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Sulphur and Chlorine Effects on Yield and Quality in Fresh Corn

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Authors' contributions

This work was carried out in collaboration between all authors. Author TZ designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors DY and HD managed the analyses of the study. Author TZ managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To investigate sulphur (S) and chlorine (Cl) effects on fresh ear yield, yield components and quality in fresh corn.
Study Design: A 3 × 1 × 3 field experiment was set up in RCBD, with three replications. This was integrated with laboratory experiments.
Place and Duration of Study: San Fen Chang Experiment Station, and Crop Genetics and Breeding laboratory of Hebei Agricultural University, Baoding, China, between March 2016 and May 2017.
Methodology: Treatments comprised Control (S_0, Cl_0), S (38 kg ha^{-1}) and Cl (84 kg ha^{-1}); and three hybrids included TDN21 (sweet), JKN2000 (waxy) and JKN928 (sweet and waxy). Total fresh ear yield was calculated from the measured components; quality evaluation focused on taste parameters (relative sweetness, aroma, texture, peel thickness and viscosity), grain nutritional composition (crude protein, starch, fat and lysine contents) and external appearance of ears; whilst Barium sulphur turbidity method was used to assess grain sulphur content.

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Results: Significant (p≤0.05) total fresh ear yield ha^{-1} increases of 18.12%, 17.53% and 6.58% in TDN21, JKN2000 and JKN928 cultivars, respectively, were realized as S influenced some yield components (average fresh ear diameter, ear length and ear weight) evaluated. However, Cl effect was insignificant. Both S and Cl significantly (p≤0.05) improved the kernel taste by increasing relative sweetness and flavour in all cultivars. Additionally, sulphur significantly increased crude protein (CP) in TDN21, whilst chlorine decreased CP by 2.78% to 6.05% in all cultivars. Sulphur significantly increased crude starch by 4.31% and 7.56% in TDN21 and JKN2000, respectively, whereas Cl significantly increased crude fat by 3.43%, 15.17% and 6.60% in cultivars 1, 2 and 3, respectively. Furthermore, sulphur enhanced harvested ears` external appearance in TDN21 and JKN2000 cultivars, contributing to quality improvement.

Conclusion: Sulphur has profound effects on enhancing both yield and quality, whilst chlorine is prominent on quality in fresh corn.

Keywords: Sulphur; chlorine; yield; quality; fresh corn.

1. INTRODUCTION

Differentiated from normal corn types (dent, flint, pop etc.) by the presence of a gene or genes that alter starch synthesis or carbohydrate composition in the endosperm, fresh corn is a specialty corn defined by its use for fresh consumption as cobs or as a vegetable [1-2] and is usually harvested at any early stage of the crop, on or before the milk or early dough stage [3]. Common examples are sweet corn (*Zea mays* L. *saccharata or rugosa*), waxy corn (*Zea mays* L. *ceratina*) and baby corn.

Fresh corn is an important crop worldwide [4-5] whose production has recently surged in China and the world over [6-7] largely because of increased domestic consumption, and export development for food, nutritional requirements, economic benefits to farmers and raw material support to the processing sector [8-9]. This rising twin trek demand has increased tendency for commercial production of fresh corn. However, like many other major food crops, its production is hampered by supply of soil plant nutrients among other challenges.

Realizing the rising local and global fresh corn demands, there is need for enhancing its production through modifying soil nutrient supply, among other strategies. Sulphur (S) macronutrient has been widely reported to enhance crop yield and quality in some crop species; particularly in sunflower (*Halianthus annuus* L.) [10], winter wheat [11], groundnuts [12], *Glycine max* L. [13], maize [14-15], spinach and pepper [16], onion [17-18], mustard [19], canola rapeseed oil [20-21] and others [22-24]. In addition, chlorine micronutrient has also been revealed to improve product quality [25-26]. Despite all this, however, fresh corn producers, have paid little attention to fulfilling the S and Cl fertilization needs because of elusive information.

This study, therefore, aimed at investigating the yield and quality effects of sulphur and chlorine in fresh corn using three different hybrid cultivars; TDN21 (*Tian dan 21*), sweet; JKN2000 (*Jing ke nuo 2000)*, waxy; and JKN928 (*Jing ke nuo 928*), sweet and waxy. The specific objectives of this research were; (1) Evaluating the effects of S and Cl on total fresh ear yield (kg ha^{-1}). (**2**) Evaluating the effects of S and Cl on yield components (ears $plant^{-1}$, ears ha^{-1}, ear length, ear diameter, average fresh ear weight, kernels row^{-1}, kernels ear^{-1}, kernel rows ear^{-1}, 100 dry-kernel-weight) and (**3**) Evaluating the effects of S and Cl on the grain quality parameters, by looking into the taste characteristics (relative sweetness, flavour, texture, viscosity and peel thickness); external quality; as well as the crude protein, starch, fat, lysine (amino acid) and sulphur contents of kernels.

