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## STUDIES ON THE EFFECT OF BORON SOURCES AND LEVELS ON GROWTH, PHYSIOLOGICAL PARAMETERS AND YIELD OF KNOL KHOL (*BRASSICA OLERACEA* VAR. *GONGYLODES* L.)

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### ABSTRACT

Nutrient deficiencies and improper nutrient management in agricultural soils are major constraints to crop productivity and nutritional quality. Among micronutrients, boron (B) is the second most widespread deficiency in worldwide and is characterized by a narrow range between deficiency and toxicity, necessitating precise management. With this background, we carried out a field study during *Rabi 2022-23* at the College of Agriculture, V.C. Farm, Mandya, Karnataka, to evaluate the influence of different boron sources and application levels on the growth, physiological parameters and yield of knol khol using a Randomized Complete Block Design with twelve treatments and three replications. Boron was applied through two sources: boric acid and solubor, both used as soil application (0.5, 1.0 and 1.5 kg ha<sup>-1</sup>) and foliar spray (250 and 500 g ha<sup>-1</sup>), along with recommended dose of fertilizers and farmyard manure. The findings indicated that boron supplementation significantly enhanced growth, physiological traits and yield attributes of knol khol. Among the treatments, soil application of solubor @ 1.0 kg ha<sup>-1</sup> along with RDF and FYM (T<sub>7</sub>) recorded maximum plant height (41.27 cm), number of leaves (11.63), leaf length (24.10 cm), leaf area (1877.74 cm<sup>2</sup>), leaf area index (2.78), chlorophyll content (60.11 SPAD), dry matter (28.41 g plant<sup>-1</sup>), knob diameter (7.37 cm), knob volume (230.20 cm<sup>3</sup>), fresh knob weight (222.33 g plant<sup>-1</sup>) and marketable yield (188.57 q ha<sup>-1</sup>) compared to RDF alone. Hence, application of boron through solubor @ 1.0 kg ha<sup>-1</sup> along with RDF and FYM was found most effective for improving productivity of knol khol under red soil conditions.

**Keywords:** Soil and foliar application, Solubor, Boric acid, Knol khol, Marketable knob yield Micronutrients

### Introduction

Boron (B) is an essential micronutrient required in small quantities for the normal growth and development of plants. It plays a vital role in several physiological and biochemical processes such as cell wall formation, membrane stability, carbohydrate metabolism, translocation of sugars and reproductive development including pollen germination and seed set. Despite its importance, boron deficiency is widely prevalent in agricultural soils and is considered the second most limiting micronutrient after zinc. The deficiency is more pronounced in light-textured soils,

acidic soils, calcareous soils and soils low in organic matter, where boron availability is inherently low (Keren and Bingham, 1985; Mandal *et al.*, 2004; Shorrocks, 1997).

In India, boron deficiency is widespread, affecting nearly 23.2% of cultivated soils and about 4.00%, 19.2% and 21.5% of the sampled sites were recorded with acute deficient ( $\leq 0.20$  mg kg<sup>-1</sup>), deficient ( $> 0.20$ – $\leq 0.50$  mg kg<sup>-1</sup>) and latent deficient ( $> 0.50$ – $\leq 0.70$  mg kg<sup>-1</sup>) in available B, respectively with higher incidence reported in states such as West Bengal (68%), Bihar (39%) and Karnataka (32%) (Shukla *et al.*, 2021). The

occurrence of deficiency is influenced by factors *viz.*, parent material, soil texture, pH, leaching and liming, which regulate boron availability in soils (Shorrocks, 1997). Recent studies have also highlighted that intensive cropping and imbalanced fertilization without micronutrients have further aggravated boron deficiency in vegetable-based systems (Alloway, 2018; Rashid *et al.*, 2020).

