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Review Article

Comparison of Deficiency and Toxicity of Copper Between Human and Crop Plants: A Review and Some Notes

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Abstract

The review on Copper (Cu) of its Deficiency and Toxicity (DAT) has been reported on human and plants but there are definite differences and similarities of Cu deficiency and toxicity between human and plants which remains to be poorly understood. In this review, similarities and differences of Cu deficiency and excess between human and plants are found. The similarities include any deficient or excessive levels of Cu can potentially produce harmful effects on human health and reducing vegetative growth ending with toxic effects in plants. The main difference for the dose-response curve of deficient or excessive levels of Cu is ∪-shaped which is based on cumulative health risk and total intake of Cu in human consumption while the dose-response curve is ∩-shaped which is based on increasing vegetative growth (and yield) and increasing Cu content in plants. This review can shed some lights on the understanding of Cu uptake on the health of the crop plant (oil palms) which is comparative to that in human.

Keywords: Copper; Deficiency; Excess

Introduction

The review on Copper (Cu) of its Deficiency and Toxicity (DAT) has been reported on human [1-4] and plants [5,6]. However, there are definite differences and similarities of Cu deficiency and toxicity between human and plants which remains to be poorly understood.

The objective of this review is to compare the Cu DAT between human and plants. This will provide some notes and insights from the monitoring and risk assessment of Cu.

Copper in human

Cu is an essential trace metal in humans [1,3] for the synthesizing of hemoglobins [7]. Cu is mostly bound to metalloproteins for detoxification purpose in the form of storage functions in living organisms. Deficiency of Cu can result in harmful toxicological conditions but it can be reversed by adequate Cu supplementation. The dietary reference intakes and guidelines for Cu for humans have been well defined [1].

Human Health Risk Assessment (HHRA) for nutrients such as Cu assumes a single population with a normal distribution of indexes of requirements and excess. Toxic levels can be defined as intakes above the upper level [2]. Elevated Cu intake by human via the marine seafood consumption can cause harmful health problems including liver and kidney failure but it is not carcinogenic to humans and animals [8].

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In human, both Cu Deficiency And Excess (DAE) can potentially produce harmful health consequences, the Dose-Response (DR) curve is ∪-shaped [3] (Figure 1). Stern., *et al*. [3] proposed a DR modelling strategy for Cu toxicity associated with DAE. The DR modelling strategy is important to understand if the existing toxicity data for Cu DAE may be effectively used in defining the limits of the homeostatic range in humans.

Figure 1 shows the use of nutrient (in this review is Cu) intake recommendations in risk assessment in a human population. The distributions of nutrient intakes for a human population have been added to explore risk of deficiency or excess [10-15]. In this model, the proportion of individuals that have nutrient intakes below the Estimated Average Requirement (EAR) are at risk of deficiency, while those exceeding Upper Limit (UL) are at risk of excess. The relevant information regarding the proportion of nutrient intakes in a population group can be found in the reports by FNB [10] and WHO [12].

Figure 1: Distribution of human population intakes of nutrients and risks of deficit and excess [9].

Note: EAR= Estimated average requirement [10-12]; RNI= Recommended nutrient intake [10-12]; UL= Upper limit [13,14].

In the marine seafood, the Maximum Permissible Limit (MPL) for human consumption for Cu suggested by Malaysian Food Regulations 1985 [16] and FAO [17] is 30 mg/kg wet weight, with the range of the legal limits of Cu as 20–70 mg/kg wet weight. Recently, there are many publications in the seafood on human health risk of essential metals have been found in the literature [18-23]. However, the comparisons of MPL with the DR curve as ∪-shaped is difficult to understand based on current knowledge, needing more clinical and ecotoxicological investigations.

Copper in plants

Both Cu DAE can also potentially diminish growth effects, the DR curve is ∩-shaped (contrasting that in human) in plants (Figure 2) and in Oil Palms (OP) (Figure 3). Likewise, Cu is an essential metal for plants [5]. It plays crucial roles in respiratory electron transport chains and photosynthesis, oxidative stress protection, ethylene sensing and cell wall metabolism [5]. Thus, a Cu deficiency can change the essential functions in plant metabolism [5].

