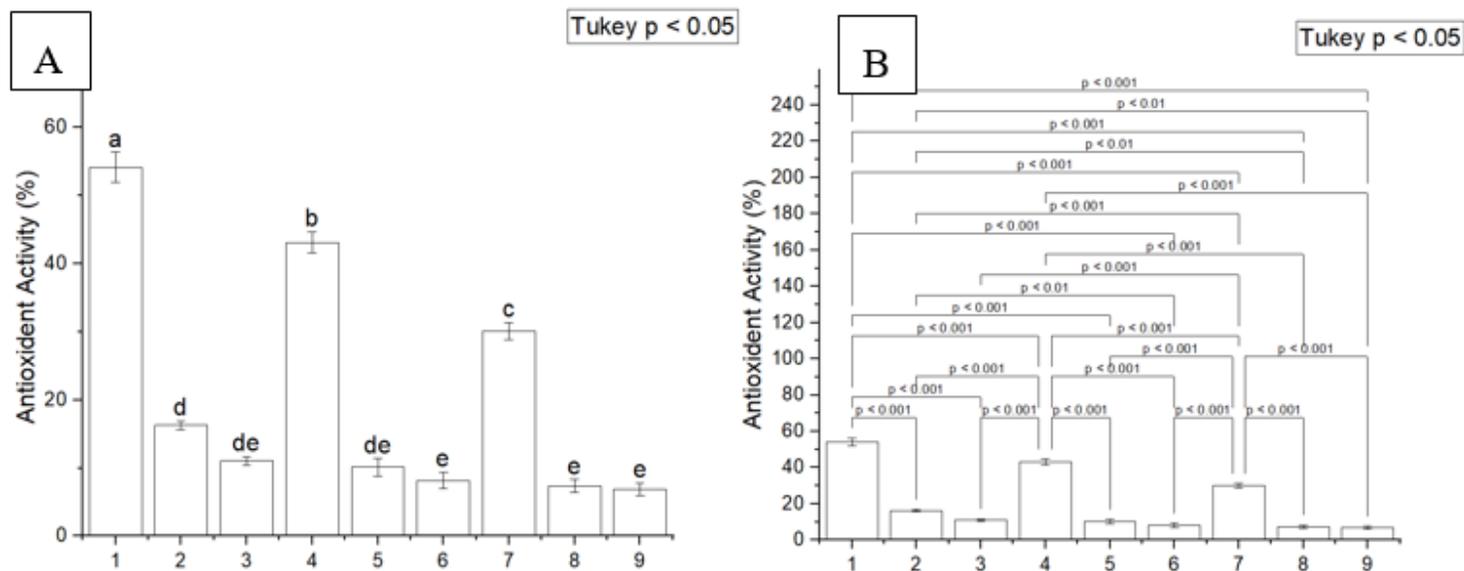


Figure 14

Effect of treatments on antioxidant activity in mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in antioxidant activity in concentration.