In vegetable crops, boron deficiency leads to several physiological disorders including cracking, deformation and reduced quality of produce. In cole crops like knol khol, deficiency symptoms such as brown heart, knob cracking and poor knob development significantly reduce marketable yield (Panda *et al.*, 2019; Gupta, 2014). Knol khol (*Brassica oleracea var. gongylodes* L.), commonly known as kohlrabi, belongs to the family Brassicaceae and is widely cultivated in India. The edible portion is the swollen stem (knob), which is rich in vitamins, minerals and dietary fibre and contains appreciable amounts of vitamin C, B-complex vitamins and antioxidants such as isothiocyanates, which contribute to its nutritional and medicinal value (Mishra *et al.*, 2012; Nagar, 2016).

Despite its importance, productivity of knol khol is often constrained by micronutrient deficiencies, particularly boron. The range between boron deficiency and toxicity is very narrow, making its management critical for optimum crop growth, especially under semi-arid and intensively cultivated conditions (Alloway, 2018). Knol khol is a heavy feeder of nutrients and responds well to balanced fertilization, including both macro- and micronutrients. In recent years, reduced marketable yield of knol khol has been associated with smaller knob size and increased incidence of knob cracking, which are often linked to boron deficiency. Inclusion of boron in nutrient management practices has been reported to improve knob development, reduce physiological disorders and enhance yield and quality (Panda *et al.*, 2019; Narayanareddy, 2018).

Considering the importance of boron in improving growth, yield and quality of knol khol and the deficiency of the B in the soil of our study area the present investigation entitled “Studies on the Effect of Boron Sources and Levels on Growth and Yield of Knol Khol (*Brassica oleracea var. gongylodes* L.)” was undertaken with the objective: To study the effect of boron sources and levels on growth, physiological parameters and yield of knol khol.

## Material and Methods

The experiment was conducted during *Rabi 2022-23* at the College of Agriculture, V.C. Farm, Mandya, under the University of Agricultural Sciences, Bengaluru. The trial was laid out in a Randomized Complete Block Design (RCBD) with twelve treatments (Table 1) and three replications. The experimental soil was red sandy loam and light textured with neutral reaction (pH 6.65), low organic carbon (0.44%) and low available nitrogen (213.13 kg ha<sup>-1</sup>), while phosphorus (51.29 kg ha<sup>-1</sup>) and potassium (261.54 kg ha<sup>-1</sup>) were in medium range. The available boron content (0.13 mg kg<sup>-1</sup>) indicated acute deficient status.

Boron was supplied through two sources, boric acid (H<sub>3</sub>BO<sub>3</sub>-17.5 % B) and solubor (Na<sub>2</sub>B<sub>8</sub>O<sub>13</sub>.4H<sub>2</sub>O - 20 % B), at different levels through soil and foliar application. The sources were decided based on the B content and the rate of solubility of these in the water which reflects the dissolution and availability of B to the plant roots through the soil solution for the plant uptake and considered the review literatures as reference. Both the sources of boron were applied as soil and foliar application. For the soil application (SA) treatments (T<sub>3</sub> to T<sub>8</sub>) at 3 levels (0.5, 1.0 and 1.5 kg ha<sup>-1</sup>) of both sources were applied at transplanting, while for foliar application (FA) treatments (T<sub>9</sub> to T<sub>12</sub>) boron sprays at two levels (250 and 500 g ha<sup>-1</sup>) of both sources were given at 25 days after transplanting, at knob initiation stage. All treatments were applied along with recommended dose of fertilizers (RDF) (150:100:125 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) and farm yard manure (FYM) @ 12.5 t ha<sup>-1</sup> except absolute control treatment (T<sub>1</sub>) (Table 1).

Healthy 20 days old knol khol seedlings raised in pro trays were transplanted in the main field. Treatment was implicated as per the design layout and standard agronomic practices were followed throughout the crop period. Observations on growth and physiological parameters were recorded at 20 DAT, 30 DAT and at harvest whereas yield parameters were at harvest stage from five randomly selected plants in each plot. Statistical analysis was carried out using standard procedures as described by Gomez and Gomez (1984).