2. MATERIALS AND METHODS

2.1 Plant Materials

Three different fresh corn hybrid cultivars were used in this research. *Tian dan 21* (TDN21) is a relatively high-sugar-content sweet cultivar from the National Maize Improvement Centre of China Agricultural University, Beijing. *Jing ke nuo 2000* (JKN2000) is a low-sugar-content waxy cultivar and *Jing ke nuo 928* (JKN928) is a sweet-and-waxy corn cultivar, both from the Maize Research Centre of Beijing Academy of Agriculture and Forestry Sciences.

2.2 Field Experimental Site

Field experiment was conducted at San Fen Chang Experiment Station of Hebei Agricultural

University, Baoding, China, during 2016-2017 summer season. The station, at 38°44′ N latitude, 115°29′ E longitude and 23 m altitude, is located in the middle of the Hebei Agricultural Plain. It is a typical temperate continental arid climate, with a mean annual temperature of 14°C and an average annual precipitation of 500 mm, most (80%) of which falls between July and September. The soil at the experimental field is clay-loam, and it had pH 6.9, 10.25 g kg^{-1} organic matter, 0.85 g kg^{-1} total nitrogen (N), 30.35 mg kg^{-1} readily available phosphorus (P) and 100.52 mg kg^{-1} readily available potassium (K) in the upper 0.4 m.

2.3 Field Experimental Design

Experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The treatments comprised the control (CK), and one level each for sulphur and chlorine. The unit plot size measured 4.8 m x 3.6 m and the plant spacings used were 0.6 m inter-row and 0.3 m in-row, giving 96 plants per plot. The calculated quantities of N, P, K, S and Cl in the form of urea ($CO(NH_2)_2$), diammonium phosphate ($(NH_4)_2H_2PO_4$), monopotassium phosphate ($K_2H_2PO_4$), potassium sulphate (K_2SO_4) and potassium chloride (KCl), respectively were applied as per the treatments to give 195 kg ha^{-1} N, 150 kg ha^{-1} P, 105 kg ha^{-1} K, 38 kg ha^{-1} S and 84 kg ha^{-1} Cl. All of P, K, S and N were applied at the time of sowing. All the agronomic practices were kept normal and uniformly applied to all treatments. Phenological observations and yield components data were recorded.

2.4 Measurement of Parameters

2.4.1 Yield estimation

The crop was harvested on attaining the appropriate maturity levels as per the harvest indices suggested by Liu [27]. Because of the intrinsic yield and quality differences of varieties, the ears were not harvested at the same days after planting (DAP), but rather, the ear water content was adopted as the harvesting index. The fresh corn ears were harvested at 70-78% for TDN21 and 65-72% ear water contents for JKN2000 and JKN928 cultivars.

Total fresh ear yield (kg ha^{-1}) was estimated from the yield components data recorded. For total fresh ear yield estimation, the fresh cobs for recording the weights were harvested from net plot area after separating the representative plants for recording biometrical observations. The observations for all the yield components, viz, number of ears per plant (EPP), average fresh ear weight (FEW), ear length (EL), ear diameter (ED), kernel rows per ear (KRPE), kernels per row (KPR), kernels per ear (KPE) and 100-kernel (dry) weight were recorded from 5 ears obtained from 5 plants sampled and labelled from the middle 3 rows (net plot) according to method of Keerthi *et al.*[28].

2.4.2 Estimation of grain quality parameters

Grain quality parameters evaluation focused on the taste as well as the proximate analysis of extracted components. For taste characteristics evaluation, sweet corn (TDN21) was harvested 21 days after pollination (DAPn) whilst waxy corn (JKN2000) and sweet and waxy corn (JKN928) were harvested 29 DAPn. Fresh ears were boiled in an electric cooker for 30 min and the quality properties of fully cooked grains obtained from the middle of the ear were evaluated by a five-member panel. The taste evaluation of the fresh corn ears was based on the parameters (tender texture, sweetness, viscosity, flavour and thickness of peel) suggested by Liu [27].

The chemical analyses of extracted components (crude protein, crude starch, crude fat and lysine content) were conducted at the Hebei Provincial Crop Variety Quality Testing Center (Shijiazhuang, China) by standard procedures [29]. Crude protein content was approximated using a UDK159 Automatic Kjeldahl Analyzer and a nitrogen-to-protein conversion factor of 6.25. Starch content was estimated by using an SGW-1 Automatic Polari meter, crude fat content determined using YG-2 Soxhlet test apparatus and lysine (amino acid) content employing a GXDL-203 Lysine tester machine. Results were expressed as g 100 g^{-1} sample on dry basis.

