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FLUCTUATIONS OF NUTRIENT LEVELS IN THE INFECTED AND HEALTHY TISSUES OF MANGO UNDER EXPOSURE TO SUDDEN DEATH DISEASE

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Mango is the tropical and subtropical tree fruit and known as the king of all fruits. Its production is continuously declining due to diseases incidence and insect pest attacks. Mango sudden death syndrome is the deadly disease of mango trees in many countries around the world. The objective of the current study was to study the effect of sudden decline on the transport of macronutrients (P, K, Ca, Mg), micronutrients (Fe, B, Mn, Cr, Zn, Cu, Mo, Ni), beneficial nutrients (Al, Co, Na, Si), toxic elements (Ba, Pb, Sr, Cd), water and ash contents in healthy and infected tissues of stem bark and aerial parts of mango tree. Sudden death disease significantly ($p<0.05$) decreased water contents in infected tissues as compared to healthy tissues which were taken as control. The quantitative mineral analysis was carried out by inductively coupled plasma-optical emission spectrometry (ICP-OES). The levels of Ba, Mn, K, B, Al, Fe, Mg, Na, Ca, Sr, Cd, Ni, Cr, Pb, Mo significantly reduced by 11.53, 12.16, 12.18, 17.40, 23.33, 26.04, 31.27, 31.46, 35.89, 39.47, 40, 40.28, 51.15, 60.00 and 71.42%, respectively, in infected stem bark as compared to healthy control. Similarly, the levels of Ni, Zn, Si, Co, Sr decreased in infected aerial parts by 10.22, 27.22, 32.07, 39.47 and 80%, respectively, as compared to healthy control. It was revealed that sudden death disease causes significant nutritional imbalance in stem bark and aerial parts of the mango plant. The present study indicated the decreased level of essential nutrients as one of the predisposing factors causing sudden death of mango trees. The findings of this study provided valuable information to manage the nutritional status of diseased mango plants in future and for the development of mango varieties resistant to changes in mineral nutrients under exposure to sudden death disease.
Keywords: *Mangifera indica* L., plant diseases, macronutrients, micronutrients, ICP-OES, moisture contents.

INTRODUCTION

Mango *(Mangifera indica* L), belongs to the family Anacardiaceae, is an important fruit tree grown in tropical and sub-tropical areas of the world. Different varieties of mangoes are grown on over an area of 94.1 thousand hectares in Pakistan with annual production of about 1,636 thousand tons. Mango fruit is exported to many countries around the world including Germany, Singapore, France, Bangladesh, Saudi Arabia, Thailand, Malaysia, Holland, England, UAE and Italy (Anonymous, 2016; Masood *et al*., 2012).

Different pests and diseases affect mango trees during all stages of its life (Nasir *et al*., 2017). Concerning mango plant diseases, mango quick decline or mango sudden death disease (hereafter termed as mango sudden death disease) needs special attention, because the menace has been spread all over the Pakistan. Mango sudden death was first reported in Brazil (Al Adawi *et al*., 2006; Silveira *et al*., 2006), later in Pakistan (Fateh *et al*., 2006) and then in Sultanate of Oman (Al Adawi *et al*., 2006). Mango sudden death has become important problem for mango growers and industry (Al Adawi *et al*., 2006; Mohsin *et al*., 2014). Mango sudden death is a serious disease in Pakistan, Oman, Brazil and some other mango producing countries and hampering its production all over the world (Akhtar and Alam 2002; Kazmi *et al*., 2005; Galdino *et al*., 2016). Its major symptoms are streaking and darkening of stem bark, drying and discoloration of branch tips, oozing and gummosis. After disease attack, leaves become dry and shed or remain attached with dying trees. Cracking or bark splitting has been observed during disease severity and it also infects the stem and collar portions of plants. Apparently healthy-looking but diseased mango trees die within weeks or few months (Galdino *et al*., 2016; Saeed *et al*., 2016).

