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Effect of selenium and silicon on yield quality of rice plant grown under drought stress

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Abstract

Improving the nutritional quality of food is an important step in addressing worldwide health problems. A field experiment was conducted to evaluate the effects of either Se (0.03mM sodium selenate) or Si (1.5mM potassium silicate) on the yield components as well as grain and straw qualities of rice cv. Giza 177 and cv. IET 1444 exposed to water deficit condition. Drought stress was imposed by withholding water (irrigation every 10 days). The plants were left to grow under the various treatments for five months. At full maturity (5 months after sowing) the experiment was terminated and grain quality in terms of grain appearance (grain length L, grain breadth B and L/B ratio), cooking quality (amylose content and water uptake WU) as well as nutritional (carbohydrates, proteins oil, phenols and flavonoid contents) and anti-nutritional (phytic and oxalic acids) values was estimated. Drought stress reduced grain yield and harvest index (HI) as well as L/B ratio of the two rice cultivars, parallel with reduction in total soluble carbohydrate, starch, protein, oil, phenols, and flavonoid contents. In contrast, drought induced a subsequent increase in stress tolerance index (STI), amylose and total antioxidant capacity for yielded grains of both rice cultivars. Moreover, the decline in grain phytic acid under drought stress was concomitant with an increase in oxalic acid, calcium and iron ions level of stressed grains. Both Se and Si pretreatments mitigated the adverse effects of drought and improved yield quality *via* the increments in the levels of amylose, phenolic compounds as well as flavonoid and oil contents concomitant with reduction in grain water uptake during cooking. In addition, selenium and silicon treatments caused further increases in lignin, cellulose and pectin contents of rice straw as compared with those of drought-stressed plants parallel with increments in total carbohydrate, protein, phytate, Ca and P ions levels.

Keywords: Drought, Selenium, Silicon, *Oryza sativa,* Phytic acid, Antioxidants, Amylose.
Abbreviations: AC_amylose content; Ca_calcium; Cl_chloride; FRAP_ferric reducing ability power; HCO_3_carbonate; HI_Harvest index; IP3_Inositol triphosphate;IP6_Inositol hexaphosphate; K_potassium; Mg_magnesium; Na_sodium; P_phosphorous; PA_ phytic acid; Pi_inorganic phosphate; Se_selenium; Si_silicon; STI_stress tolerance index; SO_4_sulphate; WU_water uptake.

Introduction

Rice (*Oryza sativa* L.) is an important and traditional cereal in many countries. However, current rice production systems rely on ample supply of water. Thus, water deficit is one of the most severe environmental stresses affecting agricultural productivity of rice worldwide (Xoconostle-Cazareset, 2010; Anjum et al., 2011). The development of rice with high yield under water deficit condition has become a breeding priority. Harvest index (Younis et al., 2000), stress tolerance index (Zandi, 2012), and the percentage of fertility (Mohammed and Tarpley, 2011) have been earlier found to be effective in characterization of the better performance of cultivars exposed to both stressful and non-stressful conditions. Naeemi et al. (2008) reported that, there is a positive and significant correlation of stress tolerance index (STI) and productivity index. Moreover, the physical properties such as size, shape, uniformity, grain length (L), grain breadth (B), and L/B ratio are important factors for consumers. The grain quality of rice is determined by the factors such as grain appearance, nutritional value and cooking quality. During cooking, the grains absorb water and increase in size. At higher water uptake, majority of rice shows pasty appearance (Hossain et al., 2009) which is not favorable for cooking and eating quality. The cooking and eating characteristic of rice are influenced by the chemical characteristics of starch in terms of amylose and amylopectin (Futakuchi et al., 2008). Rice grouped according to their amylose content into waxy (0-2%), very low (3-9), intermediate (20-25) and high (>25%) (Cruz and Khush, 2000). Intermediate amylose rice is preferred in most rice growing areas of the world. In addition, nutritional value is mostly determined by the synthesis of storage carbohydrates, proteins, oil and minerals during grain filling. Rice bran oil is notable for its desired flavor, odor and high smoke point of 213˚C, making it suitable for high-temperature cooking methods (Orthoefer, 2005). Furthermore, rice grain contains some anti-nutritional secondary substances (phytic acid and oxalic acid). Phytic acid (phytate; inositol-hexaphosphate) is the primary source of inositol and storage phosphorus in plant seeds contributing ~ 70% of total phosphorus. Moreover, Phytate (IP6) has been reported as anti-nutrient factor (Stmopen, 2013), antioxidant (Graf and Eaton, 1990) and anticarcinogenic (Shamsuddin et al., 1997). However, it is considered as an anti-nutrient at high concentration because it reduces the bioavailability of trace elements such as zinc, iron and calcium when grains are eaten by humans and non-ruminant animals (Forbes and Erdman, 1983). Phytic acid in cereals plays an important role in inhibiting oxidation during storage of oily seeds (Peterson, 2001). Rice straw is a unique relative to other cereal straws in being high in silica; this may contribute to higher rice-straw value. The silica has a function of increasing the degree of resistance against pathogen and lodging of the plant (Deren et al., 1994). The large amount of rice straw as a by-product of the rice production is mainly used as a source of feed for ruminant livestock (Sarnklong et al., 2010). Improving crop quality can help to improve the processing, safety and nutritional value of crop grown under water deficit condition. Several studies have suggested the positive effects of silicon on yeild (Kim et al., 2012; Nolla et al., 2012; Gholami and Falah, 2013). Furthermore, Se is not considered to be essential to plants, it has been shown that at low concentration it exerts positive effects on promoting growth and yield of many plants (Hawrylak-Nowak, 2009; Chu et al., 2013; Habibi, 2013). Thus, the objective of the present study was to assess ameliorative effects of either selenium or silicon on yield and the nutritional quality of two rice cultivars grown under water deficit condition.

Results

Changes in growth parameters

Imposition of drought stress reduced plant height, number of tillers, 1000-grain weight and grain yield of both rice cultivars. The panicle length was reduced from 21.6 to 15.4 cm in cv. Giza 177, however, it decreased from 22.5 to 21.0 cm in IET 1444 (Table 2). The treatment with either Se or Si has a favorable effect on1000- grain weight which up to 9.5% and 5.2% in Giza 177 and it amounted to be 6.2% and 5.5% in cv. IET 1444 compared to those of drought-stressed controls. The results in Table 2 showed that the exposure of cv. Giza 177 and cv. IET 1444 rice plants to water deficit condition results in significant reductions in grain yield /plant, number of filled grains per panicle and percentage of fertility. The pretreatment of the two rice cultivars cv. Giza 177 and cv. IET 1444 with either Se or Si increased the number of filled grains and the percentage of fertility as well as grain yield/ plant compared with those of the stressed plants. Well-watered irrigation system produced the maximum harvest index (56.8% and 74.8%) in Giza 177 and IET 1444; however drought stress reduced these values to 40.5% and 52.1% respectively. Furthermore, stress tolerance index (STI) was negatively related to water deficit condition however such index was more pronounced in cv. IET 1444 stressed rice. The pretreatment of rice plants with either Se or Si significantly enhanced the STI, particularly in cv. IET 1444.