The grain sulphur content was determined by the Barium sulphate turbidity test procedures described by Yang et al. [30] with slight modifications. The grain samples were dried by oven baking, initially for 30 min at 70℃ and then at a constant temperature of 105℃ up to 24 hours. The dried samples were finely ground using a HUACHEN HCP-100 pulverizing machine (Huachen Inc., Shanghai) and then passed over 60~80 mm sieve. One gram sample for each was mixed with 2 ml of 5% Na_2CO_3 and baked, first for 2h at 300℃ followed with another 2 h at 600℃. After cooling, the mixture was hydrolysed in 10 mL of 2% HCl by heating at 100℃ for 20 min. After filtration, the filtrate was moved into a 25 ml volumetric flask and diluted with distilled water to scale, shaking the test solution. A mixture of 2 ml of extract, 2.0 ml of glycerine-ethanol (1:1), 2.0 ml of 10% $BaCl_2$, and 2.0 ml of 25% HCl was diluted with distilled water to 25 ml at room temperature, followed by detection at 470 nm using a Beckman Coulter 800 UV/Vis spectrophotometer. Sulphur content in each sample (mg g^{-1} sample) was then determined with reference to the prepared standard sulphur curve.

2.5 Statistical Analysis of Data

The statistical analyses of data were performed with SPSS statistical software package (Version 17.0) using One-Way ANOVA, followed by Duncan`s multiple range tests (DMRT) to evaluate the significant treatment effects at $p≤0.05$ level. Data is presented as treatment means of three replications.

3. RESULTS

3.1 Treatment Effects on Total Fresh Ear Yield

The results for yield and its components are shown in Tables 1 and 2. Significant ($p≤0.05$) increase in total fresh ear yield (FEY) was realized in TDN21 and JKN2000 cultivars due to sulphur effect. Compared to control, S resulted in 18.12%, 17.53% and 6.58% increases in FEY in TDN21, JKN2000 and JKN928, respectively. The highest (12783 kg ha^{-1}) yield was recorded in TDN21 sulphur-treatment, whilst the least (9 858.9 kg ha^{-1}) was observed in JKN2000 CK-treatment. However, Cl treatment caused slight non-significant increases in FEY of 1.43%, 7.71% and 2.4% in cultivars 1, 2 and 3 respectively (Table 1).

3.2 Treatment Effects on Yield Components

Among the yield attributing factors evaluated, sulphur significantly ($p≤0.05$) influenced average ear diameter (ED), average ear length (EL), average fresh ear weight (FW) and 100-dry kernel-weight in all 3 cultivars (Table 2). JKN928 S-treatment had the highest (4.77 cm) mean ED compared to Tian dan 21 CK-treatment with the least (4.17 cm). Ear length was highest (21.46 cm) in JKN2000 S-treatment and lowest (16.33 cm) in TDN21 CK-treatment. TDN21 S-treatment recorded the highest (273.13 g) FW compared to JKN2000 CK-treatment which had the least (213.03g) (Table 2).

Compared to CK, sulphur significantly contributed to 12.71%, 6.42% and 7.67% increase in mean ED in TDN21, JKN2000 and JKN928 cultivars, respectively. In addition, sulphur resulted in 14.94%, 12.77% and 10.03% increase in EL in cultivars 1, 2 and 3, respectively. Sulphur resulted in 14.15%, 18.14% and 20.03% increase in FW in TDN21, JKN2000 and JKN928 cultivars, respectively (Table 2).

Table 1. Treatment effects on total fresh ear yield, number of ears ha^{-1}, number of ears plant $^{-1}$ and average fresh ear weight

Cultivar	Treatment	Fresh ear yield (kg ha^{-1})	No. of ears ha^{-1} (units)	No. of ears $plant^{-1}$ (units)	Average fresh ear weight (g)
TDN21	Control	10 822 a	45 267 a	0.86 a	239.27 a
	Sulphur	12 783 b	46 811 a	1.00 b	273.13 b
	Chlorine	10 977 a	42 181 a	1.00 b	253.83 a
	Mean	11 527	44 753	0.95	255.41
	CV	10.07	6.68	9.79	6.76
JKN2000	Control	9 859 a	43 724 a	0.97	213.03 a
	Sulphur	11 587 b	48 868 b	1.01	251.67 b
	Chlorine	10 619 a	45 782 ab	0.93	231.80 ab
	Mean	10 688	46 125	0.97	232.17
	CV	8.39	6.36	7.53	`
JKN928	Control	11 190 a	44 753 a	1.00	219.13 a
	Sulphur	11 926 a	49 897 b	1.07	263.03 b
	Chlorine	11 462 a	46 811 a	1.00	232.03 a
	Mean	11 526	47 154	1.02	238.07
	CV	11.65	5.69	6.57	9.41

Note: For a particular cultivar, means having similar letter (s) in same column do not differ significantly at $p≤0.05$

Table 2. Treatment effects on ear length, ear diameter, number of kernels per ear, number of kernel rows per ear and 100-dry seed weight