Different pathogens have been reported associated with mango sudden death disease. The main causal organisms reported from Pakistan, Oman and Brazil are *Ceratocystis fimbriata*, *Lasiodiplodia theobromae* and *Ceratocystis omanensis* (Malik *et al*., 2005; Al Adawi *et al*., 2006; Masood *et al*., 2010). Mango bark beetle, *H. mangiferae* plays an important role in disease transmission as a vector of

Ceratocystis fimbriata and *Lasiodiplodia theobromae* (Masood *et al*., 2010). The infection blocks the proper flow of nutrients in the phloem and xylem vascular bundles and leads to plants death (Masood *et al*., 2012; Saeed *et al*., 2016). Different types of minerals and their composition in plant cell plays a critical role in disease resistance/susceptibility through changes in metabolism and may affect the vascular system of plants by impairing the water and/or nutrient translocation, potentially leading to wilting and plant death (Spann and Schumann, 2010). Balanced distribution of nutrients is essential for normal plant growth and increased disease resistance (Crane *et al.,* 2006; Masood *et al*., 2012). In addition, water content (moisture) has significant role in the plant growth processes. Water is essential to the transportation and absorption of nutrients to carry on metabolism of materials, photosynthesis, temperature regulation, physiological reactions in plant tissues and the distribution of organic and inorganic molecules. The plant ash material contain minerals or inorganic constituents (Tang *et al*., 2006; Mcelrone *et al*., 2013).

Keeping in view the importance of mineral nutrients in normal growth, development and disease resistance of plants, a detailed investigation of macronutrients, micronutrients, beneficial nutrients and non-essential/toxic metals as well as water and ash contents was carried out in stem bark and aerial parts of mango plant suffering from sudden death disease to observe the nutrient homeostasis and distribution during pathogen attack. The concentrations/levels of these nutrients were analyzed in infected and healthy stem bark and aerial parts of mango tree in order to draw up a balance sheet for mineral nutrients and to identify the places at which sudden death disease interferes with host nutrient homeostasis and distribution.

MATERIALS AND METHODS

Sample collection and preparation**:** Samples of infected and healthy tissues (stem bark and aerial parts) of mature mango trees, cv. *Desi*, showing high attack of sudden death disease were collected during February 2017, from orchards of Multan, Pakistan. The trees under investigation were treated with similar cultural practices i.e., irrigation, fertilizers, and plant protection (Singh and Singh, 1998). The samples were thoroughly washed with distilled water as soon as they arrived in the laboratory. The plant and soil samples were dried in an oven for 48 hours to remove moisture contents. The samples were ground in stainless steel grinder and passed through a sieve of 0.5 mm to obtain homogenous mixture. The ground samples were weighed and digested in microwave digestion system (Multiwave3000, Anton Paar GmbH) by adopting already reported procedure (Brunetti *et al*., 2012) for analysis of minerals and other elements.

Minerals analysis**:** The elemental concentrations were determined by inductively coupled plasma optical emission spectrometer (ICP-OES). All chemicals used for sample preparation and standard dilutions were of analytical grade. Reagent blank and analytical duplicates were used to ensure precision in the analysis (Jiang *et al*., 2008). Laboratory NIST certified standards and spiking and recovery methods were used in each batch for validation of ICP-OES results as described earlier (Brunetti *et al*., 2012).

Determination of ash**:** One gram of dry powdered sample was weighed in a porcelain crucible and incinerated in a muffle furnace at 500°C for 5 h followed by cooling in a desiccator and weighed again. The water soluble and insoluble ash contents were also determined (Momin and Kadam, 2011).

Determination of moisture contents**:** The samples were heated in an oven at 100°C for 8 h to remove moisture and the loss of weight was used to calculate the moisture contents of the samples by adopting already reported procedure (Nielsen, 2010).

Data analysis**:** Data were analyzed statistically using Origin 2017 software (Origin Lab, Northampton, MA). Each experiment was repeated thrice. Depending on experiment, a Student's t-test or an analysis of variance (ANOVA) was performed to assess the statistical significance among different groups with $p < 0.05$ considered statistically significant.

RESULTS AND DISCUSSION

Effect of sudden death disease on the level of moisture contents**:** A significant ($p < 0.05$) decrease in moisture contents in the infected stem bark and aerial parts was observed as compared to healthy parts (Fig. 1 & 2). Generally, the mechanism of the pathological wilting of higher plants are recognized to systemic toxicity and/or vessel plugging. Wilt disease is the result of constrained water movement (Aguirreolea *et al*., 1995). Vascular wilt pathogens flourish inside xylem channels, discharging deadly chemicals and disturbing transport of water. Several *Ceratocystis* sp. and some other species such as *Ophiostoma* sp. are examples of vascular wilt pathogens (Hammerbacher *et al*., 2013). Vascular wilt pathogens have significantly direct effects on water storage and transport in trees. The disruption of xylem has fast effects and may cause sudden death of mature plants (Oliva *et al*., 2014).