Changes in cooking and eating quality

The length of the stressed yielded grains cv. Giza 177 and cv. IET 1444 reduced from 5.27 to 5.16 mm and 5.64 to 5.52 mm respectively (Table 3). The percentage of water uptake (WU) was greater in stressed grains of Giza 177 (430%) compared to that of stressed IET 1444 grains (395%). However, imposition of drought stress increased the percentage of water uptake during cooking in both cultivars grains (Table 3). Under well-watered irrigation system the amylose content was greater in cv. IET 1444 (18%) as compared to that of cv. Giza 177 (12.8%). In addition, the exposure to water deficit stress stimulated the accumulation of amylose particularly in cv. Giza 177 (Table 3). Meanwhile, presoaking of rice grains in either Se or Si increased the L/B ratio, amylose content, concomitant with reduction in water uptake of both stressed rice cultivars compared to those of drought-stressed grains.

Changes in nutritional value of rice grains

Water deficit stress manifested marked decreases in total soluble carbohydrates and starch content of rice grains of both cultivars. The percentage of decrease was 30.3% & 31.6% in Giza 177 and 44.7% & 28.3% in IET 1444. Total soluble protein was decreased more prominently in grains of IET 1444 cultivar where it was reduced by 46.4% (IET 1444) and 14.2% (Giza 177) below the well-watered control value. Both Se and Si increased total soluble carbohydrate, starch, insoluble protein accumulation in rice grains of cv. Giza 177 and cv. IET 1444 and decreased total soluble protein in grains of both cultivars (Table 4). Both Se and Si treatments stimulated the percentage of oil production to reach 52.4% and 60.1% respectively in Giza 177 while it was amounted to be 104.6% and 49.1% respectively in grains of IET 1444. It is interesting to mention that, total phenols was minimized in rice grains of cv. Giza by 36.0% while in cv. IET 1444 was 48.9% as compared with well-watered controls. The pretreatment with either Se or Si significantly increased the accumulation of total phenols and a massive increase in total antioxidant capacity of both rice cultivars grown under drought condition (Table 4). Imposition of drought stress induced a reduction in the total phosphorous content of the two cultivars Giza 177 and IET 1444 by about 6.7% and 8.9% respectively. On the other hand, imposition of drought stress brought a significant enhancement in inorganic P, Ca and Fe levels with corresponding decline in phytate P content of the two cultivars. The percentage of inorganic P reduction was amounted to be 52.5% and 14.5% in Giza 177 and IET 1444 respectively. Either Se or Si significantly increased the inorganic P content of Giza cultivar from 5.21 to 6.51 and 6.26 respectively. However, in IET 1444 cultivar, the inorganic P content increased from 4.97 to 6.39 in Se-treated plants and 7.10 in Si-treated plants (Table 5).

Changes in anti-nutritional factors

The results presented in Table 5 revealed that, drought stress significantly elevated the oxalate content of rice grains from 160.2 to 286.3 and from 220.8 to 374.5 mg per 100 g for Giza 177 and IET 1444 respectively. However, drought stress significantly reduced phytic acid content of Giza 177 from 5680 to 2698 mg per 100 g and from 4402 to 3763 mg per 100 g in IET 1444. In addition, presoaking of rice grains in either Se or Si provoke a significant accumulation of phytic acid concomitant with decrease in oxalate level.

Changes in straw yield and quality

The data given in Table 6 clearly showed that, straw yield significantly decreased from 44.2 to 23.1 (g) per plant in stressed Giza 177 and from 22.4 to 14.8 (g) per plant in stressed IET 1444. The increments in straw yield, cellulose, pectin and lignin were manifested in the straw of the Se and Si- pretreated stressed rice cultivars. The calcium ion level significantly increased in the stressed straw of the two cultivars Giza 177 and IET 1444, reaches about 139.4 mg/100g and 259.7 mg/100g respectively. Imposition of water deficit stress significantly reduced both total P and phytate-P concomitant with a significant increase in the inorganic P of the two rice cultivars. The reduction in

Table 1. Some physical and chemical properties of soil.

pH	EC ($dS\ m^{-1}$)	Ca^{++}	Mg^{++}	K^{+}	Na^{+} ($meq.L^{1}$)	HCO_3	Cl^{-}	SO_4	Clay (%)	Silt (%)	Sand (%)	Texture
8.3	2.2	4.3	2.9	0.9	10	4.2	12.5	1.1	51.2	32.5	16.3	(Clayey)

Table 2. Effects of selenium and silicon on growth and grain yield of the two rice cultivars Giza 177 and IET 1444 grown under drought condition.

Treatments / Parameters	Well-watered	Drought	Drought +selenium	Drought+ silicon	Well-watered	Drought	Drought +selenium	Drought+ silicon	LSD at 5% Cultivar	Treatment	Interaction
Plant height (cm)	115.2 ± 5.5^{a}	89.0 ± 3.0^{d}	96.8 ± 5.0^{cd}	93.0 ± 4.5^{c}	105.2 ± 6.5^{b}	73.8 ± 2.5^{f}	77.0 ± 3.7^{f}	80.8 ± 1.5^{e}	3.02	4.02	5.7
No. of tillers/plant	29.0 ± 1.1^{abc}	20.3 ± 1.2^{f}	23.5 ± 1.2^{ef}	23.0 ± 1.7^{de}	29.2 ± 1.4^{a}	24.2 ± 1.2^{bc}	30.0 ± 1.7^{ab}	24.8 ± 1.3^{cd}	0.70	1.8	2.6
No. of tillers carrying panicles/plant	23.3 ± 0.8^{ab}	11.2 ± 0.4^{e}	13.3 ± 0.4^{e}	12.3 ± 0.9^{e}	25.0 ± 0.7^{a}	15.6 ± 0.3^{d}	22.0 ± 0.6^{bc}	19.2 ± 0.8^{c}	o.79	1.65	2.3
Panicle length (cm)	21.6 ± 1.6^{abc}	15.4 ± 1.5^{e}	17.0 ± 1.5^{d}	18.4 ± 1.8^{d}	22.5 ± 2.1^{a}	21.0 ± 1.7^{c}	22.0 ± 1.2^{bc}	23.5 ± 0.8^{ab}	2.94	1.23	1.7
1000-grain Weight (g)	23.6 ± 0.6^{bc}	21.1 ± 0.3^{c}	23.2 ± 1.3^{bc}	22.2 ± 2.2^{c}	29.6 ± 1.3^{a}	27.4 ± 1.1^{a}	29.1 ± 0.5^{a}	28.9 ± 1.1^{a}	1.85	1.3	1.8
Grain yield/ plant (g)	44.2 ± 3.2^{b}	15.9 ± 0.2^{f}	21.7 ± 0.8^{d}	17.1 ± 3.4^{ef}	48.7 ± 5.1^{a}	16.1 ± 0.6^{f}	23.7 ± 1.1^{c}	20.3 ± 1.2^{de}	1.2	1.99	2.8
Filled grains/panicle	92.6 ± 3.3^{af}	62.5 ± 2.2^{f}	80.0 ± 4.2^{cd}	78.0 ± 3.3^{de}	100.0 ± 3.1^{a}	70.2 ± 1.3^{e}	78.6 ± 3.0^{de}	86.2 ± 2.3^{bc}	6.3	8.4	6.8
Total grains/Panicle	98.2 ± 3.3^{ab}	82.2 ± 2.3^{c}	100.0 ± 4.5^{a}	94.0 ± 2.6^{ab}	103.5 ± 3.9^{a}	86.0 ± 3.3^{bc}	95.0 ± 4.2^{ab}	91.4 ± 3.1^{ab}	5.8	6.9	9.9
Spikelet fertility (%)	94.2 ± 3.9^{b}	76.0 ± 2.6^{d}	80.0 ± 4.1^{c}	82.9 ± 4.0^{c}	96.6 ± 2.7^{a}	91.9 ± 3.0^{b}	94.1 ± 2.4^{ab}	92.7 ± 3.5^{ab}	0.82	2.33	3.3
Harvest index (%)	56.8 ± 4.1^{c}	40.5 ± 3.2^{f}	46.5 ± 4.2^{e}	45.0 ± 3.5^{e}	74.8 ± 5.3^{a}	52.1 ± 2.1^{d}	61.8 ± 3.8^{b}	59.6 ± 3.3^{b}	1.6	2.3	3.2
STI	00	0.33	0.44	0.35	00	0.36	0.53	0.45	0.0	0.0	0.005

Data represent mean ±*SD* of ten replicates. Different letters in each treatment and each column show significant difference at *P* 0.05 by least significant difference (LSD).

phytate-P level reaches about 43.2 % in cv. Giza 177 and 36.5% in IET 1444 (Table 7).