Cultivar	Treatment	Ear length (cm)	Ear diameter (cm)	Kernels row^{-1} (units)	Kernel rows ear^{-1} (units)	100-dry seed weight (g)
TDN21	Control	16.33 a	4.17 a	34.27	16.00	8.43
	Sulphur	18.77 b	4.70 b	35.67	16.40	9.07
	Chlorine	17.90 b	4.65 a	34.33	16.80	8.70
	Mean	17.67	4.50	34.76	16.40	8.73
	Std. dev.	1.306	0.278	1.75	0.447	0.517
	CV	7.39	6.18	5.03	2.73	5.92
JKN2000	Control	19.03 a	4.36 a	42.00	12.27	11.47 a
	Sulphur	21.46 b	4.64 b	44.07	12.53	15.57 b
	Chlorine	19.26 ab	4.48 a	42.03	13.47	13.33 a
	Mean	19.92	4.49	42.70	12.76	13.46
	Std. dev.	1.44	0.146	2.05	0.65	2.095
	CV	7.23	3.25	4.80	5.09	15.56
JKN928	Control	19.15 a	4.43 ab	34.90	14.27	14.87
	Sulphur	21.07 b	4.77 b	34.93	14.13	16.40
	Chlorine	19.61 ab	4.51 a	35.20	14.67	14.90
	Mean	19.94	4.57	35.01	14.36	15.39
	Std. dev.	1.00	0.20	1.61	0.65	1.56
	CV	5.02	4.38	4.60	4.53	10.14

Sulphur also showed a significant ($p \leq 0.05$) positive effect (35.75%) on 100-seed weight in JKN2000 cultivar. However, Cl treatment was only significant ($p \leq 0.05$) in increasing EL in TDN21, and statistically non-significant in other cultivars and other yield components (Tables 1 and 2). Both sulphur and chlorine were not significant in influencing number of kernel rows ear^{-1} (KRPE) and ears plant^{-1} (EPP) (Tables 1 and 2).

3.3 Treatment Effects on Quality of Fresh Corn

3.3.1 Treatment effects on taste parameters

In all the three cultivars, relative sweetness, flavour and peel (pericarp) thickness were more crucial in determining higher eating quality. Interestingly, both S and Cl were highly significant ($p \leq 0.05$) in increasing relative sweetness and flavour (aroma) in all the 3 cultivars (Fig. 1a; 1b). In TDN21 cultivar, S-treatment recorded the highest (87%) relative sweetness compared to CK (72.67%), whilst in JKN928, Cl-treatment had 84% relative sweetness, compared to CK (75.53%). Flavour scores were highest in JKN928 S-treatment (86.53%) and JKN928 Cl-treatment (84.47%) compared to CK (73.33%). Compared to control, S decreased the pericarp thickness, significantly ($p \leq 0.05$) improving the peel thickness score in all the 3 cultivars, whilst Cl was significant in JKN2000 and JKN928 cultivars only (Fig. 1c). However, treatments effects were not significant on mean texture and viscosity scores (Fig. 1d).

3.3.2 Proximate analysis results for grain nutritional composition

Sulphur treatment caused significant ($P \leq 0.05$) variation in the crude protein (CP) content in TDN21 and JKN928 cultivars. Compared to CK, sulphur increased CP content by 2.08% in TDN21, but significantly decreased it by 3.47% in JKN928 cultivar. On the other hand, Cl significantly ($p \leq 0.05$) decreased CP by 2.78%, 5.31% and 6.05% in TDN21, JKN2000 and JKN 928 cultivars, respectively (Table 3).

Sulphur also significantly ($p \leq 0.05$) increased the crude starch (CS) content by 4.31% and 7.56% in TDN21 and JKN2000, respectively. On the other hand, Cl caused a significant ($p \leq 0.05$) increase in CS of 4.40%, 5.70% and 3.96% in TDN21, JKN2000 and JKN928 cultivars, respectively.

Crude fat (CF) content was significantly ($p \leq 0.05$) decreased (by 4.79%) in TDN21, but significantly increased by 5.55% and 10.38% in JKN2000 and JKN928 cultivars, respectively due to sulphur treatment. Chlorine also showed significant ($p \leq 0.05$) increases in CF of 3.43%, 15.17% and 6.60% in TDN21, JKN2000 and JKN 928 cultivars, respectively. However, treatment effects were statistically insignificant on grain lysine (amino acid) content in all the 3 cultivars (Table 3).

