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Relationship of leaf nutrient concentrations on fruit yield and quality of apple

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Abstract
To evaluate the impact of leaf nutrient content on the fruit yield and quality parameters of the "Gala Redlum" apple cultivar, a study was conducted at SKUAST-K during 2020 under laboratory conditions. For leaf nutrient content the assessed parameters were nitrogen (N), phosphorus (P), potassium (K), Calcium (Ca), Magnesium (Mg), iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn) and Boron(B) and the quality parameters included fruit length, diameter, weight, volume, total soluble solids, total sugar and yield. The results demonstrated that among the leaf nutrients the N, P and K content in the leaves showed a significant and positive correlation with fruit length, diameter, weight, volume, total soluble solids, total sugar and yield, while as Ca depicted a significant and positive correlation only with fruit firmness and Mg with total sugar. Additionally, Zn, Cu, Fe, Mn and B levels in the leaves were significantly and positively co-related to fruit length, diameter, volume, weight, total sugars, total soluble solids and yield. Therefore this study highlights that nutrient levels in leaves considerably influence the yield and quality characteristics of apple.

Keywords: Correlation, leaf nutrient, fruit yield, fruit quality, apple

Introduction
Growth and yield of fruit crops are influenced by several factors, with plant nutrition being the most critical. To achieve maximum production of high-quality fruits, determining the nutritional requirements is a vital aspect of nutrient management. Maintaining proper nutrient balance in apple trees is important as the imbalances may cause deficiencies, toxicities or interruption of one nutrient in absorption by other nutrients. This may cause stress ensuing in reduction of yield, quality and storage life of apples.

Deciduous crops like apple show seasonal changes in the mineral composition of the leaves and fruits that can have important implications in relation to the diagnosis of nutrient disorders, the post-harvest storage of the fruit and in the timing of fertilizer additions (Smith *et al*., 1987) [2]. Tissue mineral analysis is the best diagnostic tool for determining nutritional status of plants and represents an efficient guide for fertilization (Chatzissavvidis *et al*., 2005) [1].

Determining nutrient concentration has received particular attention, as it provides information on fruit quality based on known adequate and critical nutrient levels in leaves (Marcelle, 1984; Suzuki and Argenta, 1994; Ernani *et al*., 2002; Nachtigall and Dechen, 2006) [8, 13, 6, 7]. Robinson, 1980, suggests that tissue analysis of perennial fruit trees is a reliable method to assess nutritional requirement of trees. Recent advancements in fruit crop nutrition have shown that leaf analysis is an excellent tool for diagnosing deficiencies and toxicities of various essential elements. Campeanu *et al.*, (2009) [5] emphasized the importance of considering the mineral nutrient status of leaves to achieve optimum yield and better quality of apple fruits as the concentration of various nutrient elements in leaves is directly related with the yield and quality of fruits. Due to their role in plant metabolism (Buchloh, 1974; Hansein and Ryugo, 1979; Nijjar, 1990; Mitra *et al.*, 1991) [4, 10, 11, 9].

For a specific nutrient, there is a relationship between its concentration in the leaves with the quality attributes of the fruits. This relationship serves as a guide to achieve maximum productivity of high-quality fruits. Awasthi *et al.*, (1998) [14] identified a direct correlation between leaf nutrient levels with the yield and quality of apples.

The nutrient concentration in leaves appears to result from the interaction between genetic factors and the environment in which the plant grows, significantly impacting fruit growth, yield, and quality. Sanchez-Alonso and Lachica (1987) [32] noted that certain soil characteristics could alter nutrient concentrations in cherry leaves. Chaplin and Westwood (1980) [15] and Ystaas (1990) [16] found significant differences in leaf content for nitrogen, phosphorus, potassium, calcium, magnesium, zinc, copper, manganese and iron, attributing these variations to differences in root system structure or between rootstock and scion. This research aims to explore the relationship between leaf nutrient content and the yield and quality attributes of apple in Kashmir valley.

