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RESEARCH ARTICLE

Effect of row spacings and micronutrients on seed yield and quality of palak

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Abstract

The experiment was conducted in an open field during the Rabi seasons of 2020 and 2021 at the Vegetable Research Centre, College of Horticulture, BUAT, Banda, to study the effect of three row spacings and four micronutrient levels on the seed yield and quality of palak. The experiment was laid out in a FRBD with two factors, *viz*., row-spacings (S) and micronutrient applications (M). The first factor had three row-spacings 30 × 10 (S_1), 40 × 10 (S_2) and 50 × 10 (S_3) whereas, the second factor had four micronutrient levels Control (M_0), Zinc Sulphate Monohydrate at 20 kg/ha (M_1), Disodium Octaborate Tetrahydrate (20 % B) at 20 kg/ha (M_2) and equal quantity of each Zinc Sulphate Monohydrate, Disodium Octaborate Tetrahydrate with a commercial formulation at 10 kg/ha (M_3) in a variety of 'All Green'. Seeds were sown on November 19, 2020 and all micronutrients were applied through soil at 40 DAS. Results indicated that S_3 recorded maximum values for plant height, number of leaves/plant, dry weight of plants, 50 % of flowering (DAS), number of spikes per plant, spike length, spikelet length, hundred seed weight, seedling shoot length, seedling root length, a total length of seedling, seedling dry weight, seedling vigour index-I (SVI-I) and seedling vigour index II (SVI-II). Maximum seed yield was found in the closest row-spacing (S_1). Germination percentage was noted in S_2 and S_3, which was significantly higher than that in S_1. Among the micronutrients, M_2 registered maximum values for most of the crop growth and seed yield traits. In view of high seed yield and quality traits simultaneously, promising treatment combinations were S_2M_1, S_2M_2 and S_3M_3.

Keywords: micronutrients; palak; quality; row-spacings; yield

Introduction

Palak (*Beta vulgaris* var. *bengalensis* L.) is one of the most popular leafy vegetables that belong to the family Chenopodiaceae. This is widely grown in tropical and subtropical regions. India is the 2nd largest vegetable producer after China. The ICMR (Indian Council of Medical Research) recommends that adults consume 125 g of leafy vegetables, 100 g of roots and 75 g of other vegetables for a healthy diet (1). In India, Palak is commonly cultivated as a cool-season vegetable crop. Palak leaves are tender and very soft and are eaten as a vegetable. It is a rich source of vitamin A (9770 IU) and vitamin C (70 mg) per 100 g of edible portion and also contains calcium (380 mg), phosphorus (30 mg), iron (16.2 mg), protein (3.4 g), energy (46 K cal), fat (0.8 g), carbohydrates (6.5 g), thiamine (0.26 mg) and riboflavin (0.56 mg) per 100 g of edible portion (2). According to an experiment, the consumption of palak is crucial in addressing deficiencies in both micro and macro-nutrients, as well as in combating degenerative diseases and cancer (3). It is well known that to obtain a higher yield and maintain its components, proper spacing, management of major and micronutrients and plant protection measures are essential aspects (4). Information is available regarding the distance and number of leaves to be harvested for green and seed production in some areas of the country (4). However, there is no recommendation on the management of plant geometry and nutrients for the quality of seed production in palak in the Bundelkhand region in India.

Seed production is another very important aspect of increasing the area and production of this crop. Like many other vegetable crops, including palak, the availability of a sufficient quantity of quality seeds is one of the challenges. For ensuring the easy availability of quality seeds, the production of a sufficient quantity is indispensable. Region-specific recommendations for sowing methodology, operations in dual -purpose crops, micronutrients and plant protection are also indispensable. In a seed crop, nitrogen, phosphorus and potassium play a pivotal role in facilitating the appropriate development of both the plant and its seeds. These essential nutrients are recognized for their ability to modify the source-sink relationship within the plant, resulting in enhanced translocation and synthesis processes. Consequently, this leads to an augmented seed yield and improved seed quality. Furthermore, maintaining an optimal plant density ensures favourable conditions for maximum light interception throughout the entire growth period, from the early stages to the harvest stage. Among the diverse agronomic practices, both plant nutrition and spacing have a substantial influence on seed quality determination (5).