Ash contents**:** The ash values refer to mineral contents after the removal of moisture and organic matter. Moisture contents and organic matter is removed by ignition or complete oxidation. The total ash contents, water soluble and insoluble ash contents of mango stem bark, aerial and less infected/ declining aerial parts were determined. Mineral nutrients are important for growth and survival of plants (Saeed *et al*., 2016). A significant variation was found in ash contents of healthy and infected stem bark and aerial parts of mango suffering from sudden death disease (Fig. 1 & 2).

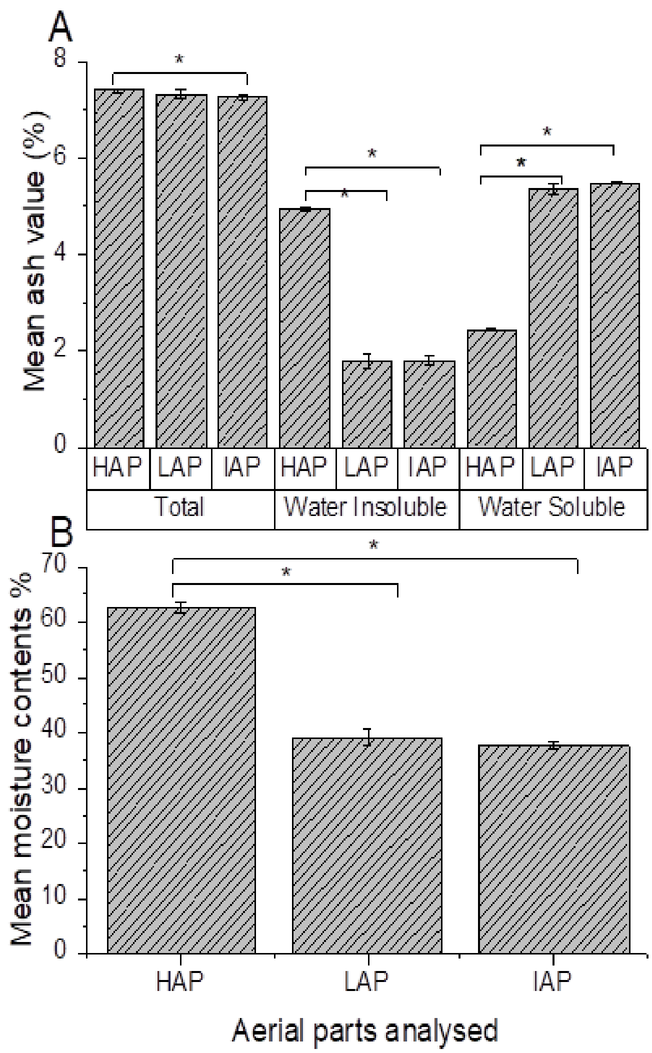

Figure 1. Effect of sudden death disease on ash (%) and moisture contents (%) of mango aerial parts. A: Quantification of ash contents, total, water soluble and insoluble in (%) healthy, infected and less infected aerial parts. **B:** Quantification of moisture contents (%) in healthy, infected and less infected aerial parts. Each bar represents mean ± SD contents of the specific ash as indicated. ∗ indicates that there was a statistically significant difference between healthy and infected sample at 95% CI. Significant differences ($p<0.05$) were determined using a two-way ANOVA followed by Bonferroni post hoc test for pairwise comparisons (A) or a student t-test (B). *HAP, healthy aerial parts; LAP, less infected aerial parts; IAP, infected aerial parts.*