Materials and Methods

To conduct this study, multiple trees of apple cultivar "Gala Redlum " were selected from the Experimental site of SKUAST-K. The trees chosen were of uniform age (5 years), vigor and growth and the following parameters were recorded:

Leaf nutrient content: The leaf nutrients calculated were nitrogen, phosphorus, potassium, calcium, magnesium zinc, copper, iron, manganese and boron. Leaf samples were collected from each tree following Chapman's (1964) procedure. The samples were washed, dried, grind and digested for analysis. N, P, K, Ca and Mg were analyzed using standard procedures outlined by Jackson (1973) while Zn, Cu, Fe, Mn and B concentrations were estimated using an atomic absorption spectro-photometer.

Fruit quality parameters: The fruit quality parameters assessed were length, diameter, weight, volume, TSS, total sugars, reducing sugars, non-reducing sugars and yield. The samples were collected followed by Waller (1980) procedure. After collection of fruit samples, they were washed and dried for analysis of physical and chemical parameters. Fruit length and diameter were measured with a digital vernier caliper and fruit weight was recorded using a weighing balance. Fruit volume was determined by the water displacement method. Fruit firmness and total soluble solids (TSS) were measured using a penetrometer and hand refractometer respectively. Fruit yield was recorded per tree and total sugar content was determined following the procedure outlined by A.O.A.C (1990) [28]. Correlation coefficients (r-values) were calculated according to the procedure described by Gomez and Gomez (1984) [30].

Results

The results obtained from this study revealed that the content of leaf nitrogen, phosphorus and potassium ranged from 1.943-1.971%, 0.172-0.197% and 1.417-1.491% with average values of 1.957%, 0.185% and 1.454%, respectively. Calcium and magnesium concentrations in the leaves were between 1.537 to 1.573% and 0.243 to 0.277%, with mean values of 1.555% and 0.260% respectively. The zinc, copper, iron, manganese and boron content in the leaves varied from 88.473 to 89.112 ppm, 26.855 to 21.878 ppm, 13.558 to 13.651 ppm, 103.942 to 104.113 ppm and 47.112 to 49.162 ppm, with average values of 88.793 ppm, 24.367 ppm, 13.605 ppm, 14.028 ppm and 48.142 ppm respectively (Table 1). All nutrient concentrations analyzed were optimal in the orchard respectively. The fruit length and diameter ranged from 53.24-57.79 mm and 64.45-67.15 mm respectively. The weight and volume of the apples ranged from 154.24-155.33 g and 141.12-143.23 cm³. Total soluble solids (TSS) were between 14.45-14.61^{0}Brix. Total sugar content, reducing sugars and non-reducing sugars in apple fruit ranged from 10.46-10.53%, 8.35-8.42% and 2.11-2.19%. The yield of trees ranged from 17.81-18.83 kg per tree in the orchard (Table 2). Correlation study between leaf nutrient content with yield and quality parameters of Gala Redlum variety showed that the Nitrogen had a significant and positive correlation with fruit length (r=0.849), fruit breadth (r=0.931), fruit weight (r=0.942), fruit volume (r=0.931), soluble solids concentration (SSC) (r=0.851), total sugar (r=0.929), reducing sugar (r=0.895) and fruit yield (r=0.949). Leaf phosphorus content was significantly positively correlated with fruit length (r=0.599), fruit breadth (r=0.566), fruit weight (r=0.387), fruit volume (r=0.388), SSC (r=0.459), total sugar (r=0.411), reducing sugar (r=0.287), non-reducing sugar (r=0.225) and fruit yield (r=0.523). Potassium in the leaves also showed significant positive correlations with fruit length (r=0.425), fruit breadth (r=0.433), fruit weight (r=0.337), fruit volume (r=0.266), SSC (r=0.207), total sugar (r=0.283), reducing sugar (r=0.282), non-reducing sugar (r=0.218) and fruit yield (r=0.494). Calcium in the leaves was positively correlated with fruit length, fruit breadth, fruit weight, fruit volume, SSC and total sugar though these were not significant. However, it was significantly correlated with fruit yield (r=0.521). Magnesium content in leaves was significantly correlated only with total sugar (r=0.502). Boron content showed significant positive correlations with fruit length (r=0.863), fruit breadth (r=0.943), fruit weight (r=0.958), fruit volume (r=0.955), SSC (r=0.884), total sugar (r=0.951), reducing sugar (r=0.922), non-reducing sugar (r=0.958) and fruit yield (r=0.964). Zinc content in leaves was significantly positively correlated with fruit length (r=0.870), fruit breadth (r=0.919), fruit weight (r=0.931), fruit volume (r=0.940), SSC (r=0.861), total sugar (r=0.928), reducing sugar (r=0.900), non-reducing sugar (r=0.941) and fruit yield (r=0.943). Copper content in leaves was significantly positively correlated with fruit length (r=0.841), fruit breadth (r=0.938), fruit weight (r=0.941), fruit volume (r=0.929), SSC (r=0.856), total sugar (r=0.931), reducing sugar (r=0.894), non-reducing sugar (r=0.919) and fruit yield (r=0.973). Iron content in leaves showed significant positive correlations with fruit length (r=0.869), fruit breadth (r=0.937), fruit weight (r=0.964), fruit volume (r=0.963), SSC (r=0.895), total sugar (r=0.953), reducing sugar (r=0.925), non-reducing sugar (r=0.968) and fruit yield (r=0.956). Manganese content in leaves was positively and significantly correlated with fruit length (r=0.859), fruit breadth (r=0.945), fruit weight (r=0.958), fruit volume (r=0.946), SSC (r=0.842), total sugar (r=0.925), reducing sugar (r=-0.977), non-reducing sugar (r=0.934) and fruit yield (r=0.977).