In spite of the specific row-spacings and levels of micronutrients employed in this research, which are conveniently accessible and potentially cost-effective for agricultural production, the primary aim was to investigate the impact of different variables on the seed yield and quality of palak (*Beta vulgaris* var. *bengalensis* L.). The main objective of this research is to enhance the income of farmers by providing quality seeds with appropriate spacing and trace nutrients in palak. The use of spacings and micronutrient levels in palak affects the maturity and development of quality seeds. However, palak is mostly used as a leafy vegetable and in the Bundelkhand region, more attention is not paid to the quality of seed production. The climate and soil of the Bundelkhand region are unique, so no study has been found to date on the quality of seed production at different spacings and micronutrients.

Materials and Methods

Experimental site and growth conditions

The experiment was conducted during the Rabi season of 2020-2021 at the vegetable research farm located near the College of Horticulture, Banda University of Agriculture and Technology, Banda. The University is situated geographically between latitudes 24 ° 53 ' and 25 ° 55 ' N and longitudes 80 ° 07 ' and 81 ° 34 ' E. The experimental region experiences a predominantly semi-arid to tropical climate, characterized by dry and warm summers, pleasant monsoons and mildly cold winters. The average annual rainfall in the region is around 800-910 mm, with more than 88-90 % of the precipitation occurring during the three months of July, August and September. However, June and October receive only a small portion of the total rainfall, approximately 7-9 %. The annual temperature exhibits considerable variation, with summer temperatures ranging from 35 to 48 °C, rainy season temperatures ranging from 23 to 28 °C and winter temperatures ranging from 12 to 20 °C. The soil of the experimental farm is of Parua type and has a pH ranging from 7.0 to 7.5, with an organic content greater than 0.50 %. The Parua soil can be characterized by a light red or yellowish red colour which is a mixture of black and red-yellow soils. The layout of experimental field is depicted in Fig. 1.

Experimental design and treatments

The experiment was laid out in a Factorial Randomised Block Design (FRBD) with two factors, namely row spacings (S) and micronutrient applications (M). The first factor of row-spacings was 30 × 10 cm (S_1), 40 × 10 cm (S_2) and 50 × 10 cm (S_3) whereas, the second factor of micronutrients levels were control (M), Zink Sulphate Monohydrate ($ZnSO_4{\cdot}H_2O$) at 20 kg/ha (M_1), Disodium Octaborate Tetrahydrate ($Na_2B_8O_{13}{\cdot}4H_2O$) at 20 kg/ha ($M_2$) and equal quantity of each Zinc Sulphate Monohydrate ($ZnSO_4{\cdot}H_2O$) and Disodium Octaborate Tetrahydrate (($Na_2B_8O_{13}{\cdot}4H_2O$) with a commercial formulation at 10 kg/ha (M_3) in variety of 'All Green'. The treatments under the two factors were applied in all possible combinations in three replications. All micronutrients were applied through a basal dose after the first leaves were cut at 40 DAS. These micronutrients are used only once in a season. The seeds of the Allgreen variety were sown on 19 November 2020 and the plants were subsequently thinned out to maintain the required spacing between them, according to the treatments. The seeds of the Palak variety (All Green), developed at IARI, New Delhi, were used as planting materials for this experiment. The distinctive features of this variety are uniformly green tender leaves, suitable for 2-3 cuttings of green leaves at 15-20 days intervals. The yield of the average green leaf was about 125 quintals and a seed yield of 15-20 q/ha.

Cultural operations

In all treatments, continuous application of fertilizers was done using farmyard manure (FYM) at a rate of 15 t/ha and NPK at a rate of 120:40:40 kg/ha. Full doses of FYM, phosphorus and potassium, along with half dose of nitrogen, were applied

Fig. 1. General view of experimental field at 110 days after sowing.

during the final tillage stage. One fourth additional dose of nitrogen was applied during the third irrigation 27 days after sowing. The remaining ¼th dose of nitrogen was applied later at final stage (55 days after sowing) when ears turned into yellow. Whereas, the full doses of micronutrients were applied during weeding-cum hoeing, which was done 35 days after sowing. The crop was harvested, threshed by hand and cleaned by separating the seeds and sieving them.

