

A REVIEW OF EFFECTS OF NUTRIENT ELEMENTS ON CROP QUALITY

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ABSTRACT

The problem of low soil fertility and poor plant nutrition does not only affect crop yields but also crop quality. A review of many refereed published journal articles and books sourced from internet and libraries was conducted with the aim of highlighting the effects of plant nutrition on crop quality. Emphasis was put on elucidating the functions through which various nutrient elements influence biochemical processes and eventually affect the overall quality of various crops and their products. Nutrients reviewed in this paper included elements such as nitrogen (N), phosphorus (P), potassium (K), sulphur (S), magnesium (Mg), calcium (Ca), zinc (Zn), iron (Fe), and cobalt (Co). The crop quality characteristics mostly reported to be affected by plant nutrition include: proteins, carbohydrate, sucrose and fructose content in grains, root crops, tuber crops and fruits; vitamins like beta-carotene content in fruits and tubers; moisture content at storage in cereal grains, potato tuber density; and frying colours, and fruit weight. It has been noted that essential and beneficial nutrient elements contribute to crop quality through functioning as raw materials for the synthesis of various plant components that have food value to humans and animals. Nitrogen and S are raw materials for protein synthesis. Others like Ca, P, Zn and Fe are involved in enzyme synthesis, activation or as electron carriers while Mg, and K are mostly involved in enzyme activation and transportation of materials such as fructose and sucrose from points of synthesis to sites of loading and hence affect quality of fruits, and root and tuber crops greatly. It has been noted that crop quality is also greatly influenced by the synergistic and antagonistic interactions in various nutrients uptake and utilization. Therefore, balanced nutrition is noted to be of paramount importance. From this review it can be concluded that crop quality is a very important area to consider advancing and putting up resources for research since it has a huge bearing on human health and socioeconomic effect on farmers through its influence on marketability of crops and crop products.

Key words: crop quality, essential elements, nutrition

INTRODUCTION

Plant growth is influenced by a number of factors including temperature, available water, light and available nutrients in the soil. A German scientist Justus von Liebig in the mid 19th century was one of the first scientists to show that nutrients are essential for plant growth [1]. Studies show that there are over 100 chemical elements but research has determined 17 nutrients that are also called essential elements [2, 3]. It is reported that for an element to be classified as essential, it must meet the following criteria: it must be needed by a plant to complete its life cycle; its function cannot be replaced by another element; it is directly involved in plant growth and reproduction; and it must be needed by most plants [2, 4].

Out of the 17 essential elements carbon (C), hydrogen (H) and oxygen (O) are the non-mineral nutrients because they are derived from the air and water [2]. The remaining 14 mineral nutrients include six macronutrients: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulphur (S); and eight micronutrients: boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni) and zinc (Zn) [1, 5]. Other nutrients that do not fall within the list of 17 essential elements but are needed in specific cases are referred to as beneficial elements [2]. Each of the nutrients is needed in different amounts and carries specific functions in the plant. Depending on the amount that is available for plant uptake, these nutrients influence crop yields and quality [6]. Some crop quality attributes influenced by the nutrients include; sugar and protein content, seed size, kernel size, fruit colour, flavour, vitamin levels and grain hardness [7]. Nutrients obtained from crops and crop products, for example nitrogen, sulphur, and phosphorus, are constituents of various types of proteins and protein enzymes, which are important for building plant tissues and activating various metabolic processes respectively [8]. Despite the many functions of the nutrient elements, in many countries especially in sub-Saharan Africa, there is concern about a low and an unbalanced use of fertilizers [9].

The objective of this review is to critically discuss the effects of some nutrients (N, P, K, Ca, Mg, S, Zn, Fe, Mo, Co and Se) on crop quality. This paper covers discussions on nutrients in relation to their effects on crop quality. An effort was made to highlight important synergistic interactions where effects of two or more nutrients are involved to bring out an effect on crop quality.

Nitrogen

Plants require N in the largest amount among the three major/primary nutrients (others being P and K). It has many functions including: promotion of rapid growth, increasing leaf sizes and quality, enhancing fruit and seed development; forms an integral component of many important components in plants including amino acids that are building blocks of proteins and enzymes, that are involved in catalyzing most biochemical processes [5, 4]. Thus, it plays a role in almost all metabolic processes. As determined by its functions N influences the rate of crop growth and crop quality. It increases the plumpness of the cereal grains, the protein content of both seeds and foliage, and the succulence of crops such as lettuce and radish [4]. Increased protein

content and physical grain quality in maize and rice with increasing N application has been reported in a good number of studies [6, 7]. A study on the effect of N rates on maize grain quality in Iran, showed highest crude protein content (8%) at the higher N rate of 200 kg ha⁻¹ as compared to lower rates (50, 100, 150 kg N ha⁻¹) [9]. It should be noted that the effects obtained may be affected by a number of factors including soil type and N sources such as inorganic or organic nutrient sources. Further crop quality improvements due to nitrogen are summarized in Table 1 [10].

