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Effect of sulphur, zinc and boron nutrition on storability of onion (*Allium cepa* L.) in northern transitional zone of Karnataka

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Abstract
A field experiment was carried out to study the response of onion to different levels of sulphur (30 and 40 kg ha^{-1}), zinc sulphate (15 and 25 kg ha^{-1}) and borax (7.5 and 10 kg ha^{-1}) during *rabi* 2020-21 and 2021-22 at All India Network Research Project on Onion and Garlic (AINRPOG), Seed Unit, Main Agriculture Research Station, University of Agricultural Sciences, Dharwad. All the treatments except absolute control and RPP received supplemental foliar applications of zinc sulphate (0.5%) and borax (0.25%) at 30, 45 and 60 days after transplanting. The experiment was laidout in randomized complete block design with sixteen treatments each replicated thrice. Results revealed that combined application of sulphur, zinc and boron exerted positive and significant influence on shelf life of onion bulb. Soil application of sulphur @ 40 kg ha^{-1} + zinc sulphate @ 25 kg ha^{-1} + borax @ 10 kg ha^{-1} significantly reduced the physiological loss in weight (10.61%), sprouting (4.10%) and rotting loss (1.90%) after two months of storage period. However, it was on par with the treatment that received sulphur @ 40 kg ha^{-1} + zinc sulphate @ 25 kg ha^{-1} + borax @ 7.5 kg ha^{-1}, sulphur @ 40 kg ha^{-1} + zinc sulphate @ 15 kg ha^{-1} + borax @ 10 kg ha^{-1} and sulphur @ 30 kg ha^{-1} + zinc sulphate @ 25 kg ha^{-1} + borax @ 10 kg ha^{-1}. It is concluded that application of sulphur (40 kg ha^{-1}), zinc sulphate (25 kg ha^{-1}) and borax (10 kg ha^{-1}) is found to be the most appropriate combination for improving the shelf life of onion.

Keywords: Onion, sulphur, zinc, boron, storability

Introduction
Soil is one of the natural resources that supports human civilization. It is a heterogeneous mass and its productivity depends on several factors. Without a productive and healthy soil, the prospect of producing enough food to feed an ever-increasing human population is impossible. Managing soil health means implementing practices that either maintain or enhance the soil's physical, chemical, and biological attributes to improve soil functions. The functioning of the physical, chemical, and biological aspects of the soil is not mutually exclusive and operate synergistically and interact in a complex way to deliver specific soil services and to enhance ecosystem functions, such as nutrient availability, erosion control and water infiltration a way to visualize sustainable productivity in relation to soil health. The apparent impact of inadequate and imbalanced application of inorganic fertilizers in intensive cropping system has been reflected in terms of emerging and spreading of multi-nutrients deficiencies in soil. Emphasis on application of major nutrients has triggered widespread deficiencies of secondary and micronutrients like S (41%), Zn (49%) and B (33%) with other micronutrients (Singh, 2009) [11].
Onion (*Allium cepa* L.) belongs to the family *Alliaceae*, is one of the most important monocotyledonous, cross-pollinated and cool season vegetable crop and is an important export earning vegetable crop worldwide. Onion has its own distinctive flavor, used in soups, meat dishes, salads and sandwiches and is cooked alone as a vegetable. Its pungency is due to the presence of volatile oil called "Allyl propyl disulphide". Generally 100 g of edible bulb of onion contains 86.6 g of moisture, 11.0 g of carbohydrates, 1.2 g of protein, 0.6 g of fiber and 0.4 g of minerals. It also contains calcium, phosphorous, iron, thiamine and nicotinic acid. It is an indispensible component of culinary in the Indian kitchen and it is popularly referred as "Queen of the Kitchen". Besides, it has a medicinal property such as anti-biotic, anti-cancer, anti-cholesterol, anti-fungal and anti-oxidant. In addition, it is being used as a diuretic and applied to cure bruises, boils, wounds and heat sensation.

Hence, its demand is increasing day by day.