Plant growth parameters

Five plants were chosen at random for each treatment and plants in the border lines were removed. They were tagged for taking biometrical observations on various growth parameters including plant height (cm), number of leaves per plant, leaf area (cm^2), dry weight of plants (g) and days to 50 % flowering. The height of each plant was measured with the help of a meter scale from the ground level to fully opened leaves at 90 days after sowing (DAS). The only largest leaf area (cm^2) of the young leaves of each plant was measured by leaf area meter (Delta-T Devices) at 60 days after seed sowing (DAS). Days to 50 % flowering was judged when there was bolting in 50 % of the plants in each treatment and the number of days from the date of seed sowing was counted. The dry weight and fresh weight of plant (g) in each treatment were calculated after uprooting at the bolting stage. The plant parts, including leaves and spikes, were dried in a hot air oven (Model: TI-125 C, Tempo Instruments, India) at 60 °C until they attained a constant weight.

Seed yield parameters

The data on seed yield and its components in palak include the number of spikes per plant, spike length (cm), spikelet length (cm), hundred-seed weight (g) and seed yield (q/ha). The spike and spikelet length (cm) of five randomly selected plants was measured in centimetres at the time of seed maturity a centimeter scale. 100 dried seeds of palak from each treatment in all three replications were counted and weight was recorded as hundred seed weight in grams and seed yield was calculated based on the following formula-1:

$$\text{Seed yield (q/ha)} = \frac{\text{Seed yield (kg/plot)} \times 10{,}000\ m^2}{\text{Net plot area } (m^2) \times 100} \qquad \text{(Eqn. 1)}$$

Seed quality parameters

The observations on seed quality of palak include germination %, seedling shoot and root length (cm), the total length of seedling (cm), seedling dry weight (mg), seedling vigour index I (SVI – I) and seedling vigour index II (SVI – II) were recorded as per the prevalent procedure. The germination test involved 400 seeds (100 × 4) from every treatment. The test was done using the blotting paper (BP) method inside a seed germinator, maintain temperature at 25 °C ± 10 °C and relative humidity (R.H.) at 95 %. After 14 days of sowing, the final germination % was computed based on the number of normal seedlings obtained during the final count. The seedling shoot length (cm) was measured from collar region to the tip of seedling shoot. Seedling root length (cm) was measured from collar region to tip of the primary root and while total seedling length (cm) was measured from tip of shoot to tip of the primary root of seedling. In the standard germination test, ten healthy seedlings were randomly chosen from each treatment in three replications during the final count. Subsequently, these selected seedlings were used to measure their shoot and root lengths, allowing for the determination of their seedling dry weight (mg). These seedlings were carefully placed on a butter paper and subjected to drying in a hot air oven maintained at a temperature 60 °C for a duration of 36 hr. Afterward, seedlings were taken out from the oven and allowed to cool for 45 min before being weighed using an electrical balance. The average value obtained from the measurements was then expressed as the seedling dry weight (mg) (6). The seedling vigour index-I (SVI – I) and seedling vigour index-II (SVI - II) was computed by using following formula suggested by (7) as under:

$$\text{SVI – I} = \text{Germination percentage} \times \text{Total seedling length (cm)} \qquad \text{(Eqn. 2)}$$

$$\text{SVI – II} = \text{Germination percentage} \times \text{Seedling dry weight (mg)} \qquad \text{(Eqn. 3)}$$

Statistical analysis

The collected data and variance were statistically analyzed, which was carried out using the appropriate method as per the standard procedure (8). Significant differences among treatments were tested using the ANOVA table suggested for a two-factor RBD by MS Excel and OPSTAT software (9).

Results and Discussion

Effect of row-spacings on plant growth parameters

The data on plant growth traits, except the number of leaves per plant, showed significant effect on 50 × 10 cm^2 row-spacing (Table 1). Row-spacing of 50 × 10 cm^2 recorded maximum values for plant height (122.21 cm), number of leaves per plant (40.23), dry weight of plants (10.61 g), leaf area (151.16 cm^2), days to 50 % flowering (100.08 DAS). It was evident that larger row spacing had a major role in the vegetative growth of plants and thus row spacing of 50 × 10 cm^2 exhibited the highest values for plant growth characteristics studied in the present investigation. This is probably because plants get more opportunity to extract nutrients available in the soil and more aerial space for vegetative propagation, thereby reducing competition among plants. Increasing plant density leads to an increase in plant height and the number of leaves on each plant. This phenomenon may be attributed to inter-plant competition (10, 11).