However, oversupplying of nitrogen can also reduce crop quality. Amount of N applied has been reported to influence potato (*Solanum tuberosum*) tuber quality [11]. Potato processing quality factors include tuber solids and tuber density (tuber specific gravity) [11]. Significant decreases in potato tuber specific gravity from 1.097 with zero N, to 1.090 with 135 kg N ha⁻¹, to 1.086 with 200 kg N ha⁻¹ application (with increasing N rates) were reported from a study done in Oregon State, USA [11]. Lower tuber specific gravity and high amount of reducing sugars such as fructose are considered as indicators of low quality [12].

Oversupplying of N especially with higher NH₄-N: NO₃-N ratios, is reported to reduce calcium uptake [13]. On the other hand, calcium is needed for synthesis of strong cell walls [14]. A quadratic relationship in Ca uptake with increase in N amount applied was reported from a study on N nutrition in pepper (*Piper nigrum* L.) in Israel in which a decrease of 50% for Ca uptake was noted from the peak (at 7.0 mmol L⁻¹ N) to the highest application of 15 mmol L⁻¹ N [13]. Increasing available N or N application has also been reported to reduce oil content in some legumes such as soybean (*Glycine max* (L.) Merr.) and groundnuts (*Arachis hypogea*, L.) [7]

Phosphorus

Phosphorus is a very important macronutrient involved in most growth processes. It is an essential component of most organic compounds in the plant including nucleic acids, proteins, phospholipids, sugar phosphates, enzymes and energy-rich phosphate compounds, a common example being adenosine triphosphate (ATP) [5, 15]. Research has determined that P improves crop quality in a number of ways including: reduced grain moisture content, winter hardiness, increased sugar content, increased protein content, increased P content, increasing proportion of marketable yields, better feed value, and improved drought and disease resistance in crops such as wheat and maize [6, 16]. An 8% increase in cowpea crude protein with 37.5kg P ha⁻¹ application compared with a control (without P application) was reported from a study done in Northern Guinea Savanna of Nigeria [17].

As noted under nitrogen discussion, most nutrients produce the best effects under balanced nutrition. A 25% maximum protein content was reported from a plot fertilized at a combination of 50-75 kg NP ha⁻¹ as compared to other combinations of N (0, 25 and 50 kg ha⁻¹) and P (0, 50, 75 and 100 kg ha⁻¹) in Pakistan [18]. Synergistic effect is one of the factors that increases crop quality as far as N and P application are concerned. Application of 40 Kg P ha⁻¹ increased N and K accumulation in the maize grain by 22.5% and 21.2% respectively [19].

Potassium

Potassium is an essential nutrient that is absorbed by plants in larger amounts than any other nutrient except N [20]. Unlike N, P and most other nutrients, K is not incorporated into structures of organic compounds; instead potassium remains in ionic form (K^+) in solution in the cell and acts as an activator of many cellular enzymes [6]. Therefore, it has many functions in plant nutrition and growth that influence both yield and quality of the crop. These include regulation of metabolic processes such as photosynthesis; activation of enzymes that metabolize carbohydrates for synthesis of amino acids and proteins; facilitation of cell division and growth by helping to move starches and sugars between plant parts. It is reported that among the many plant mineral nutrients potassium (K) stands out as a cation having the strongest influence on quality attributes that determine fruit marketability, consumer preference, and the concentration of critically important human-health associated phyto-nutrients or bioactive compounds (ascorbic acid and Beta carotene) [21, 22]. Table 2 presents the effect of K on reducing sugars and organoleptic rating in grapes. Some more examples where fruit quality increased due K application are presented in Table 3.

All the increase in quality as describe in this section can be attributed to the involvement of K in synthesis and movement of different products to their sinks [6]. A condensed review on the effect of K on fruits and vegetable quality had been published [23].

Sulphur

Sulphur is the most abundant element in the earth's crust [6]. It is absorbed by plants as Sulphates (SO_4^{2-}). It is required for synthesis of S containing amino acids cystine, cysteine and methionine which are building blocks of proteins and is an important constituent of vitamins and hormones [15]. It is responsible for the formation of the disulphide bond between cysteine residues that help to stabilize the tertiary structure of proteins [15]. It is also needed in the synthesis of coenzyme A and chlorophyll. The deficiency of S leads to accumulation of non-protein N such as NO_3^- and amine (NH_2) [6]. Sulphur deficiency has been reported to lead to accumulation of NO_3^- in vegetables which is dangerous as these lead to fatal conditions such as methemoglobinemia in infants and formation of cancer inducing nitrosamines [15]. Increased rice grain quality (N content) by S containing nitrogenous fertilizers, supernet (1.73% N) and ammonium sulphate nitrate (1.66% N) as compared to urea that produced 1.45% N was reported in India [24]. This could be attributed to the role of S in protein synthesis in which is used as an essential component of amino acids and also the balanced fertilization that lead to the general high performance of the crop including synthesis of all N containing compounds such as proteins, chlorophyll and nucleic acids.