Discussion

The significant decline in plant height of drought-stressed rice cultivars was concomitant with a significant decrease in the grain yield per plant (Table 2). The reduction in plant height of drought-stressed rice might be due to the decline in cell enlargement and cell division. These results are highly matching with those obtained by Hsiao (2000). It is also noticeable that, the grain yield decreased significantly in the two drought-stressed cultivars (Table 2). The reduction in grain yield under drought stress conditions was consistent with the results of Ibrahim et al. (2013). Such reduction appeared to be resulted from the significant reduction in the number of filled grains per panicle in the water-stressed rice cultivars Giza 177 and IET 1444. Silicon mitigated the reduction in filled grains of stressed rice plants. Such finding is confirmed by Ma (2004) who reported thatunder this condition, leaves become more erect, thus reducing self-shading and increasing the rate of photosynthesis, particularly during period of grain filling that associated with starch accumulation in grains. The weight of 1000-grain was markedly reduced under drought stress in both rice cultivars. This result was confirmed by the finding of Kousar et al. (2012) who reported that 100-seed test weight and grain starch content of wheat genotypes decreased under water deficit stress conditions. Such reduction might be attributed to the decrease in the translocation of assimilates to the grains which reduced the number of filled grains (Venuprasad et al., 2007). Results presented in Table 2 also, showed that drought stress reduced grain weight; such result was consistent with those obtained by Liu et al. (2008) who reported that water deficit conditions might inhibit photosynthesis lowering grain weight. Either Se or Si mitigated the adverse effect of drought by increasing the grain yield. The growth promoting effect of Se on stressed plants has been reported by Hawrylak-Nowak (2009). Increasing grain yield in Si- treated rice plants under water deficit condition might be attributed to the increase in dry matter production (Agarie et al., 1993) and/or stimulation of 1000-grain weight (Balastra et al., 1989). Imposition of drought stress reduced the number of tillers per plant, Katoa et al. (2008) supported this result and he added that, drought stress reduces the spike potential to act as a sink. The results also revealed that, the decrease in grain yield under drought condition was concomitant with reduction in fertility percentage. Such result was compatible with previous studies reported by Mohammed and Tarpley (2011) who found stimulation in spikelet sterility due to high temperature which in turn induces water deficit and enhances evaporation from the anthers, thereby decreasing moisture needed for pollen grain swelling. The well-watered irrigation system produced the maximum harvest index in Giza 177 and IET 1444; however drought stress reduced these values. Such effect could result from the reduction of CO_2 fixation (Younis et al., 2000), decrease of assimilates translocation (Westgate, 1994) and reduction in the expression of starch and protein synthesis genes (He et al., 2012). A higher STI value is an indicator of higher tolerance to drought (Shirani Rad and Zandi, 2012). Based on this index, stressed cv. IET 1444 was the superior compared to cv. Giza 177 with respect to drought stress tolerance. Uniformity in shape is considered as the first quality characteristics of rice. The requirements to improve quality of rice cannot be over emphasized. The length of the stressed yielded grains cv. Giza 177 and cv. IET 1444 reduced compared to well- watered grains. Thus, L/B ratio of rice IET 1444 grains was greater compared to those of cv. Giza 177. The largest increase in grain breadth was recorded in Giza 177. However, grains of IET 1444 showed high increments in length compared with Giza 177. The increase in length without increase in breadth is desirable characteristics in high quality rice cultivar (Hossain et al., 2009; Danbaba et al., 2011). IET 1444 grains has highest L/B ratio and therefore possesses good cooking qualities. The decrease in rice grain length and breadth under drought could be associated with a reduced capacity of endosperm to accumulate dry matter (Bingham, 1969). During cooking, rice grains absorb water and increase in volume in terms of length and breadth. The percentage of water absorbed (WU) by rice during cooking is considered an economic quality. Data in Table 3 showed that, the percentage of water uptake (WU) during cooking was higher in grains of Giza 177 than that in grains of IET 1444. Imposition of drought stress increased the percentage of water uptake in both cultivars under investigation particularly of Giza 177 grains which added another favorable advantage for cv. IET 1444. A higher WU of rice showed pasty appearance (Hossain et al., 2009) which is not favorable for cooking and eating quality. A positive relation between amylose content and water uptake was observed in grains of the two rice cultivars (Table 3). Such result was consistent with the results reported by Hussian et al. (1987). Either Se or Si treatment improved grain quality of both cultivars by reducing the percentage of WU. Carbohydrate that represented one of the main constituents of the dry matter is affected by drought stress. The present results indicated that, drought stress manifested marked decreases in total soluble carbohydrates and starch contents of the grains of both rice cultivars (Table 4). Such effect might be attributed to the decrease in photosynthetic rate which disrupt the carbohydrate metabolism in leaves and might lead to the reduction in assimilate transported to the sink organs, thereby increasing the reproductive abortion (Westgate, 1994). The increments in the accumulation of total soluble carbohydrate and starch contents of Se pretreated stressed rice grains might be attributed to the increments of photosynthetic pigments (Yao et al., 2009) thereby results in enhancement of carbohydrate synthesis. In addition, the antioxidative effect of Se particularly on the chloroplasts can delay senescence (Hartikainen et al., 2000). On the other hand, Si enhancement effect was attributed to its effect in stimulation of chlorophyll formation and protection of photosynthetic apparatus and consequently decreased the damage caused by water stress (Avila et al., 2010). It is clearly shown that, grain weight was positively related to grain protein content (Tables 2 and 4). Environmental conditions during grain filling influence the accumulation of protein in the developing rice grain and can alter the functional properties of the resulting flour. Variations in protein content significantly modify grain quality (Futakuchi et al., 2008). In fact, the increase in grain protein content improves the nutritional value; however, it gives very bad taste. Distelfeld et al. (2007) suggested the possible role of proteins as potential chelators for some micronutrients. Thereby, the decreased protein content in rice grains is considered a step in improving grain quality. In addition, the weight of 1000-grain was negatively related to antioxidant capacity of rice grain. These relationships may serve as indexes for selection of breeding lines (Shen et al., 2009). It is well known that drought stress, like other stresses, induces increments in the production of reactive oxygen species (ROS), which in excess could be harmful to plant cells. Phenols and flavonoids act as reducing agents, hydrogen

Table 3. Effects of selenium and silicon on the cooking and eating quality (grain length, breadth, L/B ratio, water uptake and amylose content) of the two rice cultivars; Giza 177 and IET 1444 grown under drought condition.