Effect of row-spacings on seed yield and its components

Seed yield and its components except number of spikes per plant were significantly influenced by row-spacing levels (Table 1 & Fig. 2). Row-spacing of 50 × 10 cm^2 showed highest values for number of spikes per plant (2.96), spike length (50.18 cm), spikelet length (38.19 cm) and 100 seed weight (1.42 g). While, higher seed yield per hectare were recorded in lower row-spacing (30 × 10 cm^2). The results revealed good parallelism between the increasing order of row-spacing and the increasing value for all seed yield contributing traits (number of spikes per plant, spike and spikelet length and 100-seed weight), with the maximum value at 50 × 10 cm^2 row-spacing. This might be due to lower inter-plant competition for

Table 1. Effect of row-spacings, micronutrients and their interaction on seed yield and its components of palak

Treatments	Plant height	Number of leaves per	Dry weight of plants (g)	Leaf area (cm^2)	Days to 50 % flowering	Number of spikes per	Spike length	Spikelet length (cm)	100 seed weight (g)	Seed yield (q/ha)
Factor-I: Spacing levels (S)										
S_1	108.34	31.36	9.92	131.32	97.41	2.70	42.55	34.28	1.27	32.72
S_2	107.68	35.68	10.15	148.03	99.00	2.80	48.33	34.89	1.34	29.43
S_3	122.21	40.23	10.61	151.16	100.08	2.96	50.18	38.19	1.42	27.66
SE (m)±	4.10	2.74	0.12	5.29	0.68	0.10	1.90	0.14	0.02	0.92
C.D (P=0.05)	12.12	NS	0.35	15.54	2.03	NS	5.63	0.43	0.07	2.73
Factor-II: Micronutrients (M)										
M_0	104.91	33.38	9.78	125.93	97.11	2.51	42.11	31.39	1.31	27.4
M_1	112.63	39.4	10.43	145.05	97.77	2.89	47.64	36.49	1.35	30.05
M_2	121.31	38.26	10.47	164.27	100.44	3.20	54.37	40.37	1.35	31.64
M_3	112.12	32	10.22	138.76	100.00	2.69	43.95	34.89	1.47	30.63
SE (m)±	4.74	3.16	0.13	6.11	0.79	0.12	2.20	0.17	0.02	1.2
C.D (P=0.05)	NS	NS	0.40	18.01	2.34	0.35	6.50	0.50	NS	3.17
Interaction (S×M)										
S_1M_0	104.80	24.80	9.50	119.24	95.66	2.40	37.73	32.13	1.24	29.25
S_1M_1	106.75	35.53	10.70	124.81	98.66	2.60	45.33	35.51	1.27	32.83
S_1M_2	112.75	34.86	9.61	158.82	98.00	3.13	48.46	37.60	1.27	34.44
S_1M_3	109.08	30.26	9.89	142.44	99.33	2.66	38.66	31.88	1.30	34.34
S_2M_0	99.96	30.26	9.35	152.33	97.00	2.46	43.26	28.69	1.33	27.61
S_2M_1	109.26	42.66	10.30	157.47	97.33	3.00	49.80	34.35	1.34	31.16
S_2M_2	118.46	30.60	10.48	157.29	101.33	3.13	53.86	41.57	1.35	30.20
S_2M_3	103.03	40.00	10.46	125.03	99.66	2.60	46.40	34.97	1.36	28.74
S_3M_0	109.98	34.66	10.48	126.25	96.66	2.66	45.33	33.37	1.38	25.35
S_3M_1	121.88	36.40	10.31	152.88	99.33	3.06	47.80	39.62	1.43	26.18
S_3M_2	132.73	56.93	11.34	176.71	102.00	3.33	60.80	41.95	1.43	30.30
S_3M_3	124.25	29.33	10.32	148.80	101.00	2.80	46.80	37.84	1.45	28.80
SE (m)±	8.21	5.48	0.23	10.58	1.37	0.20	3.81	0.29	0.04	1.44
C.D (P=0.05)	NS	16.18	0.70	31.11	4.04	0.61	11.15	0.86	NS	3.87

