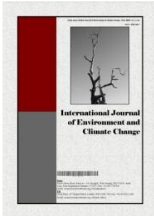

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Growth, Yield, Seed and Seedling Quality Parameters of Rapeseed-mustard Varieties under Different Seed Priming Options

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Authors' contributions

This work was carried out in collaboration among all authors. Author RD carried out the experiment. Authors SB and UB helped author RD during the experiment. Further, author SB performed all the statistical analysis and wrote the paper. Author AD planned the experiment and guided as and when required. All authors read and approved the final manuscript.

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ABSTRACT

Rationale: Crop production and quality of produce get affected by drought, stand establishment and low availability of nutrients. Apart from various prevailing methods, seed treatment through priming now-a-days has been found to noticeably improve crop establishment for increasing seed yield and quality.
Aim: To study the effect of various seed priming options on rapeseed-mustard varieties.
Place of Study: A field experiment was conducted at AB Block Farm, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal, India during winter season of 2017-2018.
Methodology: Experiment comprised six rapeseed-mustard varieties (Anushka, Sanchita, TBM-143,TBM-204, Kranti and Pusa Bold) in main plot and five seed priming options (KH_2PO_4 @ 0.15 mol 100 ml water^{-1} 5 g seeds^{-1}, KNO_3 @ 0.1 mol 100 ml water^{-1} 5 g seeds^{-1}, PEG 6000 @ -0.3 MPa 100 ml water^{-1} 5 g seeds^{-1}, hydro priming @ 100 ml 5 g seeds^{-1} and control) in subplot, replicated

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thrice in a split plot design. Observations on growth and yield contributing parameters were recorded from the field. Further, various quality parameters of seed and seedlings were evaluated in the laboratory. Data on all the parameters were finally statistically analyzed.

Results: Among the varieties, Pusa Bold performed better in terms of growth, yield contributing parameters and seed yield under seed priming through either KH_2PO_4 @ 0.15 mol 100 ml water^{-1} 5 g seeds^{-1} or PEG 6000 @ -0.3 MPa 100 ml water^{-1} 5 g seeds^{-1}. Seed and seedling quality parameters such as root and shoot lengths, seedling fresh and dry weights, germination % and vigour index were also improved under the same.

Conclusion: Cultivation of mustard variety, Pusa Bold by seed priming through any of those two chemicals (KH_2PO_4 or PEG 6000) can be recommended for New alluvial zone of West Bengal, India.

Keywords: Rapeseed-mustard; seed priming; seed quality; seed yield; variety.

1. INTRODUCTION

Oilseeds specially the edible ones hold a very important position in human life since ancient days. Use of nutritionally rich edible oils in daily life cooking or in other forms is constantly increasing in response to caloric demand of ever rising human population. Besides, edible oils maintain the activities of brain, liver and various nerves by synthesizing phospholipids [1]. India holds fourth position in global oilseed producing economy. Greater part of attention paid towards production of food grains to meet the demand of world's second largest population has made oilseeds to remain as neglected in this country. As a result, supply of edible oilseeds fall short to their demand. Further, consistent import from other countries is another factor that has made high market price of edible oils. Adequate attention towards cultivation of oilseeds followed by strengthening of demand-supply chain can only solve these high market price and availability issues. Among various oilseeds, rapeseed-mustard (*Brassica* sp.) is second and third important edible oil-seed crop of India and the world respectively. There are various uses of this winter growing annual plant ranging from edible oils for cooking, seeds as condiments to cakes as animal feed [2]. Presence of glucosinolates (pseudo-thioglucosides) has made this edible oilseed crop as unique one [3]. In India, rapeseed-mustard is grown in 5.96 million ha with a production of 8.32 million tonnes and productivity of 1397 kg ha^{-1} during 2017-18 [4]. Rajasthan, Madhya Pradesh, Gujarat, Haryana, Uttar Pradesh, Jharkhand, Assam, Bihar and West Bengal are some major rapeseed-mustard producing states of this country.

In the present context of high demand and low supply, suitable package of practices like incorporation of good quality seeds, suitable nutrient, weed and water managements etc. can uplift the productivity of this crop to some extent. Proper stand establishment is another important aim which needs to be achieved particularly in the changing climate scenario. For instance, in West Bengal, India, due to prolonged summer and short winter, high temperature or drought like situations often lead to poor germination and stand establishment which ultimately hamper qualitative and quantitative rapeseed-mustard production. Under this circumstance, evolution of varieties specific to agro-climatic situation and careful monitoring of their on-field performance are some important criteria for achieving good productivity of this oilseed crop. Besides, incorporation of best management practices or promising new technologies can further improve the performance of the varieties in a particular agro-climatic situation. In this regard, seed priming now-a-days holds a very good prospect not only in rapeseed-mustard, but also in many other crops. Seed priming is cheap and basically a pre-sowing controlled hydration process with the objective to bring some biochemical and physiological changes in seeds for initiating metabolic activities without allowing them to emerge [5]. It ensures uniform and rapid germination, high vigour resulting in proper stand establishment, growth and improvement in yield [6]. Different categories of seed priming viz. hydro-priming, halo-priming, osmo-priming, hormonal priming etc. have already been used in rapeseed-mustard [7]. Literatures indicate that seed priming hastens the germination and seedling growth which influence better field performance consequently specially under adverse agro-climatic condition [8]. Early emergence, root and shoot growths, early flowering, maturity, better water and nutrient use efficiencies, quick and prominent development of reproductive organs, resistance to drought, salinity or other environmental stresses are some notable benefits of seed priming [9]. Considering all these facts, the present experiment was planned to evaluate the efficacy of various seed priming options on growth, yield, seed and seedling quality parameters of some rapeseed-mustard varieties under New alluvial zone of West Bengal, India.