	Parameters / Treatments	Grain length (mm)	Grain breadth (mm)	L/B	Water uptake (%)	Amylose (%)
Giza 177	Well-watered	5.27 ± 0.5^{cd}	2.94 ± 0.2^{a}	1.79 ± 0.1^{cd}	430 ± 6.8^{b}	12.9 ± 1.2^{f}
	Drought	5.16 ± 0.3^{d}	2.91 ± 0.1^{a}	1.77 ± 0.3^{d}	450 ± 5.3^{a}	15.4 ± 1.3^{e}
	Drought + Se	5.24 ± 0.2^{bcd}	2.80 ± 0.2^{b}	1.87 ± 0.2^{c}	415 ± 5.8^{d}	18.4 ± 1.1^{cd}
	Drought + Si	5.44 ± 0.4^{bc}	2.88 ± 0.1^{a}	1.88 ± 0.3^{cd}	425 ± 3.9^{c}	19.5 ± 1.5^{c}
IET 1444	Well-watered	5.64 ± 0.4^{a}	2.22 ± 0.2^{c}	2.54 ± 0.2^{ab}	395 ± 7.7^{g}	18.0 ± 1.7^{d}
	Drought	5.52 ± 0.5^{cb}	2.19 ± 0.3^{cd}	2.52 ± 0.2^{b}	410 ± 4.8^{e}	19.1 ± 1.9^{c}
	Drought + Se	5.59 ± 0.3^{abc}	2.18 ± 0.4^{d}	2.56 ± 0.2^{ab}	400 ± 3.9^{f}	20.4 ± 2.1^{a}
	Drought + Si	5.60 ± 0.4^{ab}	2.13 ± 0.3^{d}	2.63 ± 0.2^{a}	390 ± 2.2^{g}	21.8 ± 1.1^{b}
LSD at 5%	Cultivars	0.04	0.10	0.06	3.83	0.45
	Treatments	0.20	0.04	0.10	2.71	0.65
	Interaction	0.287	0,056	0.138	6.67	0.92

Data represent mean ±SD of ten replicates. Different letters in each treatment and each column show significant difference at P 0.05 by least significant difference (LSD).

donators, chelators of metal catalyst and singlet oxygen quenchers (Shahidi and Wanasundra, 1992). However, our study indicated that drought stress caused increase in antioxidant capacity of both cultivars parallel with reduction in phenolic and flavonoid content (Table 4). Thus the observed increase in antioxidant capacity is not attributed to the redox properties of either phenols or flavonoids. Selenium or silicon application enhances the production of both phenols and flavonoids parallel with further promotion in grain-antioxidant capacity of drought-stressed rice plant. The finding of the present study was in conformity with previous studies which state that Se and Si can alter antioxidant levels in plants and detoxify superoxide radicals, thus preventing oxidative damage and protecting the membranes and enzymes (Habibi, 2013; Karmollachaab et al., 2013). Food crop breeding strategies, for higher levels of nutrients and low levels of anti-nutritional substances, such as phytic acid and oxalic acid, are reported (Hotz and Gibson, 2007). Our results revealed that, drought stress significantly elevated the oxalate content of rice grains under investigation concomitant with reduction in phytic acid content. It could conclude that phytate has no direct relationship with tolerance of rice. In contrast Singh et al. (2012) reported that drought stress clearly resulted in significant increase in phytic acid of wheat grains. Under drought stress IP3 accumulates (Takahashi et al., 2001) resulting in releasing of Ca^{2+} from intercellular stores which leads to stomatal closure. The drought stress-induced pathway in the two investigated cultivars does not involve the phosphorylation of IP3 thereby the observed decrease in IP6 (phytate) which was parallel with increment in Ca^{2+} and Pi level. The observed increase in grain- Pi of drought-stressed plants was concomitant with decrease in starch and consequently grain yield. Such effect might be attributed to the inhibition of starch synthesis by high (Pi) inorganic phosphate (Hannah, 1997). Previous studies on rice, wheat, rye and soy indicated that phytates cause calcium binding as oxalates. Oxalic acid is being the major chelator of calcium, hence releasing calcium for biological activities (Sarkiyayi and Agar, 2010). Thereby, the increase in calcium content in grains under water deficit condition could be due to the observed increase in oxalic acid (Table 5). On the other hand, the phytic acid concentration is negatively related with Fe concentration in the grain. This result supports the findings of Kadan and Phillippy (2007). Either Se or Si significantly reduced oxalate in grains (Table 5), thus increasing the nutritional quality of gains as reported by Hotz and Gibson (2007). Grain yield was strongly related to straw production and both were positively related to the plant height before harvest. It is of interest to mention here that the observed decrease in straw yield under drought stress was accompanied by high percentage of cellulose, pectin and lignin (Table 6) which in turn was concomitant with a sharp decrease in soluble sugar contents in the yielded straw. Such result was supported by Taiz and Zeiger (2006). Si treatment caused further increase in lignin, cellulose and pectin contents as compared with drought stressed plants. Similarly, Inanaga et al. (1995) suggested that, lignin synthesis is reduced in silicon deficient plants. The observed relative decrease in phytic acid and K contents (Table 7) in straw from drought stressed rice plants were accompanied by proportional increases in Pi and Ca ions level. Both Se and Si treatments increased K and total P levels of straw. This result was confirmed by the finding of Hu and Wang (1995) who indicated that there was a positive relationship between Si and both K and total P. Moreover, Si treatment increases Ca^{+2} and K^{+} uptake (Tuna et al., 2008). The positive effect of selenium on K^{+} and Ca^{+2} accumulations was also observed by (Saffaryazdi et al., 2010) in spinach roots.

In conclusion, the response of the two investigated rice cultivars to drought stress was different. IET 1444 rice showed good cooking and eating characteristics as well as high yield potential under drought stress. Furthermore, these results highlight that Si and Se is not only involved in amelioration of the hazards caused by water deficit, but can also improve yield quality under drought stress. However, the mechanism of grain quality improvement needs further elucidation particularly on the molecular level.

Materials and Methods

Plant materials and growth condition

This experiment was conducted at the farm of the Rice Research and Training Center, Sakha, Kafr El-Sheikh, Cairo, Egypt during the summer season 2010.

Table 4. Effects of selenium and silicon on the grain nutritional value of the two rice cultivars Giza 177 and IET 1444 grown under drought condition.

Cultivar	Treatments \ Parameters	Soluble carbohydrate	Starch	Soluble protein	Insoluble protein	Oil content (%)	Total phenols	Flavonoids	T.A.C
Giza 177	Well-watered	4.36±0.2^{a}	15.2±1.6^{d}	2.45±0.1^{cd}	1.25±0.1^{b}	4.24±0.2^{b}	0.258^{e}	0.57^{e}	0.19^{d}
	Drought	3.04±0.1^{c}	10.4±0.5^{e}	2.10±0.1^{bcd}	0.64±0.06^{c}	2.88±0.6	0.165^{f}	0.54^{e}	0.22^{bc}
	Drought + Se	4.32±0.4^{a}	19.8±0.7^{a}	1.87±0.1^{cd}	1.52±0.6^{ab}	4.39±0.3	0.173^{de}	0.71^{b}	0.25^{b}
	Drought + Si	3.39±0.2^{b}	13.5±0.9^{d}	1.75±0.2^{d}	1.89±0.6^{a}	4.61±0.6	0.230^{e}	0.66^{c}	0.22^{bc}
IET 1444	Well-watered	3.42±0.2^{b}	16.2±0.3^{bc}	4.80±0.8^{a}	1.14±0.04^{b}	6.08±0.9	0.339^{c}	0.67^{bc}	0.21^{cd}
	Drought	1.89±0.1^{e}	11.6±0.7^{e}	2.57±0.9^{b}	0.89±0.4^{c}	5.13±0.7	0.173^{d}	0.60^{d}	0.24^{b}
	Drought + Se	4.33±0.5^{a}	15.8±1.6^{cd}	2.02±1.0^{bcd}	1.60±0.7^{ab}	10.5±1.3	0.258^{a}	0.66^{ab}	0.35^{a}
	Drought + Si	2.19±0.1^{d}	16.6±1.4^{b}	2.40±0.7^{bc}	1.28±0.8^{ab}	7.65±0.5	0.303^{b}	0.79^{c}	0.33^{a}
LSD at 5%	Cultivar	0.11	0.4	0.34	0.09	0.32	0.01	0.04	0.05
	Treatment	0.22	3.9	0.32	0.24	0.44	0.02	0.04	0.04
	Interaction	0.31	5.5	0.45	0.33	0.63	0.03	0.06	0.056

Data represent mean ±*SD* of ten replicates. Different letters in each treatment and each column show significant difference at *P* 0.05 by least significant difference (LSD).