**Table 1:** Treatment details of the experiment

Treatment	Details
T <sub>1</sub>	Absolute Control
T <sub>2</sub>	100 % RDF + FYM
T <sub>3</sub>	T <sub>2</sub> + SA of B @ 0.5 kg ha <sup>-1</sup> (Boric acid)
T <sub>4</sub>	T <sub>2</sub> + SA of B @ 1.0 kg ha <sup>-1</sup> (Boric acid)
T <sub>5</sub>	T <sub>2</sub> + SA of B @ 1.5 kg ha <sup>-1</sup> (Boric acid)
T <sub>6</sub>	T <sub>2</sub> + SA of B @ 0.5 kg ha <sup>-1</sup> (Solubor)

<b>T<sub>7</sub></b>	T <sub>2</sub> + SA of B @ 1.0 kg ha <sup>-1</sup> (Solubor)
<b>T<sub>8</sub></b>	T <sub>2</sub> + SA of B @ 1.5 kg ha <sup>-1</sup> (Solubor)
<b>T<sub>9</sub></b>	T <sub>2</sub> + FA of B @ 250 g ha <sup>-1</sup> (Boric acid)
<b>T<sub>10</sub></b>	T <sub>2</sub> + FA of B @ 500 g ha <sup>-1</sup> (Boric acid)
<b>T<sub>11</sub></b>	T <sub>2</sub> + FA of B @ 250 g ha <sup>-1</sup> (Solubor)
<b>T<sub>12</sub></b>	T <sub>2</sub> + FA of B @ 500 g ha <sup>-1</sup> (Solubor)

### Observations recorded

Five plants were randomly selected from each plot of all the replications and tagged to take growth and physiological parameters at different growth stages *viz.*, 20, 30 DAT and at harvest and whereas yield parameters at the harvest stage of the crop. The procedure for recording the data are mentioned below.

### Growth parameters (follow any one format)

#### Plant height (cm)

The height of tagged plants was recorded from ground level to highest growing point of leaves with the help of scale and average height was calculated in centimetres.

#### Number of leaves plant<sup>-1</sup>

The number of fully opened leaves of selected plants in each plot was counted and the average number of leaves plant<sup>-1</sup> was recorded.

#### Leaf length (cm)

The length of leaf was measured from the base of the leaf to the tip of the leaf with a scale and expressed in centimetres (cm) and the average leaf length was calculated.

#### Leaf width (cm)

The width of leaf was measured at the widest part of the lamina by scale and expressed in centimetres (cm).

### Physiological parameters

#### Leaf area (cm<sup>2</sup>)

The leaf area of five randomly selected plants in each experimental plot was measured with leaf area meter (Model Biovis) at 20 DAT, 30 DAT and harvesting stage and average leaf area per plant was calculated.

#### Leaf area index (LAI)

Is calculated considering the leaf area per plant and ground cover of a plant.

$$LAI = \frac{\text{Leaf area per plant}}{\text{Ground area occupied by the plant}}$$

### Chlorophyll content (SPAD reading)

Chlorophyll content was recorded by SPAD meter (SPAD-502, MINLOTA Japan) at and then mean value for each treatment was calculated.

### Fresh weight of plant (g plant<sup>-1</sup>)

The fresh weight of five randomly selected plants (including vegetative parts and knob) at knob harvesting stage was determined using weighing balance. The fresh weight of plant was expressed in g plant<sup>-1</sup>.

### Dry matter (g plant<sup>-1</sup>)

After taking fresh weight, plants along with knob was dried in hot air oven at 65 °C temperature till constant weight is obtained. The dry weight of plant (including vegetative parts and knob) was expressed in g plant<sup>-1</sup>.

### Yield parameters

#### Diameter of knob (cm)

The diameter of knob of five randomly selected plants at knob harvesting stage was measured using digital vernier calliper and expressed in centimetres.