India is the second largest producer of onion in the world after China. In India, onion is being grown in an area of 16.2 lakh hectares with an annual production and productivity of 26.64 million tonnes and 16.4 million tonnes per ha, respectively. The major onion producing states includes Maharashtra, Karnataka, Madhya Pradesh, Rajasthan, Bihar, Gujarat and Odisha. The Karnataka state occupies second position in area (2.30 lakh hectare) and third in production (26.60 lakh tonnes) (Anon., 2021) [2]. The major onion growing districts in the state are Chitradurga, Gadag, Vijayapura, Bagalkot, Dharwad and Haveri.

Sulphur is recognized as the fourth major plant nutrient after nitrogen, phosphorus and potassium and it is essential for the synthesis of amino acids namely cystine, cysteine and methionine, a component of vitamin 'A' and activates certain enzyme systems in plants. Continuous removal of sulphur from soils through plant uptake has led to widespread sulphur deficiency all over the world. Its pungency is due to the presence of volatile oil "Allyl propyl disulphide. Severe deficiency of sulphur during bulb development has detrimental effect on an allylpropyl disulphide formation. These sulphur compounds are produced when the onion cell is mechanically disrupted, the enzyme allinase comes into contact with flavor precursors such as S- alk(en)yl-L-cysteine sulfoxides (ACSOs). Apart from volatile sulphur compounds, the enzymatic break down of ACSOs also produces ammonia, pyruvic acid and ascorbic acid, all of which are linked to quality of bulbs. Sulphur application not only improves bulb quality, but it also extends the shelf life of onion under storage conditions. Zinc plays an important role in various enzymatic and physiological activities of the plant body. The functional role of zinc includes auxin metabolism, influence on the activity of carbonic anhydrase, dehydrogenase enzymes, cytochrome synthesis and stabilization of ribosomal fractions. Zinc also plays a significant role in chlorophyll formation. Boron is essential for transport of carbohydrates, cell wall metabolism, permeability and stability of cell membranes and phenol metabolism, with primary role in lignin synthesis.

Materials and Methods

A field experiment were conducted at the site of All India Network Research Project on Onion and Garlic (AINRPOG), Seed Unit, Main Agricultural Research Station, University of Agricultural Sciences, Dharwad (Karnataka) during *rabi* 2020-21 and 2021-22 under irrigated condition. The analysis of the composite soil sample of the experiment site before treatment imposition revealed that soil of the experimental site was neutral (pH- 7.29), non-saline in nature (EC- 0.18 dS m^{-1}), low in available nitrogen (169.34 kg ha^{-1}), medium in available phosphorous (32.63 kg ha^{-1}), medium in available potassium (476.45 kg ha^{-1}), medium in available sulphur (23.54 kg ha^{-1}), deficit in DTPA extractable Zn (0.51 mg kg^{-1}) and hot water soluble boron (0.46 mg kg^{-1}), sufficient in DTPA extractable Fe (4.61 mg kg^{-1}), Mn (7.45 mg kg^{-1}) and Cu (0.69 mg kg^{-1}). The experiment was laid out in randomized block design with three replications. The details of the treatment are presented in Table 1.

The land was ploughed and harrowed well in order to bring the soil to a fine tilth and well decomposed farm yard manure was incorporated and then raised beds of 15 cm height was prepared by leaving 30 cm between beds to carry out the cultural operations easily. Fourty five days old healthy seedlings raised on seed beds were selected for transplanting. The beds were irrigated to uproot seedlings easily and to avoid damage to the roots. Uprooted seedlings were transplanted in eight rows in each plot with spacing of 15 cm × 10 cm. Immediately after uprooting of seedlings, they were cut to half the length, transplanted and irrigated immediately for proper establishment of the seedlings.