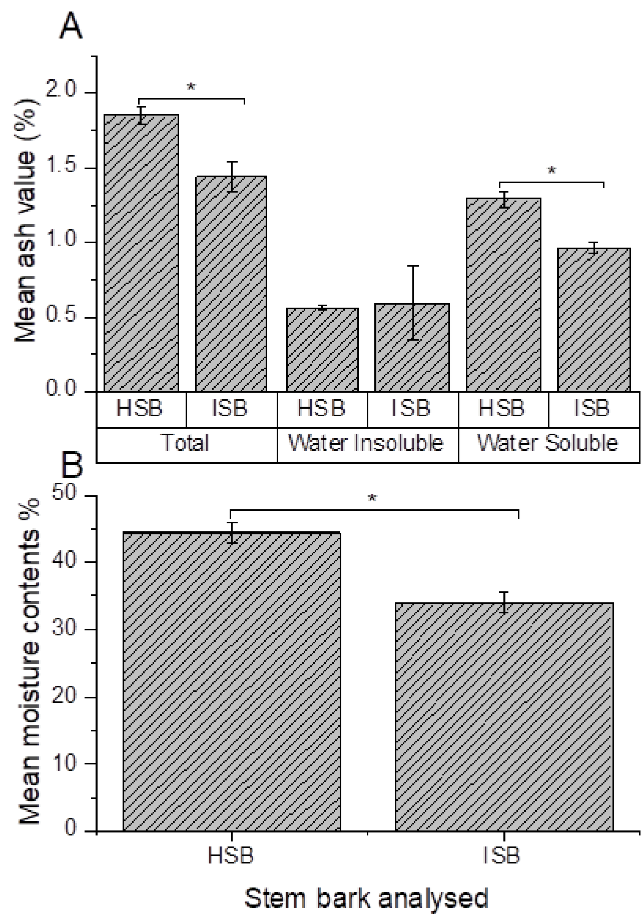

Figure 2. Effect of sudden death disease on ash (%) and moisture contents (%) of mango stem bark. A: Quantification of ash contents (%), total, water soluble and insoluble in healthy and infected stem bark of mango. **B:** Quantification of moisture contents (%) in healthy and infected stem bark of mango. Each bar represents mean ± SD contents of the specific ash as indicated. ∗ indicates that there was a statistically significant difference between healthy and infected sample at 95% CI. Significant differences ($p<0.05$) were determined using a two-way ANOVA followed by Bonferroni post hoc test for pairwise comparisons (A) or a student t-test. *HSB, healthy stem bark; ISB, infected stem bark*

***Effect of sudden death disease on the levels of macronutrients*:** The level of P increased by 61.71% in infected stem bark as compared to the healthy stem bark (Table 1). Similarly, the level of P increased in infected aerial parts by 50.15% as compared to the healthy control. P contents accumulated in infected parts as compared to the healthy parts (Tables 2 & 3). A severe disturbance in nutrients uptake was also observed due to pathogen infection (Walters,

Table 1. Levels of mineral contents (mg/kg) in the healthy (control) and infected stem bark.

Nutrients type	Elements	Healthy stem bark	Infected stem bark	% decrease/increase	P-Value
Macronutrients	P	152±0.880	397±0.59	61.71	P<0.05
	K	1396±11.77	1226±5.18	12.18	P<0.05
	Ca	1443±15.80	925±4.25	35.89	P<0.05
	Mg	774.55±3.630	532.47±1.01	31.27	P<0.05
Micronutrients	Fe	96.70±1.70	71.1±0.96	26.04	P<0.05
	B	45.84±0.35	100±0.43	55.00	P<0.05
	Mn	2.96±0.03	2.6±0.04	12.16	P<0.05
	Zn	5.91±0.01	7.95±0.03	25.66	P<0.05
	Cu	2.20±0.01	2.71±7.42	18.81	P<0.05
	Cr	3.89±0.05	1.90±0.02	51.15	P<0.05
	Mo	0.07±0.02	0.02±0.04	71.42	P<0.05
	Ni	1.69±0.06	1.00±0.05	40.28	P<0.05
Beneficial nutrients	Al	59.15±0.51	45.35±0.59	23.33	P<0.05
	Na	89.98±1.09	61.51±0.35	31.46	P<0.05
	Si	14.99±0.33	16.32±0.16	08.14	P<0.05
	Co	0.022±0.02	0.027±0.02	18.51	P<0.05
Toxic elements	Ba	2.600.015	2.30±0.01	11.53	P<0.05
	Pb	0.30±0.17	0.12±0.18	60.00	P<0.05
	Sr	43.80±0.21	26.51±0.26	39.47	P<0.05
	Cd	0.20±0.02	0.12±0.11	40.00	P<0.05

Table 2. Levels of mineral contents (mg/kg) in the healthy (control) and infected aerial parts.