Table 5. Effects of selenium and silicon on the phytate P, inorganic P, total P, Ca, Fe, phytic and oxalic acid contents of the two rice grains cultivars Giza 177 and IET 1444 grown under drought condition.

Cultivar	Treatments \ Parameters	Phytate P	Non phytate P	Inorganic P	Total P	Phytic acid	Oxalic acid	Ca	Fe
Giza 177	Well-watered	1600±5.4^{a}	39.0±3.2^{e}	4.26±0.2^{d}	1639.0±5.8^{b}	5680^{a}	160.2^{d}	26.0±1.4^{e}	11.7±0.5^{c}
	Drought	760±3.2^{f}	769.3±8.4^{a}	5.21±0.5^{c}	1529.3±4.4^{cd}	2698^{f}	286.3^{b}	27.9±1.1^{d}	12.6±0.3^{b}
	Drought + Se	1160±10.7^{d}	688.2±2.2^{ab}	6.51±0.3^{ab}	1848.2±5.1^{a}	4118^{d}	110.0^{e}	67.7±3.7^{a}	14.2±0.4^{a}
	Drought + Si	840±4.3^{e}	638.3±2.2^{b}	6.26±0.2^{b}	1478.3±3.4^{de}	2982^{e}	154.6^{d}	29.9±2.2^{c}	14.9±1.2^{a}
IET 1444	Well-watered	1240±6.6^{c}	378.6±3.1^{c}	4.38±0.1^{d}	1618.6±3.1^{b}	4402^{c}	220.8^{c}	27.5±1.0^{d}	9.6±0.6^{d}
	Drought	1060±8.3^{d}	415.1±2.3^{c}	4.97±0.5^{c}	1475.1±4.5^{f}	3763^{d}	374.5^{a}	30.6±1.8^{bc}	10.1±0.7^{c}
	Drought + Se	1320±8.2^{b}	183.8±1.2^{ed}	6.39±0.5^{a}	1503.8±4.8^{e}	4686^{b}	132.5^{d}	30.9±1.0^{b}	14.8±1.5^{a}
	Drought + Si	1340±9.1^{b}	222.5±2.7^{d}	7.10±0.2^{b}	1562.5±6.2^{c}	4757^{b}	137.4^{d}	30.4±1.4^{bc}	13.9±0.8^{b}
LSD at 5%	Cultivar	22.3	63.0	0.30	41.1	79.3	7.6	0.56	0.37
	Treatments	56.2	54.3	0.26	25.5	199	19.3	0.58	0.73
	Interaction	79.5	76.8	0.37	36.1	182	27.3	0.82	1.03

Data represent mean ±*SD* of ten replicates. Different letters in each treatment and each column show significant difference at *P* 0.05 by least significant difference (LSD).

Table 6. Effects of selenium and silicon on the straw yield quality of the two rice cultivars Giza 177 and IET 1444 grown under drought condition.

Cultivars	Giza 177				IET 1444				LSD at 5%		
Treatments / Parameters (mg/g DW)	Well-watered	Drought	Drought +selenium	Drought+ silicon	Well-watered	Drought	Drought +selenium	Drought+ silicon	Cultivar	Treatment	Interaction
Straw weight (g/plant)	44.2±3.2^{a}	23.3±1.2^{c}	26.5±2.1^{b}	25.1±3.4^{b}	22.4±3.2^{c}	14.8±1.3^{f}	16.0±0.4^{e}	20.3±0.8^{d}	2.84	1.07	1.51
Soluble carbohydrate	1.24±0.2^{bc}	0.64±0.3^{e}	1.41±0.2^{b}	1.03±0.1^{cd}	1.74±0.2^{a}	0.83±0.09^{d}	1.05±0.07^{c}	1.27±0.5^{b}	0.07	0.12	0.17
Insoluble carbohydrate	24.6±1.2^{b}	18.8±1.3^{d}	19.5±2.1^{cd}	21.3±3.2^{c}	26.4±1.1^{a}	15.7±0.8^{e}	23.5±0.4^{ab}	24.1±0.7^{ab}	2.78	1.37	1.94
Total carbohydrates	25.8±1.5^{b}	19.4±1.6^{d}	20.9±2.4^{c}	22.3±3.3^{c}	28.1±1.6^{a}	16.5±1.9^{e}	24.6±0.6^{ab}	25.4±0.5^{ab}	2.8	1.40	1.98
Soluble protein	0.61±0.01^{c}	0.15±0.01^{e}	0.80±0.03^{b}	0.38±0.05^{d}	0.86±0.06^{b}	0.23±0.04^{d}	0.31±0.04^{d}	1.16±0.07^{a}	0.11	0.07	0.10
Insoluble protein	8.0±0.4^{b}	3.0±0.3^{d}	4.6±0.6^{d}	4.1±0.2^{d}	10.6±0.8^{a}	6.5±0.3^{c}	6.9±0.3^{bc}	6.6±0.7^{c}	0.38	0.81	1.15
Total proteins	8.7±0.4^{b}	3.2±0.3^{f}	5.4±0.1^{e}	4.5±0.1^{ef}	11.5±1.0^{a}	6.7±0.8^{d}	7.2±0.5^{cd}	7.8±0.6^{bc}	0.35	1.20	1.69
Cellulose	450.2±2.4^{g}	458.3±4.3^{f}	479.3±2.1^{e}	598.1±1.9^{b}	489.5±1.7^{de}	494.6±2.6^{d}	653.4±3.5^{a}	508.8±3.2^{c}	6.12	6.63	9.38
Pectin	356.2±2.4^{e}	400.0±3.6^{c}	422.3±4.1^{b}	409.5±2.8^{b}	315.7±1.9^{f}	382.1±1.8^{d}	449.1±3.4a	390.3±3.3^{c}	9.11	6.52	9.23
Lignin	117.4±0.8^{e}	154.6±0.8^{d}	298.2±0.7^{b}	355.4±1.3^{a}	105.8±0.6^{e}	111.6±1.4^{e}	282.0±1.8^{b}	239.2±1.2^{c}	7.07	9.10	12.87

Data represent mean ±*SD* of ten replicates. Different letters in each treatment and each column show significant difference at *P* 0.05 by least significant difference (LSD).

Table 7. Effect of selenium and silicon on the phytate P, non-phytate P, phytic acid, inorganic P, total P, K and Ca contents in straw of two rice cultivars (Giza 177 and IET 1444) grown under drought condition.