Recommended dose of fertilizers (125:50:125 N, P_2O_5, K_2O kg ha^{-1}) were applied in the form of urea, di-ammonium phosphate and muriate of potash for N, P_2O_5 and K_2O respectively. At the time of transplanting, complete dose of P_2O_5 and K_2O and half the dose of recommended N were applied. The remaining half dose of N was applied at six weeks after transplanting as top dress. Sulphur, zinc and boron were applied at the time of transplanting as per the treatments. These nutrients were applied in the form of gypsum (S), zinc sulphate (Zn) and borax (B). The required quantities of fertilizer per plot was worked out and applied to soil. Zinc sulphate (0.5%) and borax (0.25%) were sprayed at 30, 45 and 60 days after transplanting (DAT) and is common for all the treatments except absolute control and recommended package of practices (RPP).

The crop was irrigated with drip irrigation at alternate days depending upon the soil moisture and climatic conditions. The herbicide oxyfluorfen at 1 ml per litre was sprayed at 30 days after transplanting. Hand weeding was carried out regularly depending upon weed intensity and the plots were kept weed free throughout the crop growth. Prophylactic measures were taken up for control of pests and diseases in onion. The crop was sprayed with propiconazole at 0.1 per cent and imidachloprid at 0.7 ml at 45 days after transplanting to protect against pest and diseases.

Onion crop was harvested when the physiological maturity was indicated by yellowing of leaves, full growth of bulbs, 60-70 per cent neck fall and showed the sign of drying of leaves and bending over the ground. The manual topping (neck fall) was made after 50 per cent neck fall for curing of the bulbs before harvest. After 8 days of manual neck fall, the bulbs were harvested by pulling the whole plants. The bulbs were cured in the field itself for 5 days and then the bulbs were separated from harvested plant by cutting at the neck portion by leaving 2 cm. The bulb yield was recorded on plot basis. Estimates were done on hectare basis using bulb yield per plot and net plot area.

Storage parameters

Physiological loss in weight

Initially 5kg bulbs were kept for storage and the whole quantity of bulbs are weighed without cleaning and the weight was recorded by subtracting with initial weight (5kg) at 30 and 60 days after storage and expressed in percentage.

Sprouting percentage

The sprouting percentage was calculated by subtracting the number of sprouted bulbs from the total number of bulb kept for storage and multiplied with hundred at 30 and 60 days after storage.

Rotting percentage

The percentage rotting losses of onion bulb was estimated by subtracting the number of rotted bulb from the total number of bulb kept for storage and multiplied with hundred at 30 and 60 days after storage.

Result and Discussion

Storage of bulbs is one of the most important aspects for post-harvest handling of onion. The storage conditions extend the period of availability of fresh onion by arresting the metabolic breakdown and decay. The shelf life of onion depends on different parameters namley physiological activity, biochemical activity and microbial invasion. Physiological loss in weight, sprouting and rotting percentage at two months after storage was significantly lower with the application of sulphur (40 kg ha^{-1}) + zinc sulphate (25 kg ha^{-1}) + borax (10 kg ha^{-1}) (T_{16}) (10.61, 1.90, 4.10%, respectively) which was statistically similar to T_{15} with sulphur @ 40 kg ha^{-1} + zinc sulphate @ 25 kg ha^{-1} + borax @ 7.5 kg ha^{-1} (10.71, 2.00, 4.20%, respectively), T_{14} with sulphur @ 40 kg ha^{-1} + zinc sulphate @ 15 kg ha^{-1} + borax @ 10 kg ha^{-1} (10.92, 2.04, 4.35%, respectively) and T_{12} with sulphur @ 30 kg ha^{-1} + zinc sulphate @ 25 kg ha^{-1} + borax @ 10 kg ha^{-1} (10.96, 2.13, 4.40%, respectively) but differed significantly with remaining treatments including RPP and absolute control (Table 2). The combined application of sulphur, zinc sulphate and borax significantly reduced the storage loss compared to their individual applications (sulphur; T_3 and T_4, zinc sulphate; T_5 and T_6 and borax; T_7 and T_8). The treatments that received sole applications of sulphur, zinc sulphate and borax did not influenced the storage parameters of onion bulbs significantly over RPP and these sole treatments did not differ significantly among themselves. At 30 days after storage, the effect of different treatments on the storage parameters of the bulbs in onion was similar to 60 days after storage.