2. MATERIALS AND METHODS

The field experiment was conducted during the winter (*Rabi*) season of 2017-2018 at AB Block farm, Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India. The soil of the experimental site was alluvial and sandy loam in texture with pH 7.8, organic carbon of 0.6%, available nitrogen of 250 kg ha^{-1}, available phosphorus of 15.8 kg ha^{-1} and potassium of 153 kg ha^{-1}. The experiment was laid out in split plot design with main plot consisting of 6 varieties (V_1: Anushka, V_2: Sanchita, V_3: TBM-143, V_4: TBM-204, V_5: Kranti and V_6: Pusa Bold) and sub plot consisting of 5 seed priming options (T_1: KH_2PO_4 @ 0.15 mol 100 ml $water^{-1}$ 5 g $seeds^{-1}$, T_2: KNO_3 @ 0.1 mol 100 ml $water^{-1}$ 5 g $seeds^{-1}$, T_3: PEG 6000 @ -0.3 MPa100 ml $water^{-1}$ 5 g $seeds^{-1}$, T_4: Distilled water @ 100 ml 5 g $seeds^{-1}$ and T_5: Control or dry seed), replicated thrice. Seeds were sown on 28^{th} November, 2017 in line at a spacing of 25 cm × 15 cm. Individual plot size was 4 m x 3 m. Half of recommended dose of N and full of P_2O_5 and K_2O i.e. 60:60:60 kg ha^{-1} were applied through urea, S.S.P., M.O.P. at basal and rest 60 kg N ha^{-1} was applied at 30 DAS. Other agronomic practices and plant protection measures were adopted as per recommendation as and when required. Observations included days to 50% flowering, days to maturity, plant height, primary branch $plant^{-1}$, number of siliqua $plant^{-1}$, no. of seeds $siliqua^{-1}$, 1000 seeds weight and seed yield. The seed quality parameters (viz. root length, shoot length, seedling fresh and dry weights, vigour index, germination percentage) were estimated at the laboratory of Department of Seed Science and Technology, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India by following the methods as prescribed by International Seed Testing Association [10] and statistically analyzed in CRD. Vigour index was expressed and estimated as following:

Vigour index = Germination percentage × Length of seedling

Data recorded for different parameters were statistically analyzed by analysis of variance techniques [11] through online OP-stat portal [12] and treatment means were compared through critical differences (C.D.) at 5% level of significance as proposed by Gomez and Gomez [13]. Further, Pearson's correlation coefficient and regression relationships between various variables were statistically estimated.

3. RESULTS AND DISCUSSION

3.1 Growth and Yield Contributing Parameters

Experimental results (Table 1) explored that seed priming options imparted significant impacts on rapeseed-mustard varieties. Among the varieties, Anushka (V_1) attained earliest days to 50% flowering (37.07 days) and maturity (84.59 days), which was followed by Sanchita (V_2) (50% flowering: 40.31 days and maturity: 96.55 days), TBM-143 (V_3) (50% flowering: 46.59 days and maturity: 103.69 days), TBM-204 (V_4) (50% flowering: 48.97 days and maturity: 108.75 days), Kranti (V_5) (50% flowering: 49.53 days and maturity: 117.51 days) and Pusa Bold (V_6) (50% flowering: 49.54 days and maturity: 118.48 days) (Table 1). However, regarding other growth attributes, variety Pusa Bold (V_3) remained superior over others with maximum plant height at harvest (194.86 cm) and primary branches $plant^{-1}$ (7.37), which was further followed by Kranti (V_5) (plant height: 180.43 cm and primary branches $plant^{-1}$: 6.61), TBM-204 (V_4) (plant height: 165.89 cm and primary branches $plant^{-1}$: 6.53), TBM-143 (V_3) (plant height: 152.01 cm and primary branches $plant^{-1}$: 6.51), Sanchita (V_2) (plant height: 114.13 cm and primary branches $plant^{-1}$: 4.29) and Anushka (V_1) (plant height: 105.59 cm and primary branches $plant^{-1}$: 3.91) (Table 1). These results might be due to the genetical characters of the varieties. Short duration varieties flowered and matured earlier than the mid and long duration varieties in response to their genetical traits. Further, vigorous growth of variety, Pusa Bold as compared to other varieties might be due to the fact that genetical structures made the varieties to attain variable plant heights and primary branches $plant^{-1}$. Rashid et al. [14] also reported that varieties due to their variable genetical traits expressed different growth attributes of mustard varieties.

Table 1. Effect of seed priming on growth and yield contributing parameters of rapeseed-mustard varieties

Treatments*	Days to 50% flowering (days)	Days to maturity (days)	Plant height (cm)	Primary branch plant^{-1} (nos.)	Siliqua plant^{-1} (nos.)	Seeds siliqua^{-1} (nos.)	1000 seeds weight (g)	Seed yield (kg ha^{-1})
Varieties								
V_1	37.07	84.59	105.59	3.91	101.2	18.15	2.46	1220.21
V_2	40.31	96.55	114.13	4.29	102.6	16.37	3.13	1411.06
V_3	46.59	103.69	152.01	6.51	116.2	14.82	3.16	1466.57
V_4	48.97	108.75	165.89	6.53	116.8	11.17	4.16	1443.62
V_5	49.53	117.51	180.43	6.61	118.4	11.54	4.59	1678.45
V_6	49.54	118.48	194.86	7.37	121.0	10.21	5.67	1865.70
S.Em (±)	0.19	0.21	0.48	0.11	4.51	0.15	0.021	65.90
C.D. (5%)	0.62	0.66	1.53	0.35	14.4	0.47	0.07	210.33
Seed priming options								
T_1	45.05	103.56	155.47	6.06	126.2	14.27	3.93	1788.46
T_2	45.45	105.24	152.22	5.91	118.8	13.72	3.85	1559.72
T_3	45.16	104.53	154.70	5.94	123.1	13.93	3.87	1689.59
T_4	45.47	105.52	150.70	5.74	104.4	13.52	3.84	1380.47
T_5	45.55	105.81	147.66	5.70	91.0	13.12	3.81	1153.12
S.Em (±)	0.12	0.18	0.47	0.08	2.88	0.12	0.018	43.96
C.D. (5%)	0.34	0.52	1.35	0.25	8.2	0.34	0.05	125.39