#### Fresh weight of knob (g plant<sup>-1</sup>)

Weight of five knobs at edible maturity stage was recorded using electronic weighing balance. The average knob weight was expressed in grams.

#### Volume of knob (cm<sup>3</sup>)

Volume of knob was recorded by measuring the displaced water which was obtained by dipping the knob in a measuring cylinder and average volume of knobs was calculated in cm<sup>3</sup>.

#### Total knob yield (q ha<sup>-1</sup>)

The total knob weight per plot was recorded at the time of harvesting and which was converted to knob yield per ha in quintals.

#### Marketable knob yield (q ha<sup>-1</sup>)

The knob weight (excluding leaves, cracked knobs, over matured and damaged knobs) was recorded, marketable yield per plot is calculated and it was converted into marketable yield per ha in quintals.

## Results and Discussion

### Effect of sources and levels of boron on growth parameters of knol khol

The data on the growth parameters of knol khol are presented in Table 1. The parameters *viz.*, plant height, number of leaves per plant, leaf length and leaf width at different growth stages of knol khol (20 DAT,

30 DAT and harvest) were significantly influenced by boron fertilization. Plant height increased progressively with crop growth under all boron applied treatments. The highest plant height was recorded in T<sub>7</sub> (RDF + FYM + SA of boron @ 1.0 kg ha<sup>-1</sup> through solubor) with 28.19 cm, 36.60 cm and 41.27 cm at 20 DAT, 30 DAT and harvest, respectively. This treatment showed considerable improvement over the RDF treatment (T<sub>2</sub>) which recorded 22.53 cm, 28.02 cm and 33.56 cm at the respective stages. However, T<sub>7</sub> remained statistically on par with T<sub>12</sub> (FA of solubor @ 500 g ha<sup>-1</sup>) and T<sub>10</sub> (FA of boric acid @ 500 g ha<sup>-1</sup>) at harvest stage. A similar trend was observed for number of leaves per plant, where T<sub>7</sub> recorded the highest values (8.23, 9.53 and 11.63 at 20 DAT, 30 DAT and harvest) compared to T<sub>2</sub> (7.37, 8.47 and 10.07). However, T<sub>7</sub> was statistically comparable with T<sub>12</sub> (11.33 leaves) at harvest. Leaf growth parameters were also significantly improved by boron fertilization. The T<sub>7</sub> recorded the highest leaf length (15.89 cm, 21.67 cm and 24.10 cm) and leaf width (12.37 cm, 16.04 cm and 16.73 cm) at different growth stages, which were markedly higher than RDF treatment (T<sub>2</sub>). However, T<sub>7</sub> remained on par with T<sub>12</sub> for several parameters at harvest.

The improvement in growth parameters due to boron application may be attributed to improved

physiological efficiency through its role in cell division, cell elongation, carbohydrate transport and cell wall formation, which enhances vegetative growth and leaf development further for the photosynthetic efficiency (Brown *et al.*, 2002). Among the sources of B tested, solubor performed comparatively better than boric acid, particularly when applied through soil as solubor is more soluble and with higher per cent of B than boric acid. However, soil application of solubor @ 1.0 kg ha<sup>-1</sup> (T<sub>7</sub>) was statistically comparable with foliar application of solubor @ 500 g ha<sup>-1</sup> (T<sub>12</sub>), indicating that both application methods were effective in improving vegetative growth.

The superior performance of boron treatments over RDF alone clearly demonstrates the beneficial role of boron supplementation in improving growth of knol khol and also reducing cracking percent of knol khol. These results are in close agreement with the findings of Arabhavi (2014) and Narayanareddy (2018) in knol-khol, as well as Shah *et al.* (2010) and Singh *et al.* (2015) in cole crops, who attributed improved growth in cruciferous crops to boron-mediated cell wall synthesis, enhanced cell elongation, and greater leaf expansion. According to Marschner (2012), boron plays a key role in cell wall development, sugar transport and meristematic growth, which ultimately enhances vegetative growth in plants.