An increase in glucosinolates, sulphur rich metabolites of the order Brassicales in the range of 25% to more than 50% with sulphur fertilization was also reported [25]. Glucosinolates are important in the defence of the plant against pests and pathogens. They are also important for humans as a flavour component, cancer prevention agent and crop bio-fumigants, making them a good quality characteristic in these plants. Evidence for glucosinolate catabolism has come from labeling studies [25]. Sulphur application has been reported to increase the quality characteristic such as pungent smell in onions [26, 27].

Calcium

Calcium is used in large amounts by plants second only to N and K [5]. It is a major component of the middle lamella (Ca-pectates) of the cell wall. It strengthens the cell walls, is involved in cell elongation and division, membrane permeability, and activation of several critical enzymes [5]. It is important in N metabolism and protein formation by enhancing NO_3^- uptake and it is also important in translocation of carbohydrates and other nutrients [6]. In accordance with its functions, calcium influences crop and food quality. Calcium is less mobile such that its influence on crop quality is easily noted with foliar application. Seven fold calcium foliar application also improved some fruit quality characteristics of 'Sinap Orlovskij' apple such as fruit calcium content (high quality) increased by 50-150mg/kg and decreased bitter pit incidence (poor quality) by two times as compared with the control in Lithuania [28].

Magnesium

Magnesium is another secondary nutrient element. It is important as a primary constituent of chlorophyll and as a structural component of ribosomes, it helps in their configuration for protein synthesis [6]. It is also required for maximum activity of almost all phosphorylating enzymes in carbohydrate metabolism. Adequate levels of Mg in USA reported increased quality and profits of potato due to improved potato specific gravity [29]. Increased specific gravity of potatoes can be attributed to increased carbohydrate synthesis and deposition from the leaves. Usually, the first things to be noticed due to influence of Mg are chlorophyll level, photosynthesis (photosynthetic CO_2 fixation), and protein synthesis, however, recently, distribution of carbohydrates among shoot and root organs have been reported as well [30]. These in turn affect quality of plant product depending on which part is used for food by humans or animals. A four-fold increase of sucrose in leaves of Mg-deficient sugar beets compared to the Mg-adequate sugar beet plants was reported and this affected quality of Mg-deficient sugar beets [31]. This was attributed to inhibition of sucrose/sugar distribution from leaves to root organs in the Mg-deficient plants.

Micronutrients

Micronutrient elements such as Zn, Fe, Bo, Mo, Cu, Mn, Cl and Ni are known to be essential for plant growth. Others such as selenium (Se) and Co, which are needed in specific cases are commonly referred to as beneficial elements. For instance, Co is required by bacteria that fix nitrogen in legumes. Zinc (Zn) and iron (Fe) are some of the most important micronutrient essential for plant growth [32, 33]. Zinc is a major metal component and activator of several enzymes involved in metabolic activities and biochemical pathways [34, 35]. It is a functional, structural or regulatory co-factor of a large number of enzymes [35]. It is required in a large number of enzymes and plays an essential role in DNA transcription [33]. Other functions of zinc include: catalyzing the process of oxidation in plant cell and is vital for the transformation of carbohydrates; and influencing the formation of chlorophyll and auxins, the growth promoting compounds [36]. On the other hand, Fe in a constituent of enzyme system which brings about oxidation-reduction reactions in the plant, it regulates respiration, photosynthesis, reduction of nitrates and sulphates [36]. These reactions are essential to plant development and reproduction. It should be noted that as the case with other plant

micronutrients Zn and Fe limit plant growth when they are present both in low concentrations and in excessive concentrations due to deficiency and toxicity respectively [37, 38]. Table 4 summarizes some positive effects of some micronutrients on various crop quality characteristics.