NS - Non significant; DAS - Days after sowing; S_1 - 30 × 10 cm^2, S_2 - 40 × 10 cm^2; S_3 - 50 × 10 cm^2; M_0 -Control; M_1- Zinc Sulphate Monohydrate; M_2- Disodium Octaborate Tetrahydrate; M_3- Equal quantity of each Zinc Sulphate Monohydrate; Disodium Octaborate Tetrahydrate with a commercial formulation

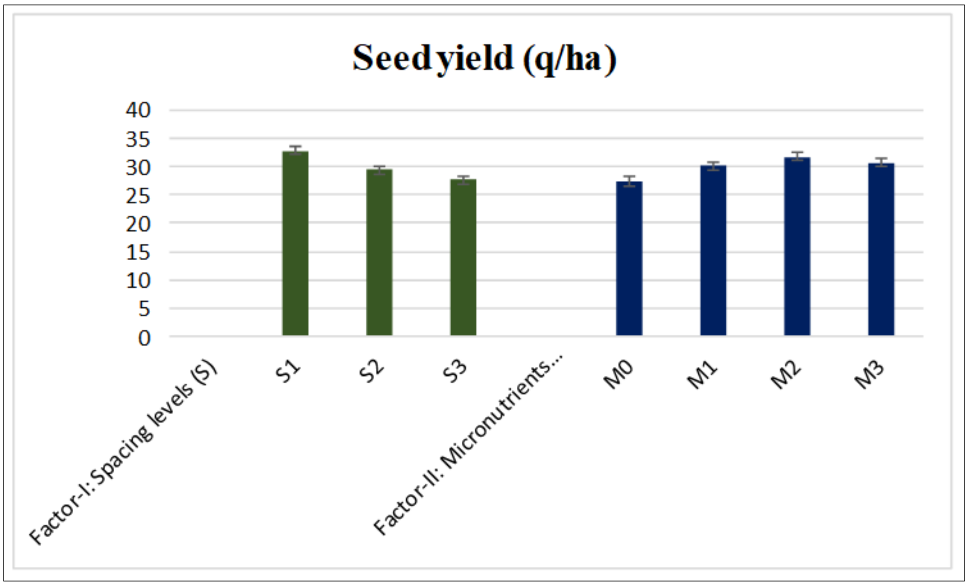

Fig. 2. Effect of row-spacings and micronutrients on seed yield of palak.

nutrients and aerial space at higher row spacings, leading to longer spikes, spikelets and bolder seeds. However, seed yield per hectare showed inverse relationship with row-spacing where lower row-spacing (30 × 10 cm^2) exhibited higher seed yield per hectare (32.72 q/ha) and higher row-spacing (50 × 10 cm) gave 18.3 % less seed yield (27.66 q/ha). Such inverse relationship indicated that higher number of plants accommodated in a unit area at closer row-spacings was principal seed yield determining factor rather than longer and more number of branches in spikes and spikelet (11, 12).

Effect of row-spacing on seed quality parameters

Seed quality parameters were significantly influenced by 40 × 10 cm and 50 × 10 cm^2 spacings presented in Table 2. The spacing of 50 × 10 cm^2 recorded highest values for seedling shoot length (9.82 cm), seedling root length (10.66 cm), total seedling length (20.52 cm), seedling dry weight (8.8 mg), seedling vigour index I (1729.11) and seedling vigour index II (741.35). While germination percentages were observed at 40 × 10 cm^2 and 50 × 10 cm^2 spacings (84.50 % and 83.83 %, respectively), which were significantly higher (16.6 %) than at 30 × 10 cm row spacing (72.50 %) (11, 13). In the view of inclusive results on seed and quality parameters, widest row spacing of 50 × 10 cm^2 gave 18.3 % lower seed yield (27.66 q/ha) as compared to closest row-spacing of 30 × 10 cm^2 (32.72 q/ha) but the seed produced at widest row spacing exhibited 16.6 % higher germination percentage (83.83 %) as compared those produced in closest row spacing (72.50 %). From such findings, it is obvious that seed yield and quality have an inverse

Table 2. Effect of row-spacings, micronutrients and their interaction on seed quality of palak