Nutrients type	Elements	Healthy aerial parts	Infected aerial parts	% decrease/increase	P-Value
Macronutrients	P	316±0.94	630±137	49.84	P<0.05
	K	2571±16.49	3694±39.6	30.40	P<0.05
	Ca	6246±43.66	6334±26.18	01.38	P<0.05
	Mg	1652±11.39	1858±5.62	11.08	P<0.05
Micronutrients	Fe	123±2.23	145±0.94	15.17	P<0.05
	B	79.13±0.38	80.62±17.40	01.84	P>0.05
	Mn	7.29±0.13	7.41±0.03	01.61	P>0.05
	Zn	14.58±0.03	10.61±2.11	27.22	P<0.05
	Cu	6.31±0.09	11.20±0.01	43.66	P<0.05
	Cr	1.69±0.01	1.70±0.33	00.58	P>0.05
	Mo	0.03±0.01	0.04±0.03	25.00	P<0.05
	Ni	0.88±0.05	0.79±0.04	10.22	P<0.05
Beneficial nutrients	Al	93.03±0.73	105±0.30	11.40	P<0.05
	Si	12.44±0.07	8.45±0.03	32.07	P<0.05
	Na	134±2.12	145±0.39	07.58	P<0.05
	Co	0.05±0.03	0.01±0.05	80.00	P<0.05
Toxic elements	Ba	5.64±0.047	7.96±0.027	29.14	P<0.05
	Pb	0.65±0.21	0.70±0.40	07.14	P<0.05
	Sr	173±1.66	168±0.94	02.89	P>0.05
	Cd	0.38±0.12	0.37±0.07	02.63	P>0.05

2015). Nevertheless, the role of P in resistance to pathogen is variable and apparently unpredictable (Dordas, 2008).

The concentration of K decreased in infected stem bark, the level of K was 12.18% higher in healthy stem bark as compared to infected stem bark (Table 1), while the level of K was 30.40%, 37.52% higher in declining and less declining aerial parts respectively as compared to the healthy aerial parts (Tables 2 & 3). During sudden death disease cankers are formed and gum like material ooze out from them. The decrease in K concentration may be due to stem injury and oozing of compounds.

The sudden death disease decreased Ca concentration in infected stem bark, Ca level was 35.89% higher in healthy stem bark as compared with infected stem bark (Table 1). The

Table 3. Levels of mineral contents (mg/kg) in the healthy (control) and less infected aerial parts.

Nutrients type	Elements	Healthy aerial parts	Less Infected aerial parts	% decrease/increase	P-Value
Macronutrients	P	316±0.94	817± 1.02	61.32	P<0.05
	K	2571±16.49	4115± 40.37	37.52	P<0.05
	Ca	6246± 43.66	7065±97.37	11.59	P<0.05
	Mg	1652±11.39	1874±2.96	11.84	P<0.05
Micronutrients	Fe	123±2.23	132±1.27	06.81	P<0.05
	B	100±0.43	80.62±17.40	01.84	P>0.05
	Mn	7.29±0.13	8.88±0.067	17.90	P<0.05
	Zn	14.58±0.03	10.65±0.06	26.95	P<0.05
	Cu	6.31±0.09	11.03±0.01	42.79	P<0.05
	Cr	1.69±0.01	2.49±0.03	32.12	P<0.05
	Mo	0.03±0.01	0.04±0.03	25.00	P<0.05
	Ni	0.88±0.05	0.66±0.04	25.00	P<0.05
Beneficial nutrients	Al	93±0.73	102±0.29	08.82	P<0.05
	Na	134±2.12	105±0.28	21.64	P<0.05
	Si	12.44±0.07	8.45±0.03	32.07	P<0.05
	Co	0.05±0.03	0.063±0.04	20.63	P<0.05
Toxic elements	Ba	5.64±0.047	9.25± 0.02	39.02	P<0.05
	Pb	0.65±0.21	0.60±0.18	07.69	P<0.05
	Sr	173±1.66	185±1.10	06.48	P<0.05
	Cd	0.38±0.12	0.26±0.08	31.57	P<0.05