Sulphur has a major role in reducing physiological loss in weight, sprouting and rotting percentage in onion bulbs followed by nitrogen and phosphorus (Smriti *et al*., 2002) [12]. Lancaster *et al*. (2001) [6] reported that onion grown at low sulphur condition reduced firmness and pungency in bulbs. The sulphur content in cell wall was reduced where the crop was grown under sulphur deficit conditions and hence adversely affected the storability of onion bulbs. Application of sulphur increased its uptake by the crop which in turn increased the firmness of the skin of bulbs in onion which had significant effects on their storability of bulbs in onion. Firmness of bulbs reduces the microbial infection causing improvement in shelf life of bulbs in onion. Similar findings were reported by Srinivasan (2015) [13] and Aske *et al*. (2017) [3] in onion. Kaur *et al*. (2017) [5] recorded minimum physiological loss in weight, sprouting and rotting with the application of sulphur @ 40 kg ha^{-1} along with recommended N, P and K fertilizers to onion. These results are in agreement with the findings of Qureshi and Lawande (2006) [10] in onion crop.

Application of zinc sulphate @ 25 kg ha^{-1} along with sulphur and borax (T_{16}) might have reduced the moisture content and increased the ash content in bulbs of onion. These improvements in quality parameter of bulb in onion might have reduced the storage loss. The lower storage losses in this treatment might be due to the effect of zinc which influence enzymatic activity which might help to accumulate higher amount of metabolites in bulbs, thereby maintaining them firm and healthy. Similar results were reported by Maurya *et al*. (2018) [9] on sandy loam soil in Bihar which showed that application of zinc sulphate @ 25 kg ha^{-1} reduced the storage losses. The findings are in agreement with the observations of Aske *et al*. (2017) [3].

Application of borax @ 10 kg ha^{-1} along with sulphur and zinc sulphate (T_{16}) resulted in reduced storage losses at two months after storage. The effect of boron on shelf life of onion could be associated with its involvement in improving calcium accumulation in the bulb which resulted in lower moisture loss from bulbs due to thickening of cell wall and formation of pectic network there by reduced physiological weight loss, rotting and sprouting of bulb. It may also be due to cell wall synthesis and lignifications according to Loomis and Durst (2012) [8], forming intramolecular or intermolecular bonds. Studies have shown the beneficial effect of boron in maintaining membrane stability (Yamouchi *et al*., 1986) [15]. The favourable effect of boron on storability of onion bulbs might be possible from negative correlation between boron uptake and total weight loss as per, Smriti *et al*. (2002) [12] and Alphonso (2007) [1].

Combined application of sulphur, zinc sulphate and borax exhibited a more positive influence on storability of onion bulb as compared to their sole applications. The improvement in storability or shelf life could be attributed due to synergistic relationship between sulphur, zinc and boron which resulted in improvement of storage qualities of onion bulbs because of increased uptake of nutrients like nitrogen, potassium, sulphur, zinc and boron which increased dry matter content of bulbs in onion. The reason may be due to increased synthesis of primary sulphur compounds such as S-allyl cysteine compounds which are positively correlated with keeping quality of bulb as reported by Diriba *et al*. (2013) [4] in garlic and Vijay *et al*. (2015) [14] in onion. These results are in conformity with the findings of Laxmi (2017) [7] who observed that application of sulphur (30 kg ha^{-1}) in combination with zinc (4 kg ha^{-1}) and boron (2 kg ha^{-1}) significantly reduced the storage losses in bulbs of onion.