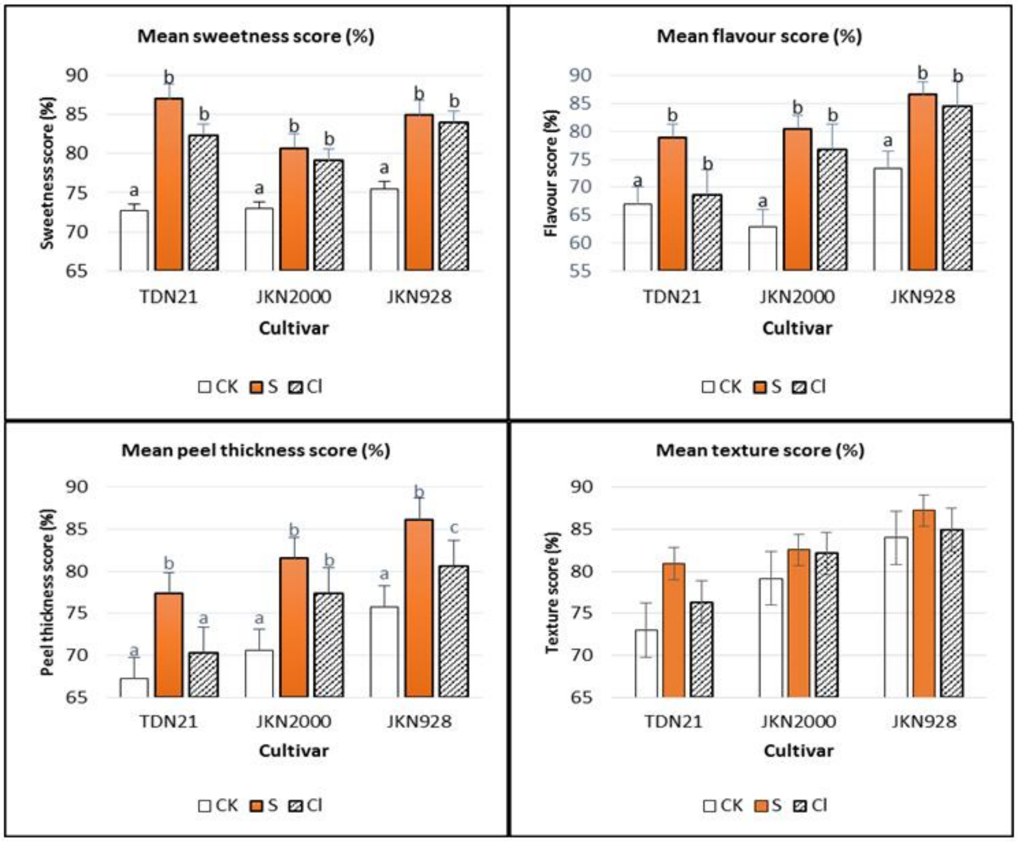

Fig. 1. Treatment effects on taste parameters; relative sweetness (a), flavour (b), peel thickness (c), and texture (d) scores (%) in three fresh corn cultivars. Note: For a particular cultivar, error bars with different letters differ significantly at *p*≤0.05

Table 3. Treatment effects on grain crude protein, starch, fat, lysine (%) and sulphur (mg kg^{-1}) contents

Cultivar	Treatment	Crude protein (%)	Crude starch (%)	Crude fat (%)	Lysine (amino acid) content (%)	Sulphur content (mg kg^{-1})
TDN21	Control	14.41 a	33.17 a	13.98 a	0.46 a	581.1 a
	Sulphur	14.71 b	34.60 b	13.31 b	0.42 b	643.0 b
	Chlorine	14.01 c	34.63 b	14.46 c	0.43 ab	575.4 a
	Mean	14.38	34.13	13.92	0.44	601.8
	CV	2.11	2.17	3.61	5.64	6.29
JKN2000	Control	11.30 a	63.46 a	3.297 a	0.32 a	573.7 a
	Sulphur	11.29 a	68.26 b	3.480 b	0.29 ab	624.1 a
	Chlorine	10.70 b	67.08 c	3.797 c	0.28 b	569.5 a
	Mean	11.10	66.27	3.52	0.30	589.1
	CV	2.69	3.27	6.59	8.76	6.86
JKN928	Control	12.39 a	62.89 a	4.24 a	0.30 a	589.1 a
	Sulphur	11.96 b	62.81 a	4.68 b	0.31 a	646.1 b
	Chlorine	11.64 c	65.38 b	4.52 c	0.29 a	591.5 a
	Mean	11.99	63.63	4.48	0.30	608.9
	CV	2.72	2.02	4.36	6.24	6.43

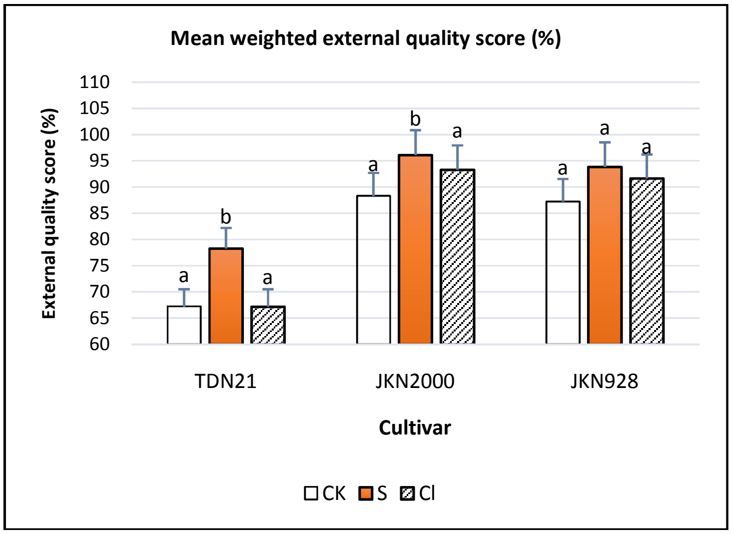

Fig. 2. Treatment effects on mean weighted external quality score (%) in three fresh corn cultivars. Mean weighted external quality score is the average for grain arrangement, consistence of ear length, ear baldness, ear tip wrapping, and insect and disease damage