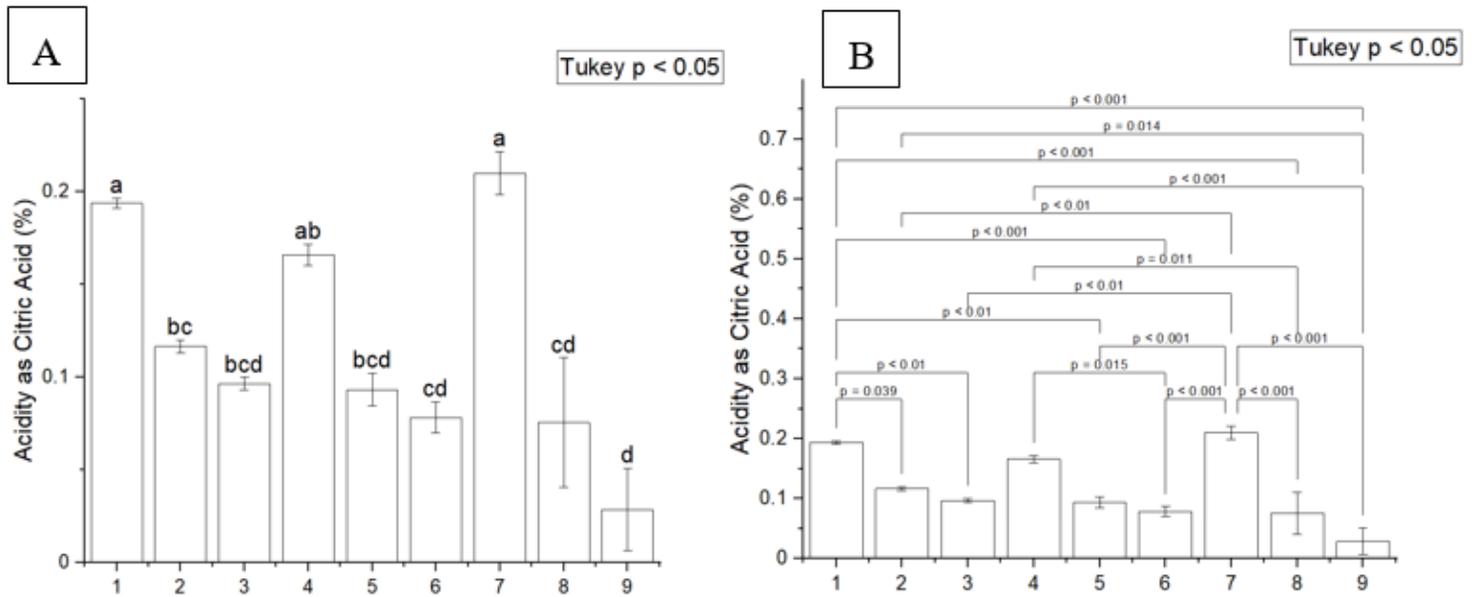


Figure 15

Effect of treatments on acidity as citric acid mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in acidity as citric acid concentration.

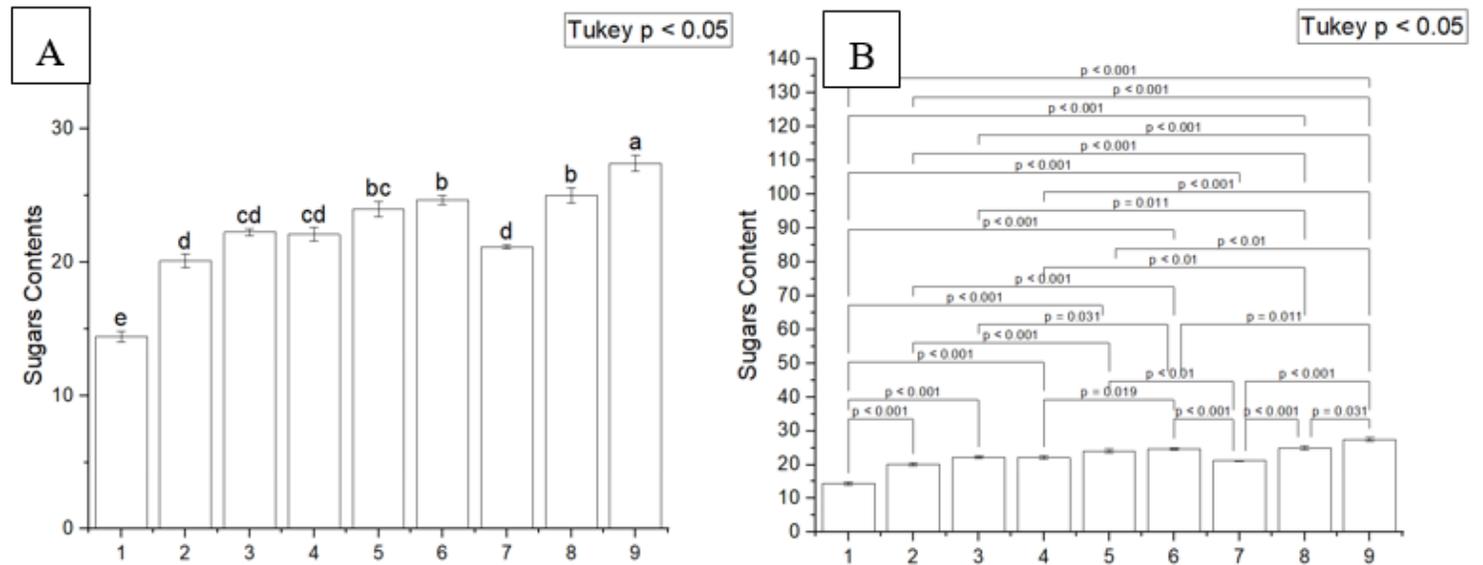


Figure 16

Effect of treatments on sugar contents of mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in sugar contents.