Interaction	**V×T**	**T×V**	**V×T**	**T×V**	**V×T**	**T×V**	**V×T**	**T×V**	**V×T**	**T×V**	**V×T**	**T×V**	**V×T**	**T×V**	**V×T**	**T×V**
S.Em (±)	0.43	0.33	0.47	0.45	1.07	1.14	0.24	0.22	10.09	7.8	0.33	0.30	0.046	0.044	147.35	116.70
C.D. (5%)	0.87	0.97	1.30	1.31	3.39	3.33	0.62	0.64	20.9	23.0	0.85	0.88	0.13	0.13	318.81	345.50

*V_1: Anushka, V_2: Sanchita, V_3: TBM-143, V_4: TBM-204, V_5: Kranti, V_6: PusaBold, T_1: KH_2PO_4 @ 0.15 mol 100 ml water^{-1} 5 g seeds^{-1}, T_2: KNO_3 @ 0.1 mol 100 ml water^{-1} 5 g seeds^{-1}, T_3: PEG 6000 @ -0.3 MPa100 ml water^{-1} 5 g seeds^{-1}, T_4: Distilled water @ 100 ml 5g seeds^{-1} and T_5: Control or dry seed

It was also noticed that seed priming options exerted positive influence on above mentioned growth attributes of rapeseed-mustard varieties over control or dry seeds (T_5). Among various seed priming options, seed priming through KH_2PO_4 @ 0.15 mol 100 ml water^{-1} 5 g seeds^{-1} (T_1) significantly fastened the growth of rapeseed-mustard varieties and helped to attain earliest 50% flowering (45.05 days) and maturity (103.56 days), which was closely followed by seed priming through PEG 6000 @ -0.3 MPa100 ml water^{-1} 5 g seeds^{-1} (T_3) (50% flowering: 45.16 days and maturity: 104.53 days). Meena et al. [15] also noticed earliest flowering of lentil under seed priming through KH_2PO_4. Control or dry seeds (T_5) on a contrary, flowered and matured most late (50% flowering: 45.55 days and maturity: 105.81 days) (Table 1). Similarly, seed priming through KH_2PO_4 @ 0.15 mol 100 ml water^{-1} 5 g seeds^{-1} (T_1) produced tallest plants at harvest (155.47 cm) and maximum primary branches plant^{-1} (6.06), which was followed by seed priming through PEG 6000 @ -0.3 MPa100 ml water^{-1} 5 g seeds^{-1} (T_3) (plant height: 154.70 cm and primary branches plant^{-1}: 5.94) and KNO_3 @ 0.1 mol 100 ml water^{-1} 5 g seeds^{-1} (T_2) (plant height: 152.22 cm and primary branches plant^{-1}: 5.91). Assefa and Hunje [16] also reported higher plant height of soybean under seed priming through KH_2PO_4. Thejeshwini et al. [17] observed better plant height of onion under seed priming through PEG 6000. Control or dry seeds (T_5) remained poorest among all in terms of both plant height (147.66 cm) and primary branches plant^{-1} (5.70) (Table 1). Seed priming enhanced α-amylase activity and total sugar concentration which helped seeds to achieve high germination and vigour and as a result, better stand establishment was ensured which ultimately accelerated crop growth. Better root proliferation and stress tolerance of plant under seed priming through KH_2PO_4 or PEG 6000 increased nutrient and moisture uptake from soil and helped to attain robust plant which subsequently expressed high photosynthetic efficiency, resulting in its elevated growth. Moreover, improvement of sucrose metabolism [18] might be another reason for such improvement in growth by seed priming through above said chemicals.

Like growth attributes, various yield contributing parameters and yield also varied among rapeseed-mustard varieties (Table 1). Among the varieties, Pusa Bold (V_6) produced maximum number of siliqua plant^{-1} (121.0) and 1000 seeds weight (5.67 g), which was further followed by Kranti (V_5) (number of siliqua plant^{-1}: 118.4 and 1000 seeds weight: 4.59 g), TBM-204 (V_4) (number of siliqua plant^{-1}: 116.8 and 1000 seeds weight: 4.16 g), TBM-143 (V_3) (number of siliqua plant^{-1}: 116.2 and 1000 seeds weight: 3.16 g), Sanchita (V_2) (number of siliqua plant^{-1}: 102.6 and 1000 seeds weight: 3.13 g) and Anushka (V_1) (number of siliqua plant^{-1}: 101.2 and 1000 seeds weight: 2.46 g) (Table 1). However, regarding number of seeds siliqua^{-1}, different trend was observed. Maximum number of seeds siliqua^{-1} (18.15) was noticed in case of Anushka (V_1) which was followed by Sanchita (V_2) (16.37), TBM-143 (V_3) (14.82), Kranti (V_5) (11.54), TBM-204 (V_4) (11.17) and Pusa Bold (V_6) (10.21) (Table 1). As a consequence of different yield contributing parameters, highest seed yield (1865.70 kg ha^{-1}) was produced by Pusa Bold (V_6) which was followed by Kranti (V_5) (1678.45 kg ha^{-1}), TBM-143 (V_3) (1466.57 kg ha^{-1}), TBM-204 (V_4) (1443.62 kg ha^{-1}), Sanchita (V_2) (1411.06 kg ha^{-1}) and Anushka (V_1) (1220.21 kg ha^{-1}) (Table 1). Varieties performed differently in terms of various yield contributing parameters due to their variable genetical makeup. Inspite of producing less number of seeds siliqua^{-1}, Pusa Bold comparatively performed better over others in terms of seed yield due to production of more number of siliqua plant^{-1}. Moreover, bigger/bold size of seeds made Pusa Bold to achieve highest 1000 seeds weight which altogether ultimately reflected on its seed yield. Although the variety, Anushka produced highest number of seeds siliqua^{-1}, seed size of that variety was much smaller than others. Besides, production of less number of siliqua plant^{-1} made the variety (Anushka) to be the poorest performer among all in terms of seed yield. Greater and prolonged vegetative growth coupled with high photosynthetic efficiency followed by better translocation of photosynthates towards reproductive parts of the plant might be the another reason for achieving highest seed yield by the variety, Pusa Bold over others. Alam et al. [1] also reported variations in plant growth, flowering, maturity, yield attributes and yield of different rapeseed-mustard varieties.