As anticipated, the mean concentration of sulphur in dried grains was highest (646.1 mg kg^{-1} sample) in sulphur-treated, and lowest in control (573.7 mg. kg. $sample^{-1}$) and Cl (569.5 mg kg^{-1} sample) treated samples in all the cultivars (Table 3). Grain sulphur content was significantly increased in TDN21 ($p\leq0.05$) and JKN 928 ($p\leq0.1$) cultivars.

3.3.3 Treatment effects on external quality

Sulphur significantly ($p\leq0.05$) improved the external appearance of the harvested commercial ears, especially in TDN21 and JKN2000 cultivars. Sulphur treatment had the highest (78.33%) mean weighted external quality score compared to CK (67.22%) in TDN21 cultivar (Fig. 2 above).

4. DISCUSSION

4.1 Treatment Effects on Total Fresh Ear Yield and Its Components

In maize, grain yield is the manifestation of yield attributing characters, and consequently, manipulation of those characters, either genetically or exogenously, contribute to higher yield. In the present study, sulphur significantly increased total fresh ear yield in fresh corn cultivars, by influencing ear diameter, ear length and ear weight, more prominently in sweet corn cultivar. The increased growth and vigour of maize plants caused by sulphur addition leads to higher yield and dry matter production, as sulphur, working in synergy with nitrogen, results in greater translocation of photosynthates from vegetative parts to developing ear and grains in a source-sink relationship.

The enhanced photosynthates in developing ear will lead to increased ear diameter, consequently increasing average ear weight and total fresh ear yield. These results confirm to the findings of Channabasamma et al. [31]. In addition, Tiwari and Gupta [32] reported that fertilization at 30 kg ha^{-1} S can increase maize yield by about 21.85% in field maize through sulphur`s enhancing effect to N . However, in the current study, Cl effect on yield was not significant. Chlorine is generally a non-limiting factor for plant growth, and in most cases, it`s effect on yield is negligible [33].

Sulphur fertilization also significantly increased the fresh ear yield by influencing the total ear number ha^{-1} (EPH) in waxy cultivars. Worrajinda et al. [4] posited that although both ear number and whole ear weight are important, ear number is more crucially used in vegetable corn, as a commercial unit, rather than ear weight. In our present study, the realized positive influence on ear number ha^{-1} was probably because of S conferring some abiotic and biotic stress tolerance compared to control plants. This is supported by the observed better plant stands and low incidences of pest and disease attack in S treated plots as compared to control plots. However, both S and Cl treatments could not influence the number of ears per plant (EPP) and kernel rows ear^{-1} (KRPE). This is mainly because EPP and KRPE are basically genetic characters that are not too much influenced epigenetically [14].

4.2 Treatment Effects on Quality of Fresh Corn

4.2.1 Treatment effects on taste parameters

Both sulphur and chlorine had significant effects on improving taste quality of kernels in sweet and waxy cultivars, by increasing relative sweetness and flavour (Fig.1a; 1b). Interestingly, study by Liu [27] showed that sulphur has the same effects. Chapagain et al. [25] posited that Cl improves fruit quality by reducing the water content of the fruits and thereby increasing the dry matter content, aroma and other components that contribute to taste and appearance. It also reduces disease attack in maize, wheat, barley and asparagus [34]. It can be suggested here that, in fresh corn ears, Cl may play a role in concentrating sugars in the kernels thereby improving the relative sweetness and flavour, as well as suppressing disease severity.

In the present study, we also found out that sulphur effect on mean texture score was only significant in JKN928 (sweet and waxy cultivar). A previous study [15] revealed that increased S supply reduce the starch and amylose contents, but increase the amylopectin content of kernels thereby improving the eating quality of waxy maize. Further, Liu [27] opined that high starch viscosity and lower pericarp and dregs content (PADC) result in high eating quality scores in waxy cultivars, whilst high soluble sugar content and lower PADC are essential in sweet corn cultivars.

4.2.2 Treatment effects on grain nutritional composition

Sulphur treatment had a profound effect in increasing crude protein and starch contents of grains. This shows that S addition to plants positively affect CP content of grains. This is because S is a key constituent of proteins, and S assimilation is highly active in growing tissues where high levels of cysteine and methionine are required for protein synthesis [35-36].