Table 1: Concentration of leaf nutrients in apple cv. Gala Redlum

Nutrient	Unit	Range	Mean*	SD
Nitrogen	%	1.943-1.971	1.957	0.020
Phosphorus	%	0.172-0.197	0.185	0.018
Potassium	%	1.417-1.491	1.454	0.052
Calcium	%	1.537-1.573	1.555	0.025
Magnesium	%	0.243-0.277	0.260	0.024
Iron	ppm	88.473-89.112	88.798	0.452
Zinc	ppm	26.855-21.878	24.367	3.519
Copper	ppm	13.558-13.651	13.605	0.066
Manganese	ppm	103.942-104.113	104.028	0.121
Boron	ppm	47.122-49.162	48.142	1.442

*Mean of 17 samples

Table 2: Quality parameters and yield of apple trees cv. Gala Redlum

Parameters	Unit	Range	Mean*	SD
Length	mm	53.24-57.79	55.52	3.22
Diameter	mm	64.45-67.15	65.8	1.91
Weight	g	154.24-155.33	154.79	0.77
Volume	cm^3	141.12-143.23	142.18	1.49
Total sugars	%	10.46-10.53	10.49	0.04
Reducing sugars	%	8.35-8.42	8.39	0.05
Non-reducing sugars	%	2.11-2.19	2.15	0.06
Total soluble solids	^{0} Brix	14.45-14.61	14.53	0.11
Yield	Kg/tree	17.81-18.83	18.32	0.72