Regarding various yield contributing parameters and yield, seed priming options followed the identical trend of growth attributes. Among the seed priming options, maximum number of siliqua plant^{-1} (126.2), seeds siliqua^{-1} (14.27), 1000 seeds weight (3.93 g) and seed yield (1788.46 kg ha^{-1}) were observed when seed priming was done through KH_2PO_4 @ 0.15 mol 100 ml water^{-1} 5 g seeds^{-1} (T_1) which was further followed by seed priming through PEG 6000 @ -0.3 MPa100 ml water^{-1} 5 g seeds^{-1} (T_3) (number of siliqua plant^{-1}: 123.1, number of seeds siliqua^{-1}: 13.93, 1000 seeds weight: 3.87 g and seed yield: 1689.59 kg ha^{-1}) and KNO_3 @ 0.1 mol 100 ml water^{-1} 5 g seeds^{-1} (T_2) (number of siliqua plant^{-1}: 118.8, number of seeds siliqua^{-1}: 13.72, 1000 seeds weight: 3.85 g and seed yield: 1559.72 kg ha^{-1}). Patil et al. [19] similarly reported enhancements of yield attributing parameters and yield under seed priming through KH_2PO_4 in finger millet. Toklu et al. [20] obtained increment of grain yield of wheat by seed priming through PEG 6000. Control or dry seeds (T_5) produced comparatively lowest number of siliqua plant^{-1} (91.0), seeds siliqua^{-1} (13.12), 1000 seeds weight (3.81 g) and seed yield (1153.12 kg ha^{-1}) (Table 1). These results might be due to the fact that elevated growth of plant under seed priming through KH_2PO_4 or PEG 6000 and consequent mobilizations of proteins, amino acids, soluble sugar and other assimilates from source (vegetative part) to sink (reproductive organs) [21] helped the rapeseed-mustard to achieve high yield contributing parameters and yield.

Interaction effects of variety and seed priming option remained statistically significant on all the mentioned growth, yield contributing parameters and yield (Table 1). It clearly indicated that a particular seed priming option exerted specific effect on a particular rapeseed-mustard variety in terms expressing various growth, yield contributing parameters and yield.

3.2 Seed and Seedling Quality Parameters

The data presented in Table 2 stated that various seed and seedling quality parameters such as root length, shoot length, seedling fresh weight, seedling dry weight, vigour index, germination percentage significantly varied among the rapeseed-mustard varieties. Maximum germination percentage (98.96%) was shown by the variety Pusa Bold (V_6) which was followed by Kranti (V_5) (98.52%), TBM-204 (V_4) (98.25%), TBM-143 (V_3) (97.79%), Sanchita (V_2) (97.48%) and Anushka (V_1) (97.07%). However, TBM-204 (V_4), Kranti (V_5) and Pusa Bold (V_6) remained statistically at par to each other. On the other hand, Anushka (V_1), Sanchita (V_2) and TBM-143 (V_3) remained statistically at par to each other (Table 2). Identical trend was also noticed in case of root length, shoot length, seedling fresh and dry weights and vigour index. Maximum root length (14.58 cm), shoot length (3.68 cm), seedling fresh weight (0.576 g), seedling dry weight (0.033 g) were exhibited by the variety Pusa Bold (V_6) which was followed by Kranti (V_5), TBM-204 (V_4), TBM-143 (V_3), Sanchita (V_2) and the variety Anushka (V_1) remained poorest among all (root length: 12.05 cm, shoot length: 2.64 cm, seedling fresh weight: 0.216 g and seedling dry weight: 0.021 g) (Table 2). Since vigour index is the product of germination % and seedling length (i.e. root length + shoot length), maximum vigour index (1807.12) was also expressed by the variety Pusa Bold (V6) which was further followed by Kranti (V_5) (1756.92), TBM-204 (V_4) (1738.10), TBM-143 (V_3) (1659.07), Sanchita (V_2) (1621.51) and Anushka (V_1) (1427.07) (Table 2). Varieties used in this study were genetically different. Variation in seed germination, seedling root and shoot lengths, fresh and dry weights and vigour index of different rapeseed-mustard varieties might be due to their variable genetical makeup. Channaoui et al. [22] similarly reported variable seed and seedling quality parameters of different rapeseed varieties in response to their genetical variation. Talukder et al. [23] also observed same in some rapeseed-mustard varieties.

Various seed priming options exerted significant influence on seed and seedling quality parameters of rapeseed-mustard over control (Table 2). Among the seed priming options, seed priming through KH_2PO_4 @ 0.15 mol 100 ml water^{-1} 5 g seeds^{-1} (T_1) significantly improved seed germination of rapeseed-mustard varieties and exhibited maximum germination percentage (99.13%), which was closely followed by seed priming through PEG 6000 @ -0.3 MPa100 ml water^{-1} 5 g seeds^{-1} (T_3) (98.83%) and KNO_3 @ 0.1 mol 100 ml water^{-1} 5 g seeds^{-1} (T_2) (97.77%). However, germination of rapeseed-mustard seeds primed through KH_2PO_4 @ 0.15 mol 100 ml water^{-1} 5 g seeds^{-1} (T_1) and PEG 6000 @ -0.3 MPa100 ml water^{-1} 5 g seeds^{-1} (T_3) remained statistically similar to each other (Table 2). Control or dry seeds (T_5) exhibited comparatively lowest seed germination percentage (96.93%). In the similar fashion, maximum root length (14.10 cm), shoot length (3.64 cm), seedling fresh weight (0.461 g), seedling dry weight (0.034 g) of rapeseed-mustard were achieved when seed priming was done through KH_2PO_4 @ 0.15 mol 100 ml water^{-1} 5 g seeds^{-1} (T_1) which was further followed by seed priming through PEG 6000 @ -0.3 MPa100 ml water^{-1} 5 g seeds^{-1} (T_3) (root length: 13.92 cm, shoot length: 3.55 cm, seedling fresh weight: 0.455 g and seedling dry weight: 0.029 g) and KNO_3 @ 0.1 mol 100 ml water^{-1} 5 g seeds^{-1} (T_2) (root length: 13.68 cm, shoot length:

3.47 cm, seedling fresh weight: 0.436 g and seedling dry weight: 0.026 g). Control or dry seeds (T_5) remained comparatively poorest in terms of root length (12.68 cm), shoot length (3.32 cm), seedling fresh weight (0.362 g), seedling dry weight (0.020 g) of rapeseed-mustard. Seed priming through PEG 6000 @ -0.3 MPa100 ml water^{-1} 5 g seeds^{-1} (T_3) remained statistically at par with KH_2PO_4 @ 0.15 mol 100 ml water^{-1} 5 g seeds^{-1} (T_1) in terms of root length, shoot length and seedling fresh weight, while seed priming through KNO_3 @ 0.1 mol 100 ml water^{-1} 5 g seeds^{-1} (T_2) showed statistical similarity with PEG 6000 @ -0.3 MPa100 ml water^{-1} 5 g seeds^{-1} (T_3) in terms of root length, shoot length, seedling fresh and dry weights (Table 2). As a consequence of germination and seedling length, vigour index also similarly varied according to several seed priming options. Maximum vigour index (1758.78) was noticed when seed priming was done through KH_2PO_4 @ 0.15 mol 100 ml water^{-1} 5 g seeds^{-1} (T_1) which was further followed by seed priming through PEG 6000 @ -0.3 MPa100 ml water^{-1} 5 g seeds^{-1} (T_3) (1726.86) and KNO_3 @ 0.1 mol 100 ml water^{-1} 5 g seeds^{-1} (T_2) (1677.87). Both vigour indexes under seed priming through KH_2PO_4 @ 0.15 mol 100 ml water^{-1} 5 g seeds^{-1} (T_1) and PEG 6000 @ -0.3 MPa100 ml water^{-1} 5 g seeds^{-1} (T_3) remained statistically indifferent to each other. Control or dry seeds (T_5) expressed poorest vigour index (1552.55) among all (Table 2). Seed priming through KH_2PO_4 exhibited better seed and seedling quality due to presence of phosphorus (phytic acid) which improved metabolic activity of the seeds and expressed antioxidant properties [24]. Moreover, phosphorus accelerated the respiratory enzymes' activity and thereby helped in biosynthesis of seeds [25]. Presence of potassium in KH_2PO_4, on the other hand, increased oxygen content by partially restricting the availability of oxygen for citric acid cycle, which enhanced seed physiological condition [26]. Checking lipid peroxidation, electrolyte leakage, buildup of inhibitors and increments of DNA, RNA, protein [27,28] and energy synthesis by seed priming through KH_2PO_4 might be some other reasons for such positive effect on seed and seedling quality parameters. Abdolahi et al. [29] reported that there were enhancements of seed and seedling quality parameters (germination and seedling growth) of rapeseed by seed priming through KH_2PO_4. Improvement of germination, vigour index and various others seedling quality parameters (root length, shoot length, seedling fresh and dry weights) through KH_2PO_4 as seed priming option has also been noticed by Hussein [30] in maize. Apart from KH_2PO_4, seed priming through PEG 6000 improved seed germination and seedling growth by increasing super oxide dismutase (SOD) and peroxidase (POD) [31], ATPase [32] activities, repairing seed parts [33] and better developing embryo [34]. Improvement of seed and seedling quality parameters (emergence and seedling growth) by seed priming with PEG 6000 have been earlier reported by Dell-Aquila and Taranto [35], Kumar et al. [36], Shim et al. [37] and Basra et al. [38] in wheat, chickpea, sesame and maize seeds respectively. The present result was in agreement with Yari et al. [39] who reported enhancement of seed germination and vigour by seed priming with KH_2PO_4 or PEG 6000 in bread wheat.

Interaction effects of variety and seed priming option were statistically significant on different mentioned seed and seedling quality parameters of rapeseed-mustard except germination % and seedling dry weight (Table 2).

3.3 Correlation Matrix between Different Growth and Yield Contributing Parameters

Pearson correlation coefficients (Table 3) indicated highly significant correlations between various growth and yield contributing parameters of rapeseed-mustard varieties under seed priming options. Among the parameters, positive and strongest correlation was found between 1000 seeds weight (SW) and seed yield (SY) (r=0.974). However, positive correlations were found between all the other parameters also. Apart from correlation between 1000 seeds weight (SW) and seed yield (SY), the next two best correlations were observed between days to 50% flowering (F) and plant height (PH) (r=0.970) and primary branches plant^{-1} (PBP) and plant height (PH) (r=0.970) which were followed by correlations between days to maturity (M) and plant height (PH) (r=0.968), primary branches plant^{-1} (PBP) and number of siliqua plant^{-1} (SLP) (r=0.967), days to 50% flowering (F) and primary branches plant^{-1} (PBP) (r=0.965), number of siliqua plant^{-1} (SLP) and number of seeds siliqua^{-1} (SSL) (r=0.965), days to 50% flowering (F) and days to maturity (M) (r=0.962), plant height (PH) and number of siliqua plant^{-1} (SLP) (r=0.958), days to maturity (M) and number of siliqua plant^{-1} (SLP) (r=0.946), plant height (PH) and number of seeds siliqua^{-1} (SSL) (r=0.942), days to 50% flowering (F) and number of siliqua plant^{-1} (SLP) (r=0.941), days to maturity (M) and number of seeds siliqua^{-1} (SSL) (r=0.941), days to maturity (M) and primary branches plant^{-1} (PBP) (r=0.939), number of seeds siliqua^{-1} (SSL) and 1000 seeds weight (SW) (r=0.934), days to 50% flowering (F) and number of seeds siliqua^{-1} (SSL) (r=0.931), primary branches plant^{-1} (PBP) and number of seeds siliqua^{-1} (SSL) (r=0.921), number of siliqua plant^{-1} (SLP) and 1000 seeds weight (SW) (r=0.902), number of seeds siliqua^{-1} (SSL) and seed yield (r=0.900), plant height (PH) and 1000 seeds weight (SW) (r=0.876), number of siliqua plant^{-1} (SLP) and seed yield (SY) (r=0.864), primary branches plant^{-1} (PBP) and 1000 seeds weight (SW) (r=0.863), days to 50% flowering (F) and 1000 seeds weight (SW) (r=0.856), days to maturity (M) and 1000 seeds weight (SW) (r=0.852), plant height (PH) and seed yield (SY) (r=0.852), primary branches plant^{-1} (PBP) and seed yield (SY) (r=0.842), days to maturity (M) and seed yield (SY) (r=0.830), days to 50% flowering (F) and seed yield (SY) (r=0.819) (Table 3). It clearly indicated that various growth, yield contributing characters and yield increased simultaneously to a certain level when seed priming was done to various rapeseed-mustard varieties. It also expressed that change in one variable will automatically exert change in other variables.