level of Ca was 11.59% higher in less infected aerial parts as compared to healthy aerial parts (Table 3) and no significant change was found in healthy and infected aerial parts (Table 2). Sudden death disease significantly decreased the Ca concentration in infected stem bark and less infected aerial parts (Tables 1-3). When the level of Ca decreases, there is an increased susceptibility to fungal infection which later attack the xylem and dissolve the cell walls of the conducting vessels eventually leads to plants wilting (Maathuis, 2009).

Mango sudden death decreased Mg level in infected stem bark as compared to the healthy stem bark. The healthy stem bark had higher level of Mg (31.27%) as compared to declining stem bark (Table 1). The level of Mg decreased (11.08%) in healthy aerial parts as compared to declining parts (Table 2) and a similar pattern was observed in less declining aerial parts (11.84%) as compared to healthy aerial parts (Table 3). If adequate amount of Mg is available to plant tissues, the severity of pathogen infection is reduced. In contrast, high rates of Mg that interfere with Ca uptake may increase the incidence of diseases (Huber and Jones, 2013).

***Effect of sudden death disease on the levels of micronutrients*:** Iron is an important and essential micronutrient for plants, required in many enzymatic steps and the synthesis of chlorophyll (Sarwar *et al*., 2010). Mango sudden death decreased the level of Fe in infected stem bark, the level of Fe was lower (26.04%) in infected stem bark as compared to healthy stem bark (Table 1). The level of Fe was lower in healthy aerial parts (15.17%) as compared to that in infected aerial parts (Table 2) and a small difference in the level of Fe was found in less infected aerial parts as compared to healthy aerial parts (Table 3). Infectious diseases are the result of competitive relationships between a host organism and a pathogen.

Table 4. Physical and chemical properties of the mango orchard soil (soil physicochemical properties (pH, organic matter, cation exchange capacity, clay content and electrical conductivity).

Parameter	Value
Texture	Clay loam
pH	8.2±0.6
Conductivity (µS cm^{-1})	1280±18
Organic matter (%)	0.82±0.05
Al (mg kg^{-1})	0.43±0.20
Ba (mg kg^{-1})	1.4 ± 0.22
Cd (mg kg^{-1})	1.02±0.14
Co (mg kg^{-1})	1.5 ± 0.2
Cr (mg kg^{-1})	1.30±0.21
Cu (mg kg^{-1})	1.20±0.12
Fe (mg kg^{-1})	4.48±0.40
B (mg kg^{-1})	2.32±0.51
Mn (mg kg^{-1})	3.56±0.22
Ni (mg kg^{-1})	0.09±0.021
Pb (mg kg^{-1})	1.2 ± 0.3
Sr (mg kg^{-1})	1.7 ± 0.4
Zn (mg kg^{-1})	2.10±0.20
Na (mg kg^{-1})	68±2.4
K (mg kg^{-1})	223±6.4
P (mg kg^{-1})	9±0.64
Ca+Mg (mg kg^{-1})	127±4.8

Values represent means ± SD (n = 3)

Plant can develop Fe suppression response that changes Fe trafficking and distribution during infection. Elucidating the mechanisms of competition for iron between plants and pathogens must help to develop innovative strategies for controlling diseases (Expert *et al.*, 2012).

The level of B decreased in infected stem bark. Boron value increased (17.40%) in healthy stem bark as compared to infected stem bark (Table 1). Boron value was higher (55.00%) in less infected aerial parts (Table 3), while no significant change was found in aerial parts of healthy and infected samples (Table 2). The sudden death disease reduced the level of B in declining tissues. Boron has a direct function in cell wall structure and stability and has a beneficial effect on reducing disease severity (Dordas, 2008). Boron reduces disease susceptibility as it has functions in cell membrane permeability, cell wall structure and stability and in metabolism of phenolics or lignins (Brown *et al*., 2002).