**Table 1:** Effect of boron sources and levels on growth parameters of knol-khol

Treatments	Plant height (cm)			Number of leaves plant <sup>-1</sup>			Leaf length(cm)			Leaf width(cm)		
	20 DAT	30 DAT	At harvest	20 DAT	30 DAT	At harvest	20 DAT	30 DAT	At harvest	20 DAT	30 DAT	At harvest
T <sub>1</sub>	16.57	20.52	25.25	6.13	7.07	8.60	9.34	12.06	14.59	6.64	9.16	10.42
T <sub>2</sub>	22.53	28.02	33.56	7.37	8.47	10.07	13.72	16.63	19.58	10.43	12.47	13.28
T <sub>3</sub>	24.02	32.08	36.87	7.63	8.67	10.33	14.28	18.90	20.55	11.20	14.28	14.88
T <sub>4</sub>	25.37	33.30	37.88	7.77	9.13	11.07	14.71	20.09	22.24	11.39	14.79	15.30
T <sub>5</sub>	24.67	32.47	37.14	7.72	9.07	10.60	14.62	19.30	21.18	11.30	14.62	15.07
T <sub>6</sub>	24.59	32.27	36.86	7.67	8.93	10.40	14.33	19.17	20.80	11.26	14.35	14.97
T <sub>7</sub>	28.19	36.60	41.27	8.23	9.53	11.63	15.89	21.67	24.10	12.37	16.04	16.73
T <sub>8</sub>	26.95	34.20	38.35	8.13	9.33	11.13	15.76	20.27	22.43	11.51	15.22	15.50
T <sub>9</sub>	22.85	32.39	37.30	7.33	9.00	10.67	13.67	19.22	21.35	10.52	14.66	15.13
T <sub>10</sub>	22.73	34.62	39.61	7.37	9.20	11.17	13.77	20.59	22.53	10.44	15.37	15.60
T <sub>11</sub>	22.70	33.14	37.71	7.40	9.10	10.75	13.63	19.58	21.59	10.54	14.70	15.24
T <sub>12</sub>	22.55	35.57	40.77	7.39	9.40	11.33	13.73	21.42	22.88	10.48	15.57	15.93
<b>S.Em±</b>	<b>0.77</b>	<b>0.98</b>	<b>1.13</b>	<b>0.18</b>	<b>0.23</b>	<b>0.29</b>	<b>0.39</b>	<b>0.56</b>	<b>0.63</b>	<b>0.32</b>	<b>0.41</b>	<b>0.44</b>
<b>CD @ 5%</b>	<b>2.25</b>	<b>2.88</b>	<b>3.31</b>	<b>0.53</b>	<b>0.68</b>	<b>0.86</b>	<b>1.15</b>	<b>1.65</b>	<b>1.85</b>	<b>0.95</b>	<b>1.21</b>	<b>1.29</b>

#### Effect of sources and levels of boron on physiological parameters of knol khol

Physiological parameters such as leaf area, leaf area index (LAI), chlorophyll content (SPAD value),

fresh weight and dry matter accumulation of knol khol were significantly influenced by different sources, levels and methods of boron application (Fig. 1 & 2). Leaf area increased progressively from 20 DAT to harvest under all boron applied treatments. The highest