Table 2. Effect of seed priming on seed and seedling quality parameters of rapeseed-mustard varieties

Treatments*	Root length (cm)	Shoot length (cm)	Seedling fresh weight (g)	Seedling dry weight (g)	Vigour index	Germination (%)
Varieties						
V_1	12.05	2.64	0.216	0.021	1427.07	97.07
V_2	13.05	3.58	0.293	0.022	1621.51	97.48
V_3	13.38	3.58	0.349	0.024	1659.07	97.79
V_4	14.05	3.64	0.547	0.028	1738.10	98.25
V_5	14.16	3.67	0.564	0.030	1756.92	98.52
V_6	14.58	3.68	0.576	0.033	1807.12	98.96
S.Em (±)	0.16	0.05	0.017	0.001	17.12	0.30
C.D. (5%)	0.46	0.14	0.048	0.004	48.55	0.84
Seed priming options						
T_1	14.10	3.64	0.461	0.034	1758.78	99.13
T_2	13.68	3.47	0.436	0.026	1677.87	97.77
T_3	13.92	3.55	0.455	0.029	1726.86	98.83
T_4	13.34	3.34	0.407	0.023	1625.43	97.39
T_5	12.68	3.32	0.362	0.020	1552.55	96.93
S.Em (±)	0.15	0.05	0.015	0.001	15.63	0.27
C.D.(5%)	0.42	0.13	0.043	0.003	44.32	0.77
Interaction	**V×T**	**V×T**	**V×T**	**V×T**	**V×T**	**V×T**
S.Em (±)	0.36	0.11	0.038	0.003	38.28	0.66
C.D. (5%)	1.04	0.32	0.106	NS	108.57	NS

**V_1: Anushka, V_2: Sanchita, V_3: TBM-143, V_4: TBM-204, V_5: Kranti, V_6: PusaBold, T_1: KH_2PO_4 @ 0.15 mol 100 ml water^{-1} 5 g seeds^{-1}, T_2: KNO_3 @ 0.1 mol 100 ml water^{-1} 5 g seeds^{-1}, T_3: PEG 6000 @ -0.3 MPa100 ml water^{-1} 5 g seeds^{-1}, T_4: Distilled water @ 100 ml 5 g seeds^{-1} and T_5: Control or dry seed*

Table 3. Correlation matrix between different growth and yield contributing parameters

	F	M	PH	PBP	SLP	SSL	SW	SY
F	1							
M	0.962**	1						
PH	0.970**	0.968**	1					
PBP	0.965**	0.939**	0.970**	1				
SLP	0.941**	0.946**	0.958**	0.967**	1			
SSL	0.931**	0.941**	0.942**	0.921**	0.965**	1		
SW	0.856**	0.852**	0.876**	0.863**	0.902**	0.934**	1	
SY	0.819**	0.830**	0.852**	0.842**	0.864**	0.900**	0.974**	1

F: Days to 50% flowering, M: Days to maturity, PH: Plant height, PBP: Primary branches plant^{-1}, SLP: Siliqua plant^{-1}, SSL: Seeds siliqua^{-1}, SW: 1000 seeds weight, SY: seed yield;
*** Highly significant*

Table 4. Correlation matrix between different seed and seedling quality parameters

	Germination %	RL	SL	SFW	SDW	VI
Germination %	1					
RL	0.997**	1				
SL	0.998**	0.999**	1			
SFW	0.987**	0.989**	0.987**	1		
SDW	0.991**	0.991**	0.990**	0.999**	1	
VI	0.990**	0.991**	0.990**	0.998**	0.998**	1

RL: Root length, SL: Shoot length, SFW: Seedling fresh weight, SDW: Seedling dry weight, VI: Vigour Index
*** Highly significant*

3.4 Correlation Matrix between Different Seed and Seedling Quality Parameters

Correlation matrix (Table 4) expressed very positive and highly significant correlations between all the seed and seedling quality parameters of rapeseed-mustard varieties under different seed priming options. Among various seed and seedling quality parameters, positive and strongest correlations were noticed between root length (RL) and shoot length (SL) (r=0.999) and seedling fresh weight (SFW) and seedling dry weight (SDW) (r=0.999) which were further followed by correlations between germination % and shoot length (SL) (r=0.998), seedling fresh weight (SFW) and vigour index (VI) (r=0.998), seedling dry weight (SDW) and vigour index (VI) (r=0.998), germination % and root length (RL) (r=0.997), germination % and seedling dry weight (SDW) (r=0.991), root length (RL) and seedling dry weight (SDW) (r=0.991), root length (RL) and vigour index (VI) (r=0.991), germination % and vigour index (VI) (r=0.990), shoot length (SL) and seedling dry weight (SDW) (r=0.990), shoot length (SL) and vigour index (VI) (r=0.990), root length (RL) and seedling fresh weight (SFW) (r=0.989), germination % and seedling fresh weight (SFW) (r=0.987), shoot length (SL) and seedling fresh weight (SFW) (r=0.987) (Table 4). It clearly suggested that various seed and seedling quality parameters increased simultaneously to a certain level when seed priming was done to various rapeseed-mustard varieties. It also expressed that change in one variable will automatically exert change in other variables.