The level of Mn contents decreased in the infected stem bark as compared to healthy stem bark. The manganese level was 12.16% higher in healthy stem bark compared to declining stem bark (Table 1). No significant variation was found in the level of Mn in infected and healthy aerial parts (Table 2), while a significant variation was found in less infected aerial parts as compared to healthy aerial parts. The level of Mn was higher (17.90%) in less infected aerial parts as compared to healthy aerial parts. The pathogen severely infects the stem bark and oozes gum and form cankers. It breaks the cell wall of diseased mango plant and the lower level of Mn in infected stem bark may be attributed due to severe infection and loss of cell wall. Manganese element is vital to create resistance in plants against various infections (Brown *et al*., 2002). Higher plants require greater concentrations of Mn as compared to fungi and bacteria (Broadley *et al*., 2012). Manganese inhibits the induction of aminopeptidase and pectin methylesterase enzyme which supplies essential amino acids for fungal growth and degrades host cell walls. Manganese controls suberin and lignin biosynthesis. Suberin and lignin are important biochemical barriers to fungal pathogen invasion. Lignin and suberin are believed to contribute to disease resistance against different pathogens (Broadley *et al*., 2012).

The level of Zn was 22.66% higher in infected stem bark as compared to healthy stem bark. An opposite pattern of Zn level was found in aerial parts, Zn concentration was higher in healthy stem bark (27.22%) as compared to infected stem bark. The level of Zn was 26.95% higher in healthy aerial parts as compared to less infected aerial parts. Zinc is an important element vital for growth and development of plant (Sarwar *et al*., 2010). Zinc reduces susceptibility to diseases, reduces diseases severity producing toxicity against pathogen and protect membrane against oxidative damage (Graham and Webb, 1991; Cakmak, 2000). Application of Zn to the soil reduced the infections caused by *Fusarium graminearum* and root rot diseases (Dordas, 2008).

The level of Cu increased in infected stem bark. The level of Cu was higher (18.81%) in infected stem bark as compared to healthy stem bark (Table 1). Similarly, the level of Cu was higher (43.66 and 42.79%) in infected aerial parts and less infected aerial parts as compared to healthy aerial parts. A significant difference in the level of Cu was found in infected parts as compared to healthy parts. Copper is an important component of many biological molecules and is required for normal functions of plants (Ducic and Polle, 2005; Maathuis and Diatloff, 2013).

The concentration of Si increased in infected stem bark. The level of Si was higher (08.14%) in infected stem bark as compared to healthy stem bark (Table 1). The level of Si decreased in infected aerial parts, the Si value was 32.07% higher in healthy aerial parts as compared to infected aerial parts (Table 2). Interestingly, similar level of Si was found in less infected aerial parts as compared to infected aerial parts (Table 3). Silicon is beneficial element for plants as it provides resistance to multiple stresses. Genetic modification of the root ability to take up Si has been proposed. The mechanism by which Si confers disease defeat is not well understood. It is supposed that Si generates a physical obstacle which can limit fungal hyphae diffusion, or it may persuade buildup of antifungal compounds such as diterpenoid phytoalexins and flavonoid which can damage fungal and bacterial cell walls (Alvarez and Datnoff, 2001; Brecht *et al*., 2004).

The level of Mo was higher (71.42%) in healthy stem bark as compared to infected stem bark (Table 1). The level of Mo was increased (25.00%) in infected aerial parts as compared to healthy aerial parts (Table 2). However, no change in the level of Mo was found in less infected aerial parts as compared to infected aerial parts (Table 3). The requirements of plants for Mo is the least of all the mineral nutrients. Only a few enzymes such as nitrate reductase, nitrogenase and xanthine oxidase/dehydrogenase have been confirmed that require molybdenum (Grusak *et al*., 2001).

The concentration of Ni was higher in healthy stem bark (40.28%) as compared to infected stem bark (Table 1). Similarly, the level of Ni was 10.22% higher in healthy aerial parts compared to infected aerial parts. The Ni value also decreased to about 25% in less infected aerial parts as compared to healthy aerial parts. The mango death pathogens infection decreased Ni values in infected parts compared to healthy parts (Tables 1-3). The requirements of plants for Mo and Ni are the least of all the mineral nutrients (Grusak *et al*., 2001).