Increased crude starch content with sulphur addition reveals that S may be involved in some important structural, regulatory and catalytic functions in context of proteins and as a major cellular redox buffer in form of tripeptide glutathione [37]. Similarly, Koca et al. [38] observed that sulphur application in field maize significantly improved the CP and CS contents of grains. Xie et al. [15] also showed that sulphur markedly increased the grain CP content by 0.65%, whilst total amino acid and soluble sugar increased by 6.68% and 7.19%, respectively compared to control.

4.2.3 Treatment effects on external appearance of ears

Sulphur and chlorine treatments enhanced the external appearance of harvested ears in sweet and corn cultivars (Fig. 2), largely by improving ear tip wrapping, reducing insect and disease damage, reducing ear baldness as well as improving grain arrangement. Consequently, the kernels of cooked ears had a high sensual appeal. Huber et al. [39] reported similar sulphur effects to product quality. In addition, it has already been posited in this paper that Cl improves ear and kernel quality by influencing appearance, aroma and reducing pest/disease attack [25]. We can, therefore, enhance fresh corn quality by addition of sulphur and chlorine to the fertilizer regimes.

5. CONCLUSION

We conclude that sulphur significantly increase fresh ear yield in fresh corn, principally by influencing average ear diameter, ear length and ear weight, among other yield attributing characters. However, chlorine effect on yield and/or its components is not significantly apparent. Both sulphur and chlorine have profound effects on fresh corn quality by improving taste parameters and nutritional composition of kernels as well as the external appearance of ears in both sweet and waxy cultivars, with S effect being more prominent than Cl. Thus, in the wake of huge demand for high quality cereal and vegetable diets, sulphur can play a key role in enhancing the production and quality of fresh corn. However, further experiments on the estimation of optimum fertilization rates of S and Cl are necessary to guide recommendations to farmers.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Stall WM, Waters L, Davis DW, Rosen C, Clough GH. Sweet corn production. National Corn Handbook (NCH-43). State of indiana: Cooperative Extension Service of Purdue University; 2008.
2. Ortiz R, Fernandez M, Dixon J, Hellin J, Iwanaga M. Speciality maize: Global horticultural crop. Chronica Horticulturae. 2007;47(4):20-25.
3. Tracy WF. Sweet corn (*Zea mays saccharata*). Genetic Improvement of Vegetable Crops. 1993;777-807.
4. Worrajinda J, Lertrat K, Suriharn B. Combining ability of super sweet corn inbred lines with different ear sizes for ear number and whole ear weight. Sabrao J Breeding and Gen. 2013;45(3):468-477.
5. Kumar MAA, Gali SK, Patil RV. Effect of levels of NPK on Quality of Sweet Corn Grown on Vertisols. Karnataka J Agric Sci. 2007;20(1):44-46.
6. Zhu M, Li K, Li F, Shi Z. Correlation between the lignin content and mechanical properties of waxy corn pericarp. Scientia Horticulturae. 2014;179:266-270.
7. Najeeb S, Sheikh FA, Ahangar MA, Teli NA. Popularization of Sweet corn (*Zea mays* L. *saccharata*) Under Temperate Conditions to Boost the Socioeconomic Conditions. Maize Genetics Cooperation Newsletter. 2011;85.
8. Ketthaisong D, Suriharn B, Tangwongchai R, Lertrat K. Changes in physicochemical properties of waxy corn starches at different stages of harvesting. Carbohydrate Polymers. 2013;98:241-248.
9. Lu D, Sun X, Wang X, Yan F, Lu W. Effect of Shading During Grain Filling on the Physicochemical Properties of Fresh Waxy Maize. J Integrative Agric. 2013;12(9): 1560-1566.
10. Rasool FU, Hassan B, Jahangir IA. Growth and yield of sunflower (*Helianthus annuus* L.) as influenced by nitrogen, sulphur and farmyard manure under temperate conditions. SAARC J Agric. 2013;11(1):81-89.
11. Jarvan M, Edesi L, Adamson A, Lukme L, Akk A. The effect of sulphur fertilization on yield, quality of protein and baking properties of winter wheat. Agronomy Research. 2008;6(2):459–469.
12. Jamal A, Fazil IS, Ahmad S, Abdin MZ. Interactive effect of nitrogen and Sulphur on Yield and Quality of Groundnut (*Arachis hypogea* L.). Korean J Crop Sci. 2006;51(6):519-522.
13. Farhad ISM, Islam MN, Hoque S, Bhuiyan MSI. Role of potassium and sulphur on the growth, Yield and oil content of soybean (*Glycine max* L.). Academic J Plant Sci. 2010;3(2):99-103.
14. Ali A, Iqbal Z, Hassan SW, Yasin M, Khaliq T, Ahmed S. Effect of nitrogen and sulphur on phenology, growth and yield parameters of maize crop. Sci Int (Lahore). 2013;25(2):363-366.
15. Xie R, Dong S, Hu C, Wang K. The role of nitrogen and sulphur interaction in maize quality (*Zea mays* L.). Agricultural Sciences in China. 2003;2(5):527-532.
16. Smatanova M, Richter R, Hlušek J. Spinach and pepper response to nitrogen and sulphur fertilization. Plant Soil Environ. 2004;50(7):303–308.
17. Ullah MH, Huq SMI, Alam MDU, Rahman MA. Impacts of sulphur levels on yield, storability and economic return of onion. Bangladesh J Agric Res. 2008;33(3):539-548.
18. Nasreen S, Imamul Haq SM, Hossain MA. Sulphur effects on growth, Responses and yield of onion. Asian J Plant Sci. 2003;2(12):897-902.
19. Singh Y, Singh T, Singh UN, Rajput TK. Effect of nutrient management on yield, quality and economics of irrigated Indian mustard (*Brassica juncea*). Indian J Agric Sci. 2010;80(8):691-694.
20. Hassan F, Manaf A, Qadir G, Basra SMA. Effects of sulphur on seed yield, oil, protein and glucosinolates of Canola Cultivars. Int J Agric and Biol. 2007;9(3):504-508.
21. Sienkiewicz-Cholewa U, Kieloch R. Effect of sulphur and micronutrients fertilization on yield and fat content in winter rape seeds (*Brassica napus* L.). Plant, Soil and Environ. 2015;61(4):164-170.
22. Njira KOW, Nabwami J. A review of effects of nutrients elements on crop quality. Afr J