Treatments	Germination percentage	Seedling shoot length (cm)	Seedling root length (cm)	Total seedling length (cm)	Seedling dry weight (mg)	Seedling vigour index I	Seedling vigour index II
Factor-I: Spacing levels (S)							
S_1	72.50	8.65	8.22	16.87	6.1	1,229.47	447.84
S_2	84.50	9.21	9.60	18.75	7.6	1,587.56	645.17
S_3	83.83	9.82	10.66	20.52	8.8	1,729.11	741.35
SE (m)±	1.13	0.14	0.25	0.31	0.2	44.64	23.02
C.D (P=0.05)	3.33	0.42	0.74	0.93	0.6	131.79	67.95
Factor-II: Micronutrients (M)							
M_0	72.77	8.31	8.57	16.89	6.5	1,232.81	481.61
M_1	79.89	9.19	9.44	18.55	7.3	1,491.33	593.14
M_2	84.33	9.59	9.66	19.30	7.6	1,634.42	648.53
M_3	84.11	9.83	10.28	20.12	8.5	1,702.96	722.53
SE (m)±	1.30	0.16	0.29	0.36	0.2	51.55	26.58
C.D (P=0.05)	3.85	0.48	0.85	1.07	0.7	152.18	77.81
Interaction (S×M)							
S_1M_0	66.00	7.53	7.35	14.89	5.3	982.73	354.02
S_1M_1	70.66	8.39	8.09	16.49	5.7	1,165.25	405.92
S_1M_2	75.66	9.66	8.28	17.94	6.2	1,357.55	475.51
S_1M_3	77.66	9.02	9.15	18.18	7.1	1,412.35	555.92
S_2M_0	77.00	8.56	8.51	17.08	6.5	1,306.00	498.57
S_2M_1	85.66	9.70	9.63	19.08	7.6	1,634.42	654.00
S_2M_2	87.67	9.21	9.61	18.83	7.6	1,650.20	667.06
S_2M_3	89.66	9.38	10.64	20.02	8.7	1,759.62	761.05
S_3M_0	75.33	8.84	9.86	18.71	7.8	1,409.71	592.25
S_3M_1	83.33	9.47	10.61	20.08	8.6	1,674.31	719.52
S_3M_2	89.66	9.89	11.06	21.14	8.9	1,895.50	803.01
S_3M_3	87.00	11.09	11.10	22.15	9.7	1,936.91	850.64
SE (m)±	2.26	0.28	0.50	0.63	0.4	89.29	46.04
C.D (P=0.05)	6.60	0.84	1.46	1.84	1.2	261.40	134.78

NS - Non significant; DAS - Days after sowing; S_1 – 30 × 10 cm^2; S_2 - 40 × 10 cm^2; S_3 - 50 × 10 cm^2; M_0 -Control; M_1- Zinc sulphate monohydrate; M_2- Disodium octaborate tetrahydrate; M_3- Equal quantity of each Zinc sulphate monohydrate; Disodium Octaborate Tetrahydrate with a commercial formulation

relationship to some extent and the highest seed-yielding row spacing results in seeds with a comparatively lower germination percentage. Among the treatments included in this investigation, medium row-spacing of 40 × 10 cm showed 6.40 % lower seed yield (29.43 q/ha) as compared to 30 × 10 cm row-spacing. Still, the seed produced under this row-spacing registered 16.60 % higher germination percentage (83.83 %) over that produced under closest spacing (30 × 10 cm). In this way, a medium row spacing of 40 × 10 cm could be appropriate to satisfy the requirements for optimum seed yield with satisfactory seed quality parameters in palak (14).

Effect of micronutrients on plant growth parameters

In the case of micronutrients, growth parameters were significantly influenced and are depicted in Table 1. The data on plant height and number of leaves/plants indicated that there was a non-significant effect of micronutrients individually. Disodium Octaborate Tetrahydrate (M_2) registered highest values for plant height (121.31 cm), leaf area (164.27 cm^2), dry weight of plants (10.47 g) and days to 50 % flowering (100.44 DAS) (15). These results prove that the application of Disodium Octaborate Tetrahydrate was a potential treatment for proper growth and development as well as a prolonged vegetative phase. Similarly, application of zinc in the form of Zinc Sulphate Monohydrate (M_1) alone or combined with the formulation of boron also showed beneficial effect on vegetative growth and prolongation of the vegetative phase of plants (16). Similar results have also been reported (14).