	Treatments / Parameters	Ca	K	Total P	Phytate P	Non phytate P	Inorganic P	Phytic acid
Giza 177	Well-watered	107.9±1.9^{f}	1498.7±4.5^{c}	2718.7±6.0^{e}	2436±5.5^{c}	282.7±5.9^{h}	6.4±0.4^{c}	8647.8±13.2^{c}
	Drought	139.4±6.8^{e}	750.0±2.5^{h}	2423.4±4.2^{g}	1384±7.3^{h}	1039.4±10.3^{d}	8.2±0.5^{a}	4913.2±10.3^{h}
	Drought + Se	209.9±2.8^{c}	1015.0±5^{g}	2623.0±6.6^{f}	2200±7.9^{d}	423.0±3.5^{f}	6.9±0.2^{c}	7810.0±14.2^{d}
	Drought + Si	233.1±2.5^{b}	1085.0±8.7^{f}	3237.4±6.7^{b}	2928±8.3^{a}	309.4±6.3^{g}	7.9±0.2^{b}	10394.4±15.3^{a}
IET 1444	Well-watered	193.5±2.1^{d}	2317.5±6.1^{a}	3563.7±9.5^{a}	2808±4.9^{b}	755.7±6.4^{e}	4.8±0.1^{e}	9968.4±12.0^{b}
	Drought	259.7±4.9^{a}	1199.4±4.1^{e}	2846.3±8.7^{d}	1784±5^{g}	1062.30±3.2^{c}	6.7±0.6^{c}	6333.2±12.4^{g}
	Drought + Se	263.0±2.7a	1260.0±2.7^{d}	3184.3±4.7^{c}	2032±6.4^{e}	1152.3±4.3^{b}	4.0±0.2^{e}	7213.6±14.1^{e}
	Drought + Si	269.7±3.1^{a}	2178.7±5.4^{b}	3555.4±6.2^{a}	1904±3.9^{f}	1651.4±9.4^{a}	5.0±0.2^{d}	6759.2±16.4^{f}
LSD at 5%	Cultivar	3.71	5.58	8.99	1.44	9.78	0.30	5.10
	Treatment	5.64	11.41	6.02	4.88	9.27	0.36	17.4
	Interaction	7.98	16.14	8.52	6.97	10.31	0.50	24.1

Data represent mean ±SD of ten replicates. Different letters in each treatment and each column show significant difference at P 0.05 by least significant difference (LSD).

Two local rice (*Oryza sativa* L.) cultivars were utilized in this study namely; Giza 177 and IET 1444. The planting area was divided into 8 plots, each of which was divided into three subplots, each of six m^2 in area; the first four plots were used for cv. Giza 177 and the second ones for cv. IET 1444. The grains were surface sterilized by immersing in 1% sodium hypochlorite solution for 5 minutes, then rinsed thoroughly with distilled water. The sterilized grains divided into three equal lots, which were soaked in water, sodium selenate, and potassium silicate at concentration 0.03 mM and 1.5 mM respectively. Rice grains of the two investigated cultivars were grown in the nursery and after thirty days from sowing; seedlings of each parent were individually transplanted in the permanent field in ten rows. Each row was five meters long and contained 25 hills. The physical and chemical analysis of soil properties of the experimental field are given in (Table 1). Randomized complete block design was used with three replicates. Weeds were chemically controlled by applying 2 liters of Saturn/feddan, four days after transplanting. Nitrogen fertilizer was applied at 40 Kg N/fed. The relative humidity ranged between 55 and 65%. Maximum day temperature was 30-35°C, while minimum night temperature was18-22°C. Seeding rate was 70 kg/feddan. All plots were applied with sufficient irrigation until 30 days before transplanting. Then drought stress condition was imposed in half of each group by withholding water (irrigation every 10 days). The plants were left to grow under the various treatments for five months. Growth measurements were carried out at the end of the experiment. At full maturity (5 months after sowing) the experiment was terminated and ten randomized plants were harvested from each treatment for carrying out the following measurements: plant height (cm), harvest index (%), 1000-grain weight (g), spikelet fertility (%), tillers/plant, tillers carrying panicles/plant, panicle length (cm), filled grains/panicle, total grains/panicle, grain yield/plant, straw weight (g). Moreover, quantity and quality of grain and straw yield were investigated.

Estimation of stress tolerance index (STI)

Stress tolerance index was calculated using the formula of Fernandez (1993) $[STI = Y_p \times Y_s / (\bar{Y}_p)^2]$
Where, Y_p is the yield of cultivar under irrigated condition, Y_s – the yield of cultivar under water deficit stress, $\bar{Y}_p$ – the mean yield of all cultivars under non stress conditions.
Estimation of harvest index (HI)
HI = Economic yield (grain yield) / Biological yield (above ground dry matter) × 100 (Beadle, 1993).

Estimation of dimensional changes

Milled rice length (L) and breadth (B) were measured by randomly picking whole grains and measured with a digital caliper (Hossain et al., 2009).

Estimation of carbohydrate

Soluble sugar was extracted following the method adopted by Homme et al. (1992). Sugar free residue were extracted with 1.5N H_2SO_4 following the method adopted by Naguib (1963). Soluble sugars and those resulting after polysaccharides hydrolysis were estimated by the method adopted by Blakeney and Mutton (1980). Starch was extracted following the method adopted by Hassid and Neufeld (1962) and was determined with the anthrone reagent (Fairbairn, 1953).

Estimation of protein and oil content

The total soluble protein contents were measured by using Folin-Cicalteu reagent according to the procedure described by Daughaday et al. (1952). Extraction of oil was carried out for 2 h with sohxlet extraction units. Hexane was refluxing at a steady rate. The solvents were recovered and the oil was dried in the oven at 70ºC for 1 h. and then weighed according to the AOAC (2002) method.

Estimation of flavonoids, total antioxidant capacity and phenols

Flavonoids were estimated according to the method described by Harborne (1998), while total antioxidant capacity or ferric reducing ability power (FRAP) was carried out following the method reported by Oyaizu (1986). Total phenols were extracted and estimated following the method described by Malik and Singh (1980).

Amylose content (AC)

A simplified procedure of Juliano (1971) was used for amylose content analysis. 100 mg of rice powder was mixed with 1ml of 95% ethanol and 9 ml of 1N NaOH and were heated on a boiling water bath to gelatinize the starch. 1 ml of 1N acetic acid, 2 ml iodine solution was added and volume made up with distilled water. Absorbance was measured at 620 nm with a spectrophotometer (Model AA-6650, Shimadzu Co. Japan)

Determination of Phytate and non phytate phosphorus content

The method based on phytic phosphorus analysis in the precipitate after reaction of phytate with ferric chloride. Phytate P was determined spectrophotometrically at 480 nm; phytic acid was then calculated using the factor 3.55 (Wheeler and Ferrel, 1971). Non phytate P was calculated by subtracting phytate P from total P of the untreated samples. Total P was determined according to the method described by Hanson (1973). Inorganic P was extracted by the method described by Khetarpaul and Chauhan (1989) and then determined according to the method described by Hanson (1973).

Oxalate Determination

Oxalate was estimated according to the titration method as described by Day and Underwood (1986). The oxalate content was then calculated by taking 1ml of 0.05m KMnO4 as equivalent to 2.2mg oxalate (Chinma and Igyor, 2007).

Extraction and determination of certain elements

The method of extraction adopted in this investigation was essentially that of Chapman and Pratt (1961). Calcium, potassium and iron were analyzed from the triple acid digestion (wet digestion method) and were measured using atomic absorption spectrophotometer according to the method of The AOAC (2002).