*Mean of 17 samples

Discussion

Proper mineral nutrition positively influences the quality and yield of apples, with each essential element playing a crucial role in the plant's growth and development. There is a notable relationship between essential nutrients and the quality of fruit, serving as a guide for achieving maximum productivity of high-quality fruits. Our study revealed that leaf nitrogen significantly correlates with fruit length, diameter, volume, SSC, total sugar and yield at 5% significance level. This is likely due to its role in cell division and elongation; which enhances leaf area development, stimulates buds, initiates flowers and increases fruit set, thereby enhancing yield and quality. These findings align with those of Kumar and Chandel (2004), Fallahi *et al*. (2010) [31, 17] and Dar *et al*. (2012) [19]. Analysis of correlation matrix reveal significant and positive relation between leaf phosphorus content and fruit length, diameter, volume, SSC, total sugar and yield at 5% level of significance. This could be because it is an essential constituent of cell and its organelles. Similar findings were earlier reported by Kumar and Chandel (2004); and Kumar *et al.* (2015) [31, 24]. Phosphorus participates in certain essential metabolic processes by supplying energy, increasing acid neutralization, and sugar synthesis, results in fruits that are less acidic and more sugary (Kader, 2008). The leaf potassium also shows a significant positive correlation with fruit length, weight, SSC, total sugar, and yield. Th reason could be due to its role in enzyme activation, translocation of photosynthate for efficient utilization, enhancing cell division and meristematic tissue development. These findings are consistent with the results of Farooqui *et al*. (2004) and Kumar *et al*. (2015). Stino *et al*. (2011) also found that potassium directly influences fruit growth, maintains cell turgidity and equilibrium between acid and sugar content, enhances fruit ripening and eating quality. Leaf calcium significantly correlates with fruit length, diameter, weight, volume, and yield at the 5% significance level. This is because calcium plays central role in cell functioning and pectin formation thereby enhances fruit firmness (Dar *et al*., 2014; Kumar *et al*., 2015) [20]. High calcium levels in apples are linked to slower cellular structure degradation which in turn will enhance fruit quality attributes and the shelf life of apple fruits. Magnesium content shows a positive correlation with fruit quality and yield. This may be because this element plays essential role in chlorophyll synthesis and various physiological and biochemical processes. Cakmak and Kirkby, 2008 reported it is an essential element for plant growth and development. Micronutrient cations such as boron, zinc, copper, iron, and manganese shows significant positive correlations with fruit parameters;fruit length, diameter, weight, volume, SSC, total sugar and yield whereas manganese revealed significant and positive relation with fruit length, diameter, weight, volume, SSC, total sugar and yield at 5% level of significance. This is likely due to their involvement in plant physiological processes, essential for enzyme activation; involved in respiration, nitrogen fixation, protein synthesis, carbohydrate synthesis and synthesis of chlorophyll (Mansour *et al.*, 2008 and Fallahi *et al.*, 2010) [17]. This is also supported by Bandy (2015) and Singh *et al. (*2005). The leaf boron exhibited significant and positive correlation with fruit length, diameter and yield indicates its role in cell division and activation; of several enzymes and as constituent of many amino acids These findings are supported by Bandy (2015) and Singh *et al*. (2005). Zn is an essential component of numerous enzymes, aids in the synthesis of the growth hormone auxin, which directly impacts fruit quality (Shivanandam, 2007; Dar, 2014) [26]. Copper also showed positive relationship. This may be due to its involvement in photosynthetic and respiratory electron transport chains and acts as a co-factor in many metabolic enzymes, including ATP synthesis (Harrison, 1999) [23].

Table 3: Correlation of leaf nutrient content with yield and quality attributes of apple cv. Gala Redlum

Leaf nutrient Yield Attributes and quality	N	P	K	Ca	Mg	B	Zn	Cu	Fe	Mn
Fruit length	0.849**	0.599**	0.425**	0.307	0.473	0.863**	0.875**	0.845**	0.869*	0.859**
Fruit breadth	0.931**	0.566**	0.443*	0.399	0.456	0.943**	0.924**	0.943**	0.937*	0.945**
Fruit weight	0.942*	0.387**	0.337*	0.321	0.379	0.958**	0.936*	0.942**	0.964**	0.958*
Fruit volume	0.931*	0.388**	0.266**	0.319	0.373	0.955**	0.938*	0.935*	0.963*	0.946*
SSC	0.851*	0.459*	0.207**	0.109	0.241	0.884*	0.869**	0.859*	0.895**	0.842*
Total sugar	0.929*	0.411*	0.283**	0.234	0.502**	0.951**	0.933*	0.934*	0.953**	0.925*
Reducing sugar	0.895*	0.287*	0.282**	0.206	0.307	0.922*	0.900*	0.899*	0.925*	0.878*
Non-reducing sugar	0.928*	0.225*	0.218*	0.259	0.308	0.958*	0.947*	0.925*	0.968*	0.934*
Fruit yield	0.949**	0.523**	0.494**	0.521**	0.385	0.964**	0.946**	0.977	0.956**	0.977**

**Significant at 5% level

Conclusion

In conclusion, the comprehensive analysis of leaf nutrient content and its correlation with apple fruit quality and yield underscores the critical role of mineral nutrition in orchard management. Nitrogen, phosphorus, potassium, calcium, magnesium, and micronutrients like boron, zinc, copper, iron, and manganese exhibited significant positive correlations with various fruit parameters, highlighting their essential roles in enhancing fruit size, sugar content, and overall yield. These findings emphasize the importance of balanced nutrient management strategies for optimizing apple production and ensuring high-quality fruit, aligning with previous research in the field. Effective nutrient management practices are pivotal in achieving sustainable orchard productivity and meeting market demands for premium apples.

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