Effect of micronutrients on seed yield and its components

Among the micronutrients affecting seed yield and its components, those presented in Table 1 showed a significant effect. The data on 100 seed weight was a non-significant effect of micronutrients. The treatment Disodium Octaborate Tetrahydrate registered maximum values for number of spikes per plant (3.20), spike and spikelet length (54.37 cm & 40.37 cm, respectively) and seed yield (31.64 q/ha). While, M_3 reported highest values for 100 seed weight. Such findings might be due to the positive role of boron in the proper growth of seed stalks, seed setting and maturation. In addition to boron, zinc and mixture of boron, zinc and many other micronutrients had beneficial effects on seed stalk growth, seed setting and maturation in palak crops (16, 17).

Effect of micronutrients on seed quality parameters

In case of seed quality traits, Disodium Octaborate Tetrahydrate (M_2) registered maximum values for germination percentage (84.33 %) and the treatment comprising M_3 showed second highest germination percentage (84.11 %), seedling root length (10.28 cm), seedling shoot length (9.83 cm), total seedling length (20.12 cm), seedling dry weight (8.5 mg), SVI-I (1702.96) and SVI-II (722.53) (Table 2 & Fig. 3). Shoot and root length were observed higher due to application of micronutrient (15). Soil application of borax alone gives germination percentage, hundred seed weight and SVI (seedling vigour index) over control (16).

Interaction effect of row-spacing and micronutrients on plant growth and seed yield parameters

The growth and seed yield traits were significantly influenced by the interaction of row-spacings and micronutrient levels (Table 1). The data on plant height and 100 seed weight indicated that there was a non-significant effect of the interaction of both spacings and micronutrients on these traits. The interaction of row-spacing $S_3$and M_3 showed a maximum value for 100 seed weight (1.45 g). From the interaction effects, it could be summarized that wider row-spacing (S_3 or S_2) accompanied with application of M_2, M_1 and M_3 had a

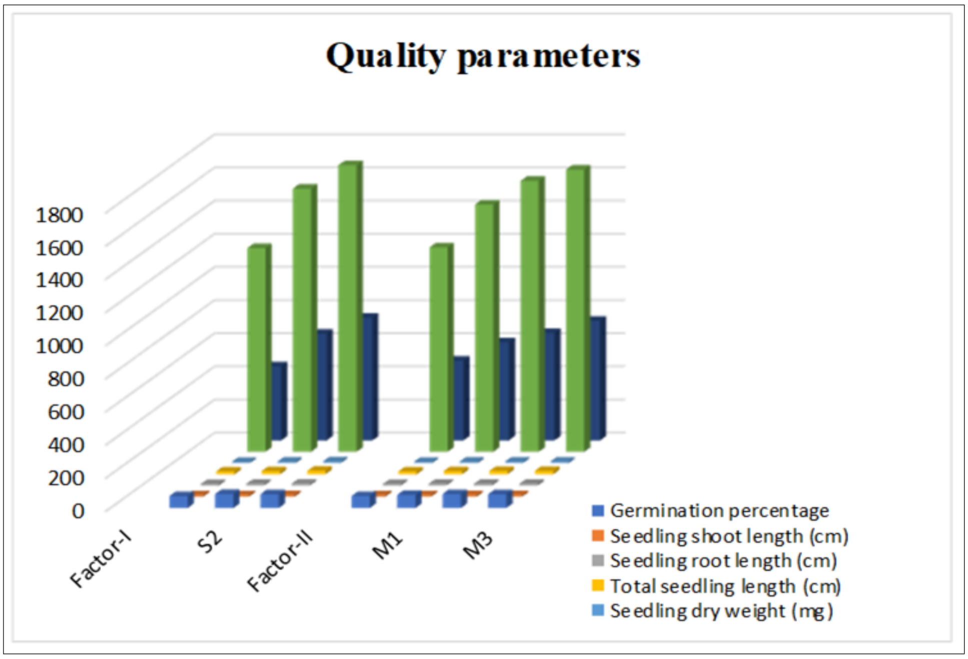

Fig. 3. Effect of row-spacings and micronutrients on quality parameters of palak.