3.5 Relationships between Various Growth and Yield Contributing Parameters

Experimental results depicted in Figs. 1-7 explored that there existed linear relationships between various growth and yield contributing parameters of rapeseed-mustard varieties under different seed priming options. Based on the coefficient of determination (R^2), among the parameters, highly strong, positive linear relationships were found between days to maturity and plant height (R^2=0.9122) (Fig. 4), days to 50% flowering and days to maturity (R^2=0.9021) (Fig. 3) and days to 50% flowering and plant height (R^2=0.8967) (Fig. 5). It clearly was able to explain 91.22%, 90.21% and 89.67% variations between days to maturity and plant height, days to 50% flowering and days to maturity and days to 50% flowering and plant height, respectively and indicated that slight changes in the parameters shown in X-axis were responsible for the changes of parameters shown in Y-axis. Further, strong to moderate, positive linear relationships also existed between number of siliqua plant^{-1} and seed yield (R^2=0.8154) (Fig. 1), plant height and primary branches plant^{-1} (R^2=0.794) (Fig. 2), days to 50% flowering and primary branches plant^{-1} (R^2=0.7834) (Fig. 7) and days to maturity and primary branches plant^{-1} (R^2=0.7106) (Fig. 6) indicating possible explanation of 81.54%, 79.4%, 78.34% and 71.06% variations respectively by the regression model.

3.6 Relationships between Various Seed and Seedling Quality Parameters

Relationships between some seed and seedling quality parameters of rapeseed-mustard varieties plotted in Figs. 8-10 were found linear under different seed priming options. There existed very strong, positive linear relationships between germination % and seedling dry weight (R^2=0.9275) (Fig. 8) and root length and vigour index (R^2= 0.9413) (Fig. 9) indicating that seedling dry weight and vigour index were very much related with germination % and root length respectively to the extents of 92.75% and 94.13%. Fig. 10, on the other hand, expressed moderate, positive linear relationship between shoot length and vigour index (R^2=0.6574) indicating ability of the regression model to explain only 65.74% variation.