On the contrary, excessive Cu exposure ending to high Cu accumulation in the plant can lead to phytotoxicity by the formation of reactive oxygen radicals that damage cells. The overly high Cu uptake in plants can disturb the normal interaction with proteins that can damage cellular functions including inactivating enzymes and disturbing protein structure [5].

Cu excess due to Cu pollution in the environment can cause problems of growth and yield of food crops such as OP. This can incur public concern from food safety and security threats standpoints [6]. In OP, Cu deficiency instigates stunted new leaves, with reduction of leaflets size and an extensive tip necrosis following the death of the meristem [24,25].

Figure 2 shows the dependence of plant growth and yield dependence on nutrient supply [26]. Almost the same diagram and concept has been outlined by Brady and Weil [27] and Nutrient Management Handbook [28] for plant growths or yields in relation to their excessive and deficient uptake of nutrients in plants.

Figure 2: Plant growth and yield dependence on nutrient supply [26].

The nutrient status of a plant ranges from acute deficiency to acute toxicity (Figure 2). In general, the nutrient status of the plants can be divided into three groups: deficient, optimal and excess. Acute deficiency is related to definite visible symptoms and poor growth. Its addition can cause an increase in growth and yields. The optimal supply can result in healthy green plants, good growth and high yields. Hence, good quality crop plant can be expected. For the acute toxicity, plants are impaired by toxic nutrient (such as Cu) levels causing toxicity symptoms, with poor yield and low quality [26].

In Figure 3, the ∩-shaped curve of DAE in relation to leaf nutrient concentrations and yield in the OP is like Figure 2. The Cu DAE in plants is exemplified by using OP trees, as shown in Figure 3 (diagram edited from Hartley [29]). This is because the OP (for example *Elaeis guineensisis*) can produce the commercial edible vegetable oil which is derived from the mesocarp of the fruit of the OP [30], and the palm oil can produce significant source of fat and a food staple in many cuisines [31]. Based on the original diagram edited from Hartley [29].

Figure 3: Diagram of deficiency and toxicity in relation to leaf nutrient concentrations and yield in the oil palm [29].

Note

Zone A: Normal growth response with increasing nutrient concentration reaching the 'critical' level or zone.

Zone B: No growth response but increasing nutrient concentration (this further increase does not occur in oil palm).

Zone C: Increasing nutrient concentration with toxic effect.

Between the nutrient concentrations of the deficiency range and those of no deficiency (adequate supply), there is the critical nutrient range as described in Figure 3 [32]. Critical Cu concentrations in the case of oil-palm are different for young palms and for older palms have been well established since OP is a cash commodity crop [32,33]. According to the Cu guideline in leaves of OP of 1-6 years (or > 6 years) after planting suggested by von Uexküll and Fairhurst (1991), the three Cu concentrations (mg/kg) are 'Deficiency (<3.0)', 'Optimum (5.00-7.00)', and 'Excessive (>15.0)', while for the mature OP are 'Deficiency (<3.0)', 'Optimum (5.00-8.00)', and 'Excessive (>15.0)'. These Cu guidelines point to the significance of DAT of Cu. Recently, the HHRA of essential metals (including Cu) in the vegetables have been reported in the literature [34-38]. However, HHRA of Cu has not been established in the palm oil in the literature.

Concluding Remarks

Similarities and differences of Cu DAE between human and plants are found. The similarities include any deficient or excessive levels of Cu can potentially produce harmful effects on human health and reducing vegetative growth ending with toxic effects in plants. The main difference for the DR curve of deficient or excessive levels of Cu is ∪-shaped which is based on cumulative health risk and total intake of Cu in human consumption while the DR curve is ∩-shaped which is based on increasing vegetative growth (and yield) and increasing Cu content in plants. This review can shed some lights on the understanding of Cu uptake on the health of OPs has similar response as in the human.

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