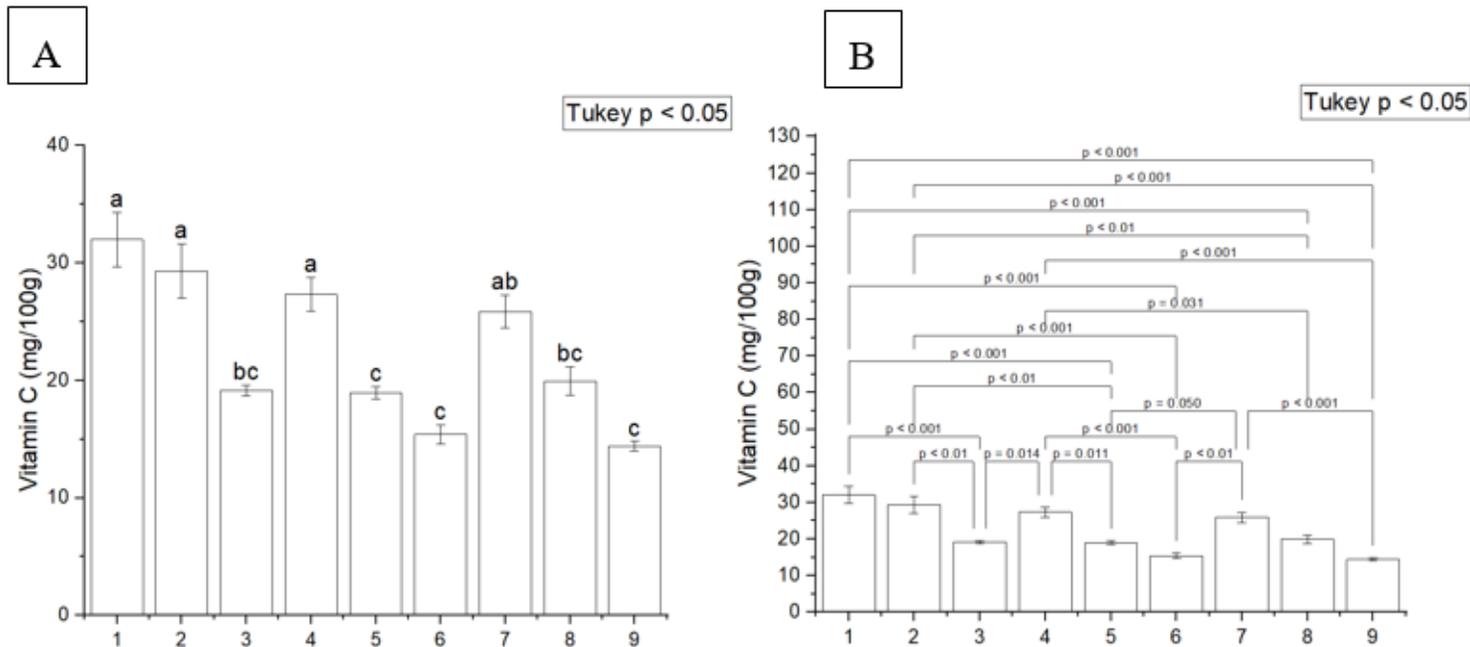


Figure 17

Effect of treatments on vitamin C of mango. Different letters on bars indicated significant difference (Tukey test; $p < 0.05$) Tukey test. P values for each applied treatment are provided graph B for comparison of changes in vitamin C concentration.