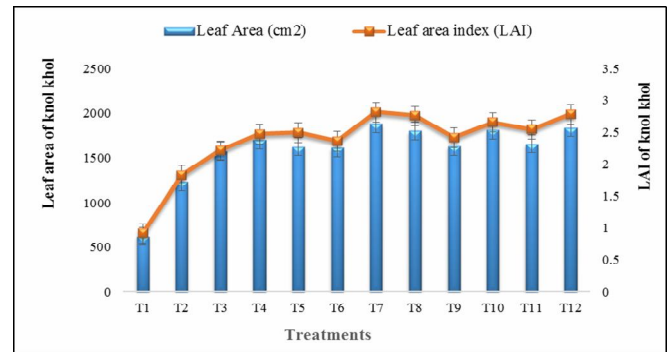
leaf area was recorded in T<sub>7</sub> (RDF + FYM + SA of boron @ 1.0 kg ha<sup>-1</sup> through solubor) with 830.12 cm<sup>2</sup>, 1286.33 cm<sup>2</sup> and 1877.74 cm<sup>2</sup> at 20 DAT, 30 DAT and harvest, respectively. This was markedly higher than the RDF treatment (T<sub>2</sub>) which recorded 681.16 cm<sup>2</sup>, 896.43 cm<sup>2</sup> and 1233.33 cm<sup>2</sup>. However, T<sub>7</sub> was statistically on par with T<sub>12</sub> (FA of solubor @ 500 g ha<sup>-1</sup>) which recorded 1836.78 cm<sup>2</sup> leaf area at harvest.

A similar trend was observed for leaf area index (LAI), where T<sub>7</sub> recorded the highest values (1.34, 1.91 and 2.81) compared to T<sub>2</sub> (1.01, 1.38 and 1.83) at respective stages. However, T<sub>7</sub> remained statistically comparable with T<sub>12</sub> (2.78) at harvest. The increase in LAI indicates improved canopy development and enhanced light interception. Chlorophyll content also varied significantly among treatments. The highest SPAD values were recorded in T<sub>7</sub> (59.60, 61.23 and 60.11) which were higher than T<sub>2</sub> (53.78, 54.19 and 52.82). However, T<sub>7</sub> was statistically on par with T<sub>12</sub> (57.04) and T<sub>8</sub> (56.39) at harvest. Fresh biomass and dry matter accumulation followed a similar trend. The highest fresh weight (297.98 g plant<sup>-1</sup>) and dry matter (28.41 g plant<sup>-1</sup>) were recorded in T<sub>7</sub>, which were considerably higher than T<sub>2</sub> (164.94 g and 16.45 g plant<sup>-1</sup>). However, T<sub>7</sub> remained statistically comparable with T<sub>12</sub> (293.87 g and 27.09 g plant<sup>-1</sup>).

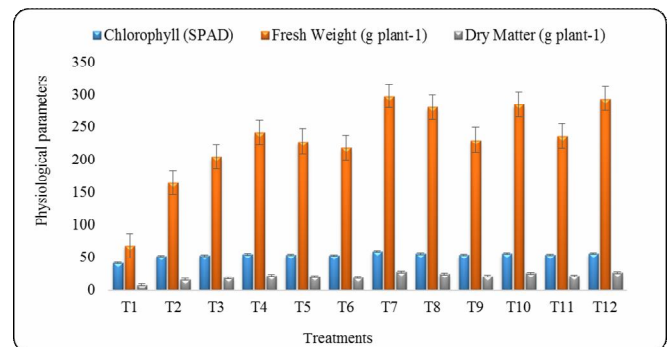
Among the boron sources tested, solubor performed comparatively better than boric acid, particularly when applied through soil. However, foliar application of solubor @ 500 g ha<sup>-1</sup> (T<sub>12</sub>) produced results statistically comparable with soil application of solubor @ 1.0 kg ha<sup>-1</sup> (T<sub>7</sub>) for several parameters. Similar findings have been reported in knol khol and other cole crops where boron application improved physiological efficiency and biomass production (Shah *et al.*, 2010; Narayanareddy, 2018).