Determination of cellulose, pectin and lignin contents

The methods were described by Jenkins (1930), Nanji and Norman (1928) and Rittler et al. (1932), respectively.

Statistical analysis

Statistical analysis was performed using the two- way analysis of variance (ANOVA) test following Steel and Torrie (1980). Mean values were compared with a least significance difference test (LSD) following Snedecor and Cochran
(1980).

References

Agarie S, Uchida H, Agata W, kubota F, kaufamn B (1993) Effect of silicon on growth, dry matter production and photosynthesis in rice (*Oryza sativa* L.). Crop Prod Improve technol. 34: 225-234

Anjum SA, Xie X, Wang L, Saleem MF, Man C, Lei W (2011) Morphological, physiological and biochemical responses of plants to drought stress. Afri J Agric Res. 6: 2026-2032

Anonymous (2004) Laboratory manual on rice grain quality procedure. Directorate of rice research, Rajendranagar, Hyderabad, India, p 1-20

AOAC (2002) Official methods of analysis. Association of official analytical chemistinternational, ed 17th. Gaithersburg MD, USA. Rosenthal A, Pyle

Avila FW, Baliza DP, Eaquin V, Araújo JL, Ramos SJ (2010) Silicon-nitogen interaction in rice cultivated under nutrient solution. Rev Ciência Agron. 41: 184-190

Balastra ML, Juliano CM, Villreal P (1989) Effect of silica level on some proprieties *Oryza sativa* straw and Hult. Can J Bot. 67: 2356-2363

Beadle CL (1993) Growth analysis. In: Photosynthesis and production in a changing environment. A field and laboratory manual (eds: Hall DO, Scurlock JMO, Bolhar- Nordenkampf HR, Leegood RC and Long SP), Chapman and Hall, London, p 36-46

Bingham J (1969) The physiological determinants of grain yield in cereals. Agric Progr. 44: 30-42

Blakeney AB, Mutton LL (1980) A simple calorimetric method for the determination of sugars in fruits and vegetables. J Sci Food Agric. 31: 889-897

Chapman HD, Pratt PF (1961) Method of analysis for soil, plants and waters. University of California, Agricultural Science, Berkeley, p309

Chinma CE, Igyor MA (2007). Micronutrients and anti-nutritional contents of selected tropical vegetables grown in Southeast, Nigeria. Nigerian Food J. 25: 111-116

Chu J, Yao X, Yue Z, Li H, Zhao J (2013) The effects of selenium on physiological traits, grain selenium content and yield of winter Wheat at different development stages. Biol Trace Elem Res. 151: 434-440

Cruz ND, Khush GS (2000) Rice grain quality evaluation procedures. In: Singh RK, Singh US and Khush GS (Eds). Aromatic Rices, Oxford and IBH Publishing Co Pvt. Ltd, New Delhi, p 15-28

Danbaba N, Anounye JC, Gana AS, Abo ME, Ukwungwu MN (2011) Grain quality characteristics of *Ofada* rice (*Oryza sativa* L.): Cooking and eating quality. Int Food Res J. 18: 629-634

Daughaday WH, Lowry OH, Rosebrough NJ, Fields WS (1952) Determination of cerebrospinal fluid protein with the folin phenol reagent. J Lab Clin Med. 39: 663-665

Deren CW, Datnoff LE, Snyder GH, Martin FG (1994) Silicon concentration, disease response, and yield components of rice genotypes grown on flooded organic histosols. Crop Sci. 34: 733-737

Distelfeld A, Cakmak I, Peleg Z (2007) The high grain protein concentration locus, *Gpc-B1*, on chromosome arm 6BS of wheat is also associated with high grain iron and zinc concentrations. Physiol Plant. 129: 635-643

Fairbairn NJ (1953) A modified anthrone reagent. Chem Indust. 4: 285-313

Fernandez GCJ (1993) Effective selection criteria for assessing stress tolerance: proceedings of the International symposium on adaptation of vegetables and other food crops in temperature and water stress tolerance. World Vegetable Center (AVRDC). Shan Hua, Taiwan, p 257-270

Forbes RM, Erdman JW (1983) Bioavailability of trace mineral elements. Ann Rev Nutr. 3: 213-231

Futakuchi K, Watanabe H, Jones MP (2008) Relationship of grain protein content to other grain quality traits in interspecific *Oryza sativa* L. *Oryza glaberrima* steud. Progenies Agric J. 3: 50-57

Gholami Y, Falah A (2013) Effects of two different sources of silicon on dry matter production, yield and yield components of rice, Tarom Hashemi variety and 843 Lines. Int J Agric Crop Sci. 5: 227-231

Graf E, Eaton JW (1990) Antioxidant functions of phytic acid. Free Rad Biol Med. 8: 61-69

Habibi G (2013) Effect of drought stress and selenium spraying on photosynthesis and antioxidant activity of spring barley. Acta agric Slovenica. 101: 31-39

Hannah LC (1997) Starch synthesis in the maize seed. In Larkins BA, Vasil IK, (eds), Cellular and Molecular Biology of Plant Seed Development. Kluwer Academic Publishers, Dordrecht, the Netherlands, p 375-405

Hanson NW (1973) Official, standardized and recommended methods of analysis, London: the Society for Analytical Chemists. 12: 34-35

Harborne JB (1998) Photochemical methods: A guide to modern technique of plant analysis, 3rd Ed. Champman and Hall, London, UK, p 302

Hartikainen H (2005) Biogeochemistry of selenium and its impact on food chain quality and human health. J Trace Elem Med Biol. 18: 309-318

Hartikainen H, Xue T, Piironen V (2000) Selenium as an antioxidant and pro-oxidant in ryegrass. Plant and Soil. 225: 193-200

Hassid WZ, Neufeld EF (1962) Whole starches and modified starches. Quantitative determination of starch in plant tissues. Vol.4. In Whistler, R.L. (ed). Methods in Carbohydrate Chemistry. Academic Press. Inc. New York, p 33-36

Hawrylak-Nowak B (2009) Beneficial effects of exogenous selenium in cucumber seedlings subjected to salt Stress. Biol Trace Elem Res. 132: 259-269

He JF, Goyalb R, Larocheb A, Zhaoa, ML, Lu ZX (2012) Water stress during grain development affects starch synthesis, composition and physicochemical properties in triticale. J Cereal Sci. 56(3): 552–560

Hotz C, Gibson RS (2007) Traditional food-processing and preparation practices to enhance the bioavailability of micronutrients in plant-based diets. J Nutr. 137: 1097-100

Homme PM, Gonalez B, Billard J (1992) Carbohydrate content, fructane and sucrose enzyme activities in roots, stubble and leaves of rye grass (*Lolium perenne* L.) as affected by source/sink modification after cutting. J Plant Physiol. 140: 282-291

Hossain MS, Singh AK, Fasih-uz-Zaman (2009) Cooking and eating characteristics of some newly identified inter sub-specific (*indica/japonica*) rice hybrids. Sci Asia. 35: 320-325

Hsiao TC (2000) leaf and root growth in relation to water status. Hort Sci. 35: 1051-1058

Hu DJ, Wang FH (1995) Silica nutrition of rice. Agric Sci Hubei (Chinese). 5: 33-36

Hussian AA, Muarya DM, Waish CP (1987) Studies on quality status of indigenous up land rice (*Oryza sativa*). Indian J Genet. 47: 145-152