* $p \leq 0.05$ ** $p \leq 0.01$ *** $p \leq 0.001$

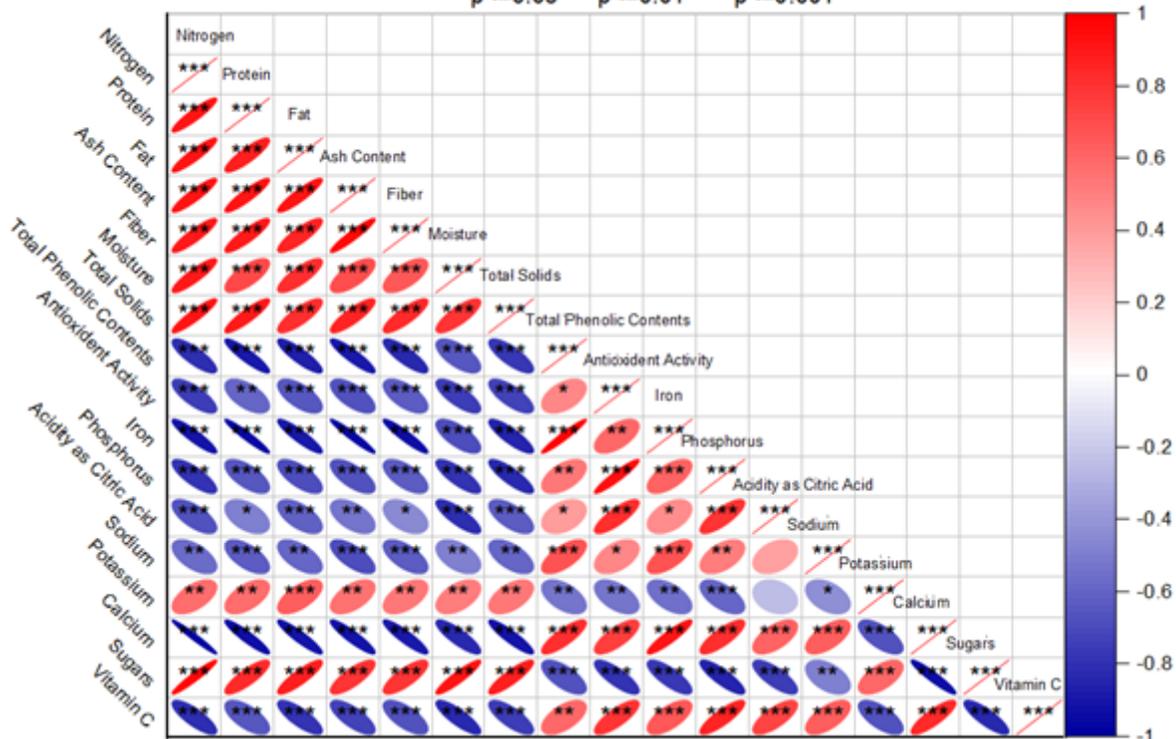


Figure 18

Pearson correlation of different mango quality attributes and nutrients contents.

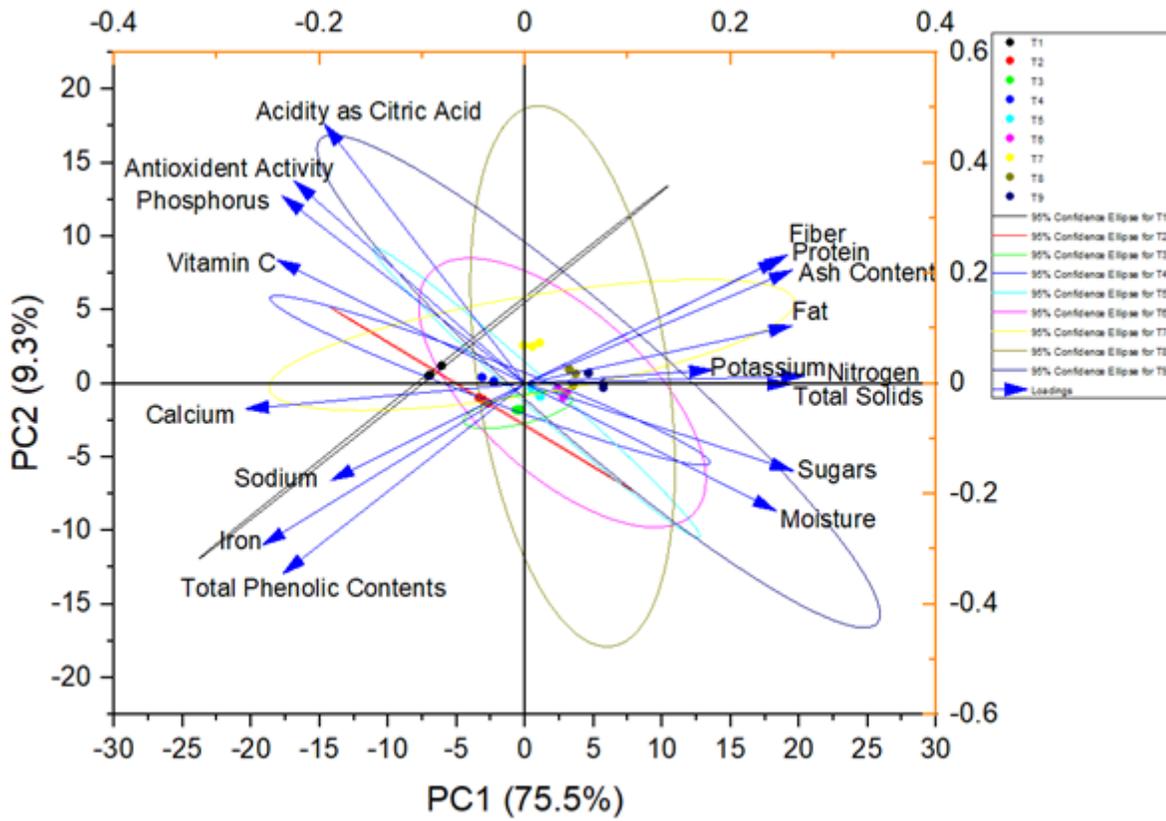


Figure 19

Principle component analyses of different mango quality attributes and nutrients contents.