Application of boron significantly improved physiological parameters of knol khol due to its essential role in plant growth and metabolism. Boron enhances cell wall formation by cross-linking rhamnogalacturonan-II (RG-II) pectic polysaccharides, promoting cell division, elongation and leaf expansion, which increases leaf area and LAI (Matoh, 1997; O'Neill *et al.*, 2004). It improves chlorophyll synthesis and photosynthetic efficiency by maintaining membrane stability and enzymatic activity (Marschner, 2012; Brown *et al.*, 2002). Boron also facilitates translocation of carbohydrates by forming boron-sugar complexes, leading to higher biomass accumulation (Brown and Hu, 1996). Additionally, it ensures proper vascular tissue development and nutrient transport (Goldbach *et al.*, 2001). Its influence on hormonal regulation further enhances vegetative growth and

physiological efficiency (Camacho-Cristobal *et al.*, 2008).



**Fig. 1 :** Effect of different sources and levels of boron on Leaf area and leaf area index at harvest



**Fig. 2 :** Effect of different sources and levels of boron on Physiological parameters (Chlorophyll, fresh weight and dry matter) of knol khol at harvest

### Effect of sources and levels of boron on yield parameters of knol khol

The data pertaining to the effect of different sources, levels and methods of boron application on yield parameters of knol khol are presented in Table 2. The results revealed that yield attributes such as average knob diameter, knob volume, fresh knob weight, total knob yield and marketable knob yield were significantly influenced by boron fertilization. The average knob diameter differed significantly among the treatments. The maximum knob diameter was recorded in T<sub>7</sub> (RDF + FYM + SA of boron @ 1.0 kg ha<sup>-1</sup> through solubor) which recorded 7.37 cm, which was higher than the RDF treatment (T<sub>2</sub>) that recorded 6.28 cm. However, T<sub>7</sub> was statistically on par with T<sub>12</sub> (7.24 cm) indicating similar effectiveness of soil and foliar boron application at higher levels. A similar trend was observed with respect to knob volume. The treatment T<sub>7</sub> recorded the highest knob volume (230.20 cm<sup>3</sup>) which was substantially greater than T<sub>2</sub> (127.67 cm<sup>3</sup>). However, T<sub>7</sub> remained statistically on par with T<sub>12</sub> (222.11 cm<sup>3</sup>). Increased knob volume indicates better enlargement of the edible swollen stem portion of knol khol due to improved

physiological activity under boron fertilization. The fresh knob weight per plant also varied significantly among treatments. The highest fresh knob weight was recorded in T<sub>7</sub> (222.33 g plant<sup>-1</sup>) which was considerably higher than RDF treatment (114.68 g plant<sup>-1</sup>). However, this treatment was statistically comparable with T<sub>12</sub> (219.68 g plant<sup>-1</sup>).

The influence of boron fertilization was clearly reflected in the total knob yield and marketable knob yield. The treatment T<sub>7</sub> produced the highest total knob yield (192.08 q ha<sup>-1</sup>) and marketable knob yield (188.57 q ha<sup>-1</sup>) which was markedly higher than the RDF treatment (131.75 q ha<sup>-1</sup> and 116.87 q ha<sup>-1</sup>, respectively). However, T<sub>7</sub> remained statistically on par with T<sub>12</sub> which recorded total knob yield of 184.17 q ha<sup>-1</sup> and marketable yield of 180.38 q ha<sup>-1</sup>, followed by T<sub>10</sub> which recorded 179.17 q ha<sup>-1</sup> total yield and 175.16 q ha<sup>-1</sup> marketable yield. The superior yield obtained with boron treatments compared to RDF alone clearly highlights the beneficial role of boron supplementation in enhancing productivity of knol khol. Similar results were reported by Shah *et al.* (2010), Arabhavi (2014) and Narayanareddy (2018), who observed significant improvement in knob development and yield of knol khol with boron fertilization.