Balanced nutrition and nutrient interactions

As noted in the previous section, nutrient elements do not bring the effect in isolation but work together. As a balanced diet is required for a human body so is it required by the plant, and this has an implication on crop quality. For instance, the ratio of N:S is very critical for the synthesis of proteins. Research shows that most crops attain optimal protein synthesis with N:S ratio within 15:1 [39]. Nutrient interactions may be synergistic where a positive effect is enhanced by balanced application of the two nutrients as the case of N and S or antagonistic where an increase in one nutrient reduces uptake and function of the other and eventually reducing crop quality. For instance, the rate of Mg uptake can be depressed by Ca and vice versa [40]. This is attributed to the competitiveness of Ca with Mg whereby the root plasma membrane binding sites have the higher affinity to Ca than to Mg [41]. A decreased yield of marketable tomato fruits was reported when Ca: Mg ratio was less than one [42]. Plant uptake and utilization of Zn is reduced by the available or applied P [43, 44]. On the other hand increase in N fertilizer is reported to increase Zn uptake and utilization [44].

CONCLUSION

From this review, it can be concluded that all nutrient elements focused in this study (N, P, K, S, Ca, Mg, Fe, Zn) influence crop quality. This is manifested by changes or differences in quality attributes of different crops with different rates of nutrient elements applied or available to various crops. The common quality attributes that are influenced as reported by many authors include protein and carbohydrate content of the sink organs of plants, fruit colour, flavour and vitamin related attributes for example *Beta*-carotene, grain hardness and moisture content at storage of crops such as maize and wheat, potato tuber density and internal colour.

Undersupplying and oversupplying of nutrients may lead to reduced crop quality. This can result from the nutrient being a raw material for synthesis of a product but also from its involvement in enzymatic activities, for instance low N (as a raw material) will lead to reduced amount of proteins whereas low K will lead to reduced amount of proteins due to reduced activation of enzymes that metabolize carbohydrates for synthesis of amino acids and proteins. Too much $\text{NH}_4\text{-N}$ will suppress uptake of Ca and its functions. On the other hand, low levels of Mg and K will lead to reduced distribution of carbohydrates. It should be noted that nutrients do not work in isolation; therefore balanced nutrition is needed to optimize crop quality.

From this review, it can be noted that apart from crop yields, crop quality is another area that needs to be considered with serious attention as it affects human nutrition and profitability of crop products. It is recommended that research in soil fertility and plant nutrition take a multidisciplinary approach where soil scientists, breeders and human nutrition experts come face to face in planning a research agenda.

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Table 1: Reported quality characteristic improvements by nitrogen application in some crops

Crop	Quality characteristic	References
Wheat (<i>Triticum aestivum</i> L.)	Total protein content; gluten (protein that improves bread making quality)	[45]
Maize (<i>Zea mays</i> L.)	Kernel weight, grain protein and seed starch	[46,47]
Sweet potato (<i>Ipomea batatas</i> L.)	Crude protein ⁴	[48]
Potato (<i>Solanum tuberosum</i> L.)	Protein content, starch and total carbohydrate content	[49]
Rice (<i>Oryza sativa</i> L.)	Protein content	[50]
Mandarin orange (<i>Citrus reticulata</i> L.)	Fruit size and weight	[51]

Table 2: Effect of graded doses of potassium on reducing sugars and organoleptic rating in grapes

K ₂ O doses (g/vine)	Reducing sugars (%)		Organoleptic rating	
	1992	1993	1992	1993
0	9.07	9.15	6.72	6.68
100	10.05	9.80	7.16	7.09
200	10.35	10.27	7.36	7.90
300	11.25	10.24	7.78	7.78
400	11.32	11.15	8.01	8.01
500	11.82	12.00	8.12	8.13
LSD (p=0.05)	0.62	0.64	0.17	0.17
SEM±	1.039		0.548	

Source: Ganeshamurthy *et al.* [52]

Table 3: Some fruit quality characteristics influenced by K application

Crop	Quality characteristics	References
Muskmelon (Cucumis melo L.)	Ascorbic acid concentration; Beta carotene concentration; relative sweetness; consumer preference and marketability	[21, 23]
Banana	Bunch weight; decreasing acidity; increasing shelf	[53]
Tomato	Increased carotenoids and flavour	[54]
Pawpaw	Sugar content	[23]

Table 4: Crop quality characteristics improvements by some micronutrients application in various crops

Crop	Quality characteristic	Nutrient element	References
Groundnut (<i>Arachis hypogaea</i> L.)	Protein content; oil content	Zn	[55]
Rice (<i>Oryza sativa</i> L.)	Amino acid content; protein content; grain Zn and Fe content	Zn; Fe	[56]
Pomegranate (<i>Punica granate</i> L. Cv 'Ghojagh')	Fruit weight; fruit diameter	Zn; Fe	[57]
Cotton (<i>Gossypium hirsutum</i> L.)	Ginning percentage; spinning consistency index (SCI)	Zn	[58]
Chilli	Ascorbic acid concentration	Cu	[59]
Sweet pepper	Protein, total carbohydrate content, ascorbic acid content	Co	[60]

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