Food, Agric, Nutr and Dev. 2015; 15(1):9777-9793.

23. Edis R, Norton R. Sulphur nutrition and fluid fertilisers. 2012 Victorian Liquid Fertiliser Forum; 2012.
(Accessed 5 May 2017)
Available: http://www.ipni.net/

24. Rehm GW. Sulfur and micronutrient response on corn and soyabeans. Department of soil, water and climate. University of Minnesota. St Paul MN, USA; 2011.

25. Chapagain BP, Wiesman Z, Zaccai M, Imas P, Magen H. Potassium chloride enhances fruit appearance and improves quality of fertigated greenhouse tomato as compared to potassium nitrate. J Plant Nutrition. 2003;26(3).

26. Xu G, Magen H, Tarchitzky J, Kafkaf U. Advances in chloride nutrition of plants. Advanced Agronomy. 2002;28:97-150.

27. Liu P. Establishment of yield and quality evaluation system for fresh sweet corn and waxy corn varietal experiment in China. A doctoral thesis in crop production and physiology. Agricultural College of Yangzhou University. People`s Republic of China; 2007.

28. Keerthi S, Upendra Rao A, Ramana AV, Ramesh G. Relationship between fresh cob yield and yield components of sweet corn. Scholars J Agric & Vet Sci. 2014; 1(4A):227-229.

29. Association of Official Analytical Chemists (AOAC). Official methods of analysis. Washington DC. 1995;4125-4142.

30. Yang L, Zhu M, Yiliminuer, Li H. Study on the determination of sulfur content in plant leaves. Applied Chemical Industry. 2015; 44(3):575-579.

31. Channabasamma A, Habsur NS, Bangaremma SW, Akshaya MC. Effect of nitrogen and sulphur levels and ratios on growth and yield of maize. Mol Pl Breeding. 2013;4(37):292-296.

32. Tiwari KN, Gupta BR. Sulphur for sustainable high yield agriculture in Uttar Pradesh. Indian Journal of Fertilizers. 2006;1(11):37-52.

33. Fixen PE. Crop responses to chloride. Advanced Agronomy. 1993;50:107-150.

34. Biocyclopedia. Chlorine functions in plants. Plant Nutrition; 2012.
(Accessed 23 May 2017)
Available: Biocyclopedia.com

35. HARSCO. Sustainable management of greens and tees under abiotic stress. Cross over – from soil to plant: Product Information Bulletin. Florida, USA; 2015.
(Accessed 26 April 2017)
Available: www.numeratortech.com

36. Rotte C, Leustek T. Differential subcellular localization and expression of ATP sulfurylase and APS reductase during ontogenesis of Arabidopsis thaliana leaves indicates that cytosolic and plastid forms of ATP sulfurylase may have specialized functions. Plant Physiology. 2000;124:715-724.

37. Jamal A, Moon Y, Abdin MZ. Sulphur – A general overview and interaction with nitrogen, Australian J Crop Sci. 2010; 4(7):523-529.

38. Koca YO, Canavar O, Kaptan MA. Changes of seed yield and quality of maize (*Zea mays* L.) fertilized with sulphur in early and late sowing date. Presentation made at the 9th international soil science congress on 'the soul of soil and civilization', 14-16 october 2014, side, Antalya, Turkey. Soil Science Society of Turkey & Federation of Eurasian Soil Science Societies. 2014;1002-1007.

39. Huber D, Romheld V, Weinmann M. Relationship between Nutrition, Plant diseases, and Pests. In: Marschner, editor. Mineral Nutrition of Higher Plants. 3rd ed. New York: Elsevier; 2012.

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