The improvement in yield attributes with boron fertilization may be attributed to its role enhancing assimilate translocation, reproductive efficiency, which promotes knob formation and enlargement in knol khol. Boron facilitates efficient carbohydrate transport from leaves (source) to the developing knob (sink), leading to increased knob size, weight, and volume. It also strengthens cell wall formation and membrane stability, which reduces physiological disorders like knob cracking and deformation, thereby increasing marketable yield. Furthermore, boron improves metabolic activities and dry matter accumulation, resulting in higher knob firmness, better quality, and increased yield per hectare in cruciferous crops like knol-khol (Manojet *al.*, 2023). Adequate boron nutrition also enhances nutrient utilization efficiency and promotes uniform knob development, contributing significantly to higher economic yield (Panda *et al.*, 2019).

Among the boron sources tested, solubor performed comparatively better than boric acid, particularly when applied through soil. However, soil application of solubor @ 1.0 kg ha<sup>-1</sup> (T<sub>7</sub>) was statistically comparable with foliar application of solubor @ 500 g ha<sup>-1</sup> (T<sub>12</sub>), indicating that both soil and foliar application methods were effective in improving crop yield.

**Table 3:** Effect of boron sources and levels on yield parameters of knol-khol

Treatments	Average knob Diameter (cm)	Knob volume (cm <sup>3</sup> )	Fresh knob weight (g plant <sup>-1</sup> )	Total knob yield (q ha <sup>-1</sup> )	Marketable knob yield (q ha <sup>-1</sup> )
T <sub>1</sub>	3.79	50.67	48.92	49.58	31.98
T <sub>2</sub>	6.28	127.67	114.68	131.75	116.87
T <sub>3</sub>	6.50	143.87	137.26	145.00	139.03
T <sub>4</sub>	6.78	170.33	169.86	159.83	155.04
T <sub>5</sub>	6.68	149.33	157.78	149.58	144.74
T <sub>6</sub>	6.63	148.00	152.39	148.17	143.06
T <sub>7</sub>	7.37	230.20	222.33	192.08	188.57
T <sub>8</sub>	7.06	208.00	207.25	177.92	173.44
T <sub>9</sub>	6.69	153.67	159.42	150.17	145.21
T <sub>10</sub>	7.15	216.12	210.67	179.17	175.16
T <sub>11</sub>	6.72	164.33	164.19	154.83	150.14
T <sub>12</sub>	7.24	222.11	219.68	184.17	180.38
<b>S.Em±</b>	<b>0.18</b>	<b>6.38</b>	<b>7.81</b>	<b>6.38</b>	<b>5.63</b>
<b>CD @ 5%</b>	<b>0.54</b>	<b>18.7</b>	<b>22.9</b>	<b>18.7</b>	<b>16.5</b>

Overall, the results indicate that combined application of RDF, FYM and boron significantly improved growth parameters, physiological efficiency, yield parameters and productivity of knol khol compared to RDF alone, with soil application of solubor @ 1.0 kg ha<sup>-1</sup> (T<sub>7</sub>) produced the highest of all the recorded parameters by majorly reducing the

cracking percentage of knol khol by avoiding the deficiency of B in knol khol.

### Conclusion

It is concluded from the present investigation that application of boron significantly influenced the growth, physiological characteristics and yield parameters of knol khol. Combined application of RDF

and FYM along with boron improved vegetative growth, leaf development, chlorophyll content, biomass accumulation and knob development compared to RDF alone. Among the treatments, the optimum level, right source and appropriate method of boron application proved most effective in maximizing productivity and nutrient use efficiency. Where, soil application of boron through solubor @ 1.0 kg ha<sup>-1</sup> recorded superior performance with respect to plant growth, physiological efficiency and yield attributes which was statistically on par with foliar application of boron through solubor @ 500 g ha<sup>-1</sup> (T<sub>12</sub>) for several parameters, indicating that both soil and foliar application methods were effective. Therefore, balanced boron nutrition can be considered a crucial strategy for improving the performance of knol-khol under field conditions. Further research may focus on site-specific boron management and its interaction with other nutrients to achieve sustainable yield enhancement.

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