favourable impact most on plant growth and seed yield traits, plant height (132.73 cm), number leaves per plant (56.93), dry weight of plants (11.34 g), leaf area (176.71 cm^2), days to 50 % flowering (102.00 DAS), number of spikes per plant (3.33), spike & spikelet length (60.80 cm and 41.95 cm), 100 seed weight (1.45 g), The micronutrients of M_2 or M_3 with S_1 was favourable for seed yield per hectare, as the number of plants was higher at closer spacing. The treatment combination involving the application of Zinc Sulphate Monohydrate and Disodium Octaborate Tetrahydrate with a closer spacing of 30 × 10 cm resulted in significantly higher values for various yield parameters (13). Spacing of 50 × 10 cm reduces competition between plants and provides more nutrients, space, air and sunlight, resulting in better seed quality. Whereas, boron is an essential micronutrient for pollen tube growth and cell wall formation, which is responsible for flowering and fertilization for quality seeds. Fe provides a role in chlorophyll synthesis, enzymatic activities and energy transfer in plant cells. In combination, suitable iron and boron nutrition with higher spacing create favorable physiological conditions that provide better plant growth and seed quality in palak. Similar results were in conformity with earlier reports (11).

Interaction effect of row-spacing and micronutrients on seed quality parameters

The row-spacing S_3 and M_3 showed maximum value for most of the quality parameters (Table 2). Among the interaction effects, it could be summarized that wider row-spacing (50 × 10 cm and 40 × 10 cm^2) accompanied with application of M_1, M_2 and M_3 had favorable effects on most of the seed quality character, germination percentage (89.66), seedling shoot length, seedling root length and total seedling length (11.09 cm, 11.10 cm and 22.15 cm) seedling dry weight (9.7 mg) and seedling vigour index-I & II (1936.91 & 850.64). In the view of higher yield of seeds meeting optimum quality standards specifically germination percentage up to or above 85 % The given treatment combinations S_2M_1, S_3M_3 and S_2M_2 observed 31.16 q/ha seed yield with 85.66 % germination percentage, 30.30 q/ha seed yield with 89.66 % germination percentage and seed yield with 87.67 % germination percentage, respectively. This may be due to the maximum thousand-seed weight recorded in this treatment combination (13). Similar results were observed with previous reports (11, 18).

More generally, there may be several reasons why there is very little meaningful data present in this research report. While inherent variability exists in palak growth, it may not be difficult to observe whether noticeable differences in certain growth and seed yield measurements, such as plant height, number of leaves per plant, number of spikes per plant and 100 -seed weight, exist with different row-spacing and micronutrient treatments. It is also possible that the chosen treatments did not have a sufficiently large effect on these parameters to produce statistically significant changes. In addition, crop-specific responses and uncontrolled environmental factors may have influenced these results. All of these aspects require understanding and attention for the refinement of experimental designs as well as direction of future research.

Conclusion

In the present investigation, it was revealed that row spacing and micronutrients had a significant effect on growth variables, seed yield and quality of palak. Adopting proper row spacing and a balanced supply of micronutrients can achieve optimum spinach production for higher crop productivity and also increase seed yield along with improved seed quality. Row spacing of 50 × 10 cm^2 obtained the highest values for all the traits related to yield and quality, except seed yield. The maximum yield of seed was observed at the closest row spacing (30 × 10 cm^2). Germination percentage was found at S_2 (40 × 10 cm^2) and S_3 (50 × 10 cm^2) row-spacings, which were significantly higher than S_1 (30 × 10 cm^2) row-spacing. In micronutrients, M_2 recorded the highest values for plant height, leaf area, plant dry weight, 50 % days to flowering, spike and spikelet length, number of spikes per plant, seed yield and germination percentage. M_3 treatment showed the highest seedling dry weight, seedling shoot length, seedling root length, total length, seedling vigour index I and II and the highest germination percentage. The promising treatment combinations S_2M_1, S_2M_2 and S_3M_3 showed the highest seed yield, as well as the best seed quality parameters. For optimal balance between seed yield and quality, a 40 × 10 cm row spacing, combined with Disodium Octaborate Tetrahydrate (M_2), can be more beneficial in accruing better dividends for marginal and small farmers in the Bundelkhand region.

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Authors' contributions

IS performed the experimental field trial and writing the manuscript while ACM critically advised and monitored the entire research work. RKS helped in manuscript drafting and monitored the entire research work, SS assisted in manuscript drafting and editing and SK assisted in manuscript editing. AK assisted in manuscript reading and final editing and SP helped in manuscript editing. ADK conducted the statistical analysis. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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