***Effect of sudden death disease on the level of beneficial and non-essential elements*:** Sodium is classified as a functional plant nutrient (Subbarao *et al*., 2003). Following infection with sudden death, the Na level was decreased by 31.46% in the declining stem bark as compared to healthy ones (Table 1), while the concentration of Na decreased by 07.58% in healthy aerial parts when compared with declining aerial parts (Table 2). The level of Na decreased in less declining aerial parts (21.64%) as compared to healthy aerial parts (Table 3). A varying trend of Na was observed in mango sudden death as the Na level decreased in infected stem bark, increased in infected aerial parts and then decreased in less infected aerial parts (Tables 1-3).

Aluminum concentration decreased in declining stem bark, the level of Al was 23.33% higher in healthy stem bark as compared to declining aerial parts (Table 1), while the level of Al accumulated in declining aerial parts by 11.40% as compared to healthy aerial parts (Table 2). Similar trend of Al metal concentration was found in less declining aerial parts, Al value decreased in less declining aerial parts (08.82%) as compared to healthy aerial parts (Table 3).

The level of Ba decreased in declining stem bark, the level was 11.53% higher in healthy stem bark as compared to declining stem bark (Table 1). During comparison with aerial parts, Ba was found to be accumulated in declining aerial parts, the level was 29.14% higher in declining aerial parts over healthy aerial parts (Table 2). Similarly, the level of Ba accumulated in less declining aerial parts was 39.02% higher as compared to healthy aerial parts (Table 3). Barium is a nonessential element to terrestrial organisms and is known to be toxic at elevated concentrations (Lamb *et al*., 2013).

The cobalt contents accumulated in infected stem bark, the level was 18.51% higher in declining stem bark as compared to healthy stem bark (Table 1). The level of Co decreased by 80% in declining aerial parts as compared to healthy aerial parts (Table 2), while the Co level was 20.63% higher in less declining aerial parts as compared to healthy aerial parts (Table 3). Cobalt is not classified as an essential element for plants, however, it is usually described as "beneficial" (Bakkaus *et al*., 2005) as it is an essential component of several enzymes and co-enzymes. The helpful effects of Co include retardation of increase in drought, senescence of leaf, resistance in seeds, inhibition of ethylene biosynthesis (Pilon-Smits *et al*., 2009).

Chromium concentration decreased in declining stem bark, the level of Cr was 51.15% higher in healthy stem bark compared to declining stem bark (Table 1). No significant difference was found in declining and healthy aerial parts regarding Cr contents (Table 2) while Cr metal accumulated in less declining aerial parts, the level was 32.12% higher in less declining aerial parts as compared to healthy aerial parts (Table 3).

The level of cadmium was 40% higher in declining stem bark as compared to healthy stem bark (Table 1). No significant change was observed in Cd contents in healthy and declining aerial parts (Table 2) while the level was 31.57% higher in healthy stem bark as compared to less declining aerial parts.

The level of lead decreased in declining stem bark, the level was 60% higher in healthy stem bark as compared to declining stem bark (Table 1). The Pb metal accumulated in declining aerial parts, the level of Pb was 07.14% higher in infected aerial parts as compared to healthy aerial parts (Table 2) while the level of Pb was 7.69% higher healthy stem bark as compared to less infected aerial parts (Table 3).

The level of strontium decreased in infected stem bark, the Sr was 39.47% higher in healthy stem bark as compared to infected stem bark (Table 1). No significant variation was found in the level of Sr in the infected and healthy aerial parts (Table 2), while the Sr contents was 06.48% higher in less declining aerial parts as compared to healthy aerial parts (Table 3).

***Conclusion*:** In the current study it was recorded that the concentrations of essential nutrients such as K, Ca, Mg, Fe, B, Mn, Zn, Si, Ni, Mo decreased in infected parts after pathogen infection as compared to healthy parts. Overall, sudden death disease produced nutritional imbalance and this disorder may enhanced the sudden wilting of mango plants. The improvement in plant nutrition by adopting different strategies such as introduction of manures and fertilizers during pathogen attack may enhance plant survival and might make the plant more resistant to or compensate for the effect of disease. Future studies are required to conduct greenhouse experiments to observe the effect of nutrients during fungal infection to rehabilitate the diseased plants. Mechanistic studies are also required to observe how the fungal infection induces changes in the distribution and translocation of mineral nutrients.

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