Ibrahim AH, El-Shahaby OA, Abo-Hamed SA, Younis ME (2013) Parental drought and defoliation effect on yield, grains. Biochemical aspects and drought performance of sorghum progeny. J Stress Physiol Biochem. 9: 258-272

Inanaga S, Okasaka A, Tanaka S (1995) Does silicon exist in association with organic compounds in rice plant? Soil Sci Plant Nutr. 41: 111-117

Jenkins SH (1930) Determination of cellulose in straw. Biochem J. 24: 1428

Juliano BO (1971). A simplified assay for milled rice amylose. Cereal Sci Today. 16: 334-338

Kadan RS, Phillippy BQ (2007) Effects of yeast and bran on phytate degradation and minerals in rice bread. J Food Sci. 72: 208-211

Karmollachaab A, Bakhshandeh A, Gharineh MH, Telavat MRM, Fathi G (2013) Effect of silicon application on physiological characteristics and grain yield of wheat under drought stress condition. Int J Agron Plant Prod. 4: 30-37

Katoa Y, Kanoshitab A, Yamagishia J (2008) Pre-flowering abortion reduces spikelet number in upland rice (*Oryza sativa* L.) under water stress. Crop Sci Soc Am. 48: 2389-2395

Khetarpaul N, Chauhan BM (1989) Effect of fermentation on protein, fat, minerals and thiamine content of pearl millet. Plant Food Hum Nutr. 39: 169-177

Kim YH, Khan AL, Shinwari ZK, Kim DH, Waqas M, Kamran M, Lee IJ (2012) Silicon treatment to rice (*Oryza sativa* L. cv 'gopumbyeo') plants during different growth periods and its effects on growth and grain yield. Pak. J Bot. 44: 891-897

Kousar A, Mallick SA, Moni G, Sachin G, Mondal AK (2012) Drought stress responses of wheat genotypes with respect to nutritional quality. Indian J Agri Biochem. 25: 94-99

Liu K, Ye Y, Tang C, Wang Z, Yang J (2008) Responses of ethylene and ACC in rice grains to soil moisture and their relations to grain filling. Front Agric China. 2: 172-180

Ma JF (2004) Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses. Soil Sci Plant Nutr. 50: 11-18.

Malik CP, Singh MB (1980) In: Plant enzymology and histo-enzymology. Kalyani Publishers. New Delhi, p 286

MSTAT (1988) MSTAT- C, a microcomputer program for the design, arrangement and analysis of agronomic research. Michigan State University, East Lansing

Mohammed AR, Tarpley L (2011) High night temperature and growth regulator effects on spikelet sterility, grain characteristics and yield of rice (*Oryza sativa* L.) plants. Canadian J Plant Sci. 91: 283-291

Naeemi M, Akbari G, Shirani Rad AH, Modares Sanavi SAM, Sadat- Nuri SA, Jabari H (2008) Evaluation of drought tolerance in different Canola cultivars based on stress evaluation indices in terminal growth duration. Electronic J Crop Prod. 1(3): 83-98

Naguib MI (1963) Colourimetric estimation of plant polysaccharides. Zucher. 16: 15-18

Nanji DR, Norman AG (1928) Pectin estimation of the individual pectic substances in nature. Biochem J. 22: 596-604

Nolla A, de Faria RJ, Korndörfer GH, da Silva TRB (2012) Effect of silicon on drought tolerance of upland rice. J Food Agric Enviro. 10: 269-272

Orthoefer FT (2005) Bailey's industrial oil and fat products, Chapter (10): Rice bran oil, 6^{th} ed., Wiley J and Sons, Inc., p 465-489

Oyaizu M (1986) Studies on products of browning reaction prepared from glucoseamine. Jpn J Nutr. 44: 307-314

Peterson DM (2001) Oat antioxidants. J Cereal Sci. 33: 115-129

Rittler GJ, Seborg R, Mitchell RI (1932) Factors affecting determination of lignin by 72 percent sulphuric acid method. Ind Eng Chem Ann. 4: 202

Saffaryazdi A, Lahouti M, Ganjeali A, Bayat H (2012): Impact of selenium supplementation on growth and accumulation on spinach (*Spinacia oleracea* L.) plants. Not Sci Biol. 4: 95-100

Sarkiyayi S, Agar TM (2010) Comparative analysis on the nutritional and anti-nutritional contents of the sweet and bitter cassava varieties. Adv J Food Sci Technol. 2: 328-334

Sarnklong C, Cone JW, Pellikaan W, Hendriks WH (2010) Utilization of rice straw and different treatments to improve its feed value for ruminants. Asian-Aust J Anim Sci. 23: 680-692

Shahidi F, Wanasundara PK (1992): Phenolic antioxidants. Crit Rev Food Sci Nutr. 32: 67-103

Shamsuddin AM, Vucenik I, Cole KH (1997) IP6: a novel anticancer agent. Life Sci. 61: 343-354

Shirani Rad AH and Abbasian A (2008) Evaluation of drought tolerance in winter rapeseed cultivars based on tolerance and sensitivity indices. Žemdirbystė Agric. 98: 41-48

Singh S, Gupta AK, Kaur N (2012) Influence of drought and sowing time on protein composition, anti nutrients, and mineral contents of wheat. The Sci World J. 9:2344-2352

Steel RGD, Torrie JH (1980) Principles and Procedures of Statistics, second ed. McGraw Hill, New York

Stmopen (2013) Phytic acid content in different parts of grain and its correlation with rice quality traits. Adv J Food Sci Technol. 2: 328-334

Snedecor GW, Cochran WG (1980) Statistical Methods, seventh ed. Iowa State University Press, Ames, Iowa

Taiz L, Zeiger E (2006) Plant Physiology. Publishers: Sinauer Associates, Inc., Massachusetts, USA

Takahashi S, Katagiri T, Hirayama T, Yamaguchi-Shinozaki K, Shinozaki K (2001) Hyperosmotic stress induces a rapid and transient increase in inositol 1,4,5-trisphosphate independent of abscisic acid in Arabidopsis cell culture. Plant Cell Physiol. 42: 214-222

Tuna AL, Kaya C, Higgs D, Murillo-Amador B, Aydemir S, Girgin AR (2008) Silicon improves salinity tolerance in wheat plants. Environ. Exp. Bot. 62:10-16

Venuprasad R, Lafitte HR, Atlin GN (2007) Response to direct selection for grain yield under drought stress in rice. Crop Sci. 47: 285-293

Westgate ME (1994) Water status and development of the maize endosperm and embryo during drought. Crop Sci. 26: 951-956

Wheeler, Ferrel (1971) A method for phytic acid determination in wheat and wheat fraction. Cereal Chem. 48: 312-320

Xoconostle-Cázares B, Ramírez-Ortega FA, Flores-Elenes L, Ruiz-Medrano R (2010) Drought tolerance in crop plants. Am J Plant Physiol. 5: 241-256

Yao X, Chu J, Wang G (2009) Effects of selenium on wheat seedlings under drought stress. Biological Trace Elem Res. 130: 283-290

Younis ME, El-Shahaby OA, Abohamed SA, Ibrahim AH (2000) Effects of water stress on growth, pigments and $^{14}CO_2$ assimilation in three sorghum cultivars. J Agron Crop Sci. 185: 73-82

Zanjani KE, Rad AHS, Naeemi M, Aghdam AM, Taherkhani T (2012) Effects of zeolite and selenium application on some physiological traits and oil yield of medicinal pumpkin (*Cucurbita pepo* L.) under drought stress. Curr Res J Biol Sci. 4: 462-470