Table 1: Treatment details

T_1	Absolute control
T_2	RPP
T_3	SA of S @ 30 kg ha^{-1} + FA of $ZnSO_4$ @ O.5% and borax @ 0.25%
T_4	SA of S @ 40 kg ha^{-1} + FA of $ZnSO_4$ @ O.5% and borax @ 0.25%
T_5	SA of $ZnSO_4$ @ 15 kg ha^{-1} + FA of $ZnSO_4$ @ O.5% and borax @ 0.25%
T_6	SA of $ZnSO_4$ @ 25 kg ha^{-1} + FA of $ZnSO_4$ @ O.5% and borax @ 0.25%
T_7	SA of borax @ 7.5 kg ha^{-1} + FA of $ZnSO_4$ @ O.5% and borax @ 0.25%
T_8	SA of borax @ 10 kg ha^{-1} + FA of $ZnSO_4$ @ O.5% and borax @ 0.25%
T_9	SA of S @ 30 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} + borax @ 7.5 kg ha^{-1} + FA of $ZnSO_4$ @ O.5% and borax @ 0.25%
T_{10}	SA of S @ 30 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} + borax @ 10 kg ha^{-1} + FA of $ZnSO_4$ @ O.5% and borax @ 0.25%
T_{11}	SA of S @ 30 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} +borax @ 7.5 kg ha^{-1} + FA of $ZnSO_4$ @ O.5% and borax @ 0.25%
T_{12}	SA of S @ 30 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} + borax @ 10 kg ha^{-1} + FA of $ZnSO_4$ @ O.5% and borax @ 0.25%
T_{13}	SA of S @ 40 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} +borax @ 7.5 kg ha^{-1} + FA of $ZnSO_4$ @ O.5% and borax @ 0.25%
T_{14}	SA of S @ 40 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} + borax @ 10 kg ha^{-1} + FA of $ZnSO_4$ @ O.5% and borax @ 0.25%

T_{15}	SA of S @ 40 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} +borax @ 7.5 kg ha^{-1} + FA of $ZnSO_4$ @ O.5% and borax @ 0.25%
T_{16}	SA of S @ 40 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} + borax @ 10 kg ha^{-1} + FA of $ZnSO_4$ @ O.5% and borax @ 0.25%
Note: 1. RPP (Recommended package of practise): FYM @ 30 t ha^{-1} + 125:50:125 NPK kg ha^{-1} is common for all the treatments except absolute control. 2. Sulphur is applied through gypsum 3. Foliar application will be at at 30, 45 and 60 days after transplanting SA: Soil application, FA: Foliar application	

Table 2: Effect of application of sulphur, zinc and boron on physiological weight loss, sprouting and rotting percentage of bulbs in onion at 30 and 60 days after storage (Pooled data)

Treatments	Physiological weight loss (%)		Sprouting percentage		Rotting percentage	
	At 30 days after storage	At 60 days after storage	At 30 days after storage	At 60 days after storage	At 30 days after storage	At 60 days after storage
T_1	10.72	15.47	0	5.24	6.95	8.9
T_2	7.13	12.18	0	3.06	3.61	5.56
T_3	6.93	11.96	0	2.84	3.41	5.31
T_4	6.88	11.87	0	2.81	3.35	5.25
T_5	7.01	12.05	0	2.92	3.49	5.41
T_6	6.97	12.01	0	2.88	3.44	5.36
T_7	7.03	12.08	0	3.00	3.53	5.85
T_8	6.99	12.04	0	2.97	3.49	5.39
T_9	6.51	11.37	0	2.42	2.88	4.80
T_{10}	6.46	11.29	0	2.34	2.81	4.62
T_{11}	6.34	11.19	0	2.27	2.62	4.57
T_{12}	6.19	10.96	0	2.13	2.41	4.40
T_{13}	6.30	11.06	0	2.15	2.49	4.51
T_{14}	6.09	10.92	0	2.04	2.28	4.35
T_{15}	6.00	10.71	0	2.00	2.08	4.20
T_{16}	5.93	10.61	0	1.90	2.00	4.10
S.Em.±	0.10	0.13	-	0.09	0.15	0.12
CD (P= 0.05)	0.31	0.39	-	0.28	0.45	0.37
CV (%)	6.87	6.11	-	6.82	6.64	6.01

Conclusion

Soil application of sulphur @ 40 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} + borax @ 10 kg ha^{-1} along with foliar applications of zinc sulphate (0.5%) and borax (0.25%) at 30, 45 and 60 days after transplanting improved the shelf life of onion.

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Statements and Declarations

Conflict of interest: The authors declare that they have no conflict of interest.

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