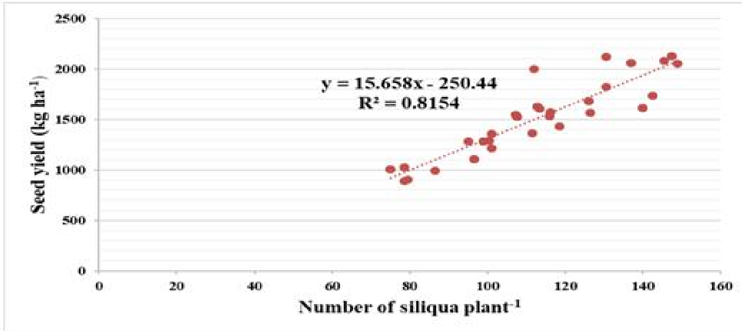

Fig. 1. Relationship between number of siliqua plant^{-1} and seed yield

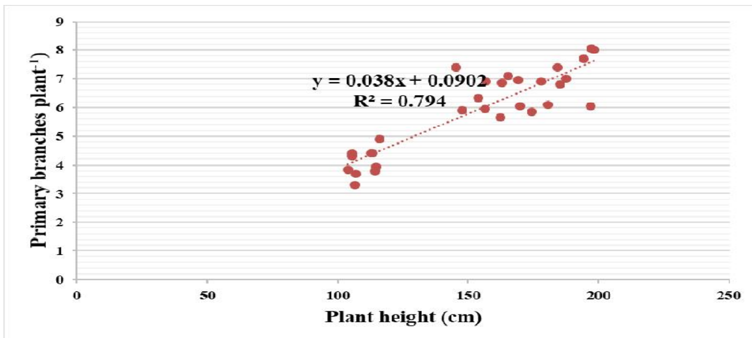

Fig. 2. Relationship between plant height and primary branches plant^{-1}

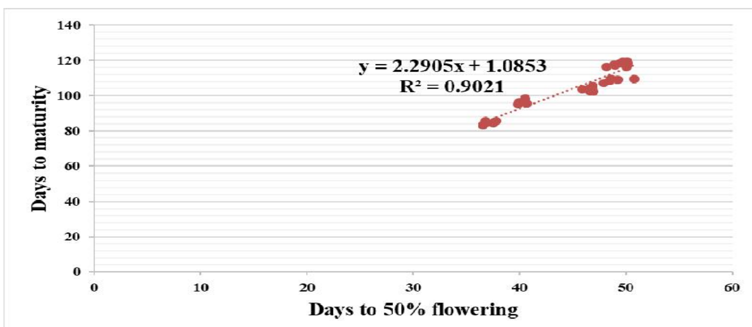

Fig. 3. Relationship between days to 50% flowering and days to maturity

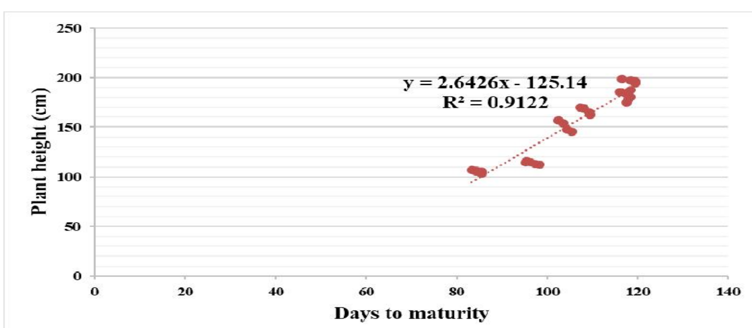

Fig. 4. Relationship between days to maturity and plant height

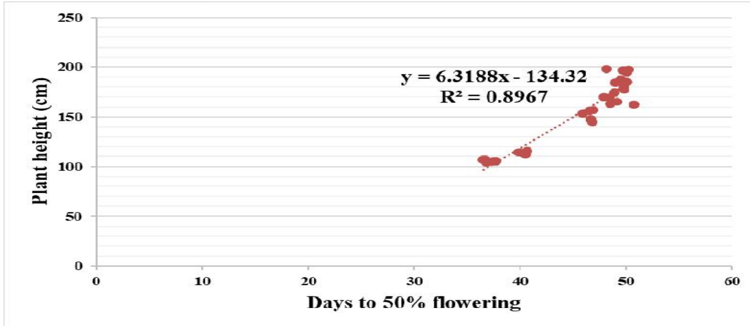

Fig. 5. Relationship between days to 50% flowering and plant height

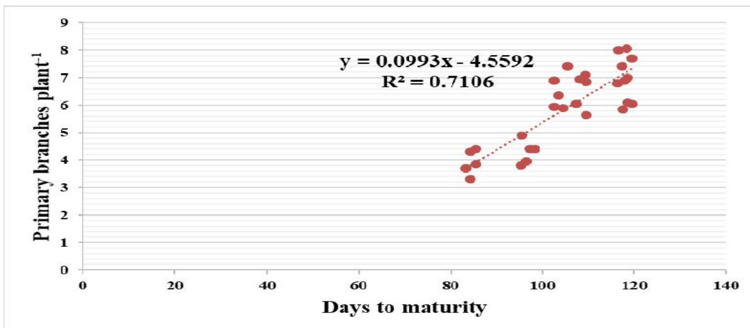

Fig. 6. Relationship between days to maturity and primary branches plant^{-1}

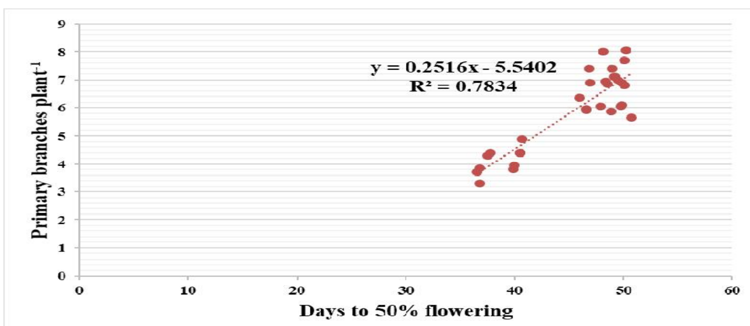

Fig. 7. Relationship between days to 50% flowering and primary branches plant^{-1}

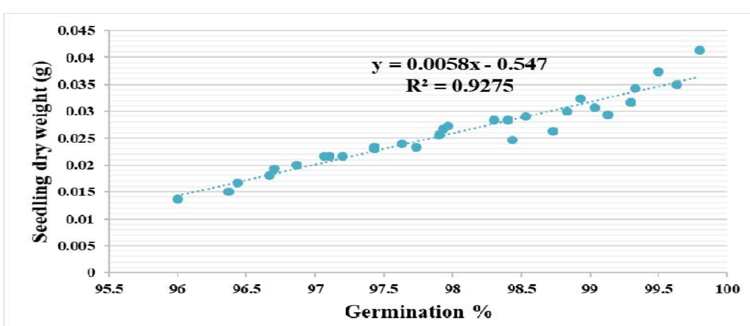

Fig. 8. Relationship between germination % and seedling dry weight

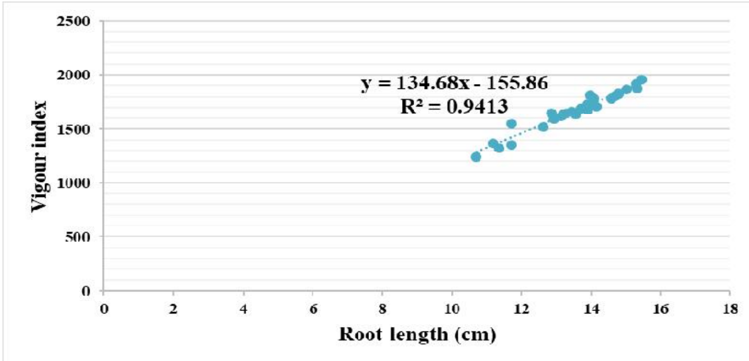

Fig. 9. Relationship between root length and vigour index

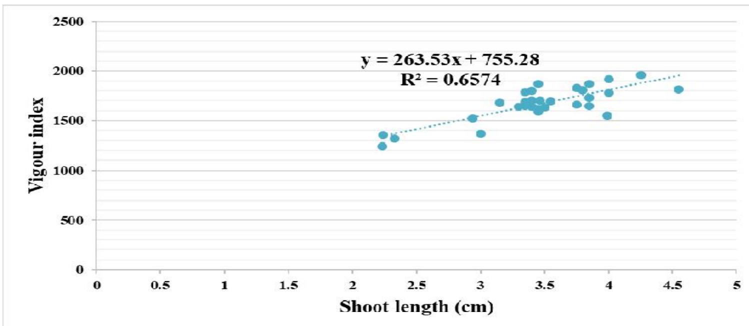

Fig. 10. Relationship between shoot length and vigour index

4. CONCLUSION

Overall, the study confirms the efficacy of various seed priming options on growth, yield and seed and seedling quality parameters of rapeseed-mustard varieties. Based on the experimental results, it was found that mustard variety, Pusa Bold performed better among all under seed priming through KH_2PO_4 @ 0.15 mol 100 ml water^{-1} 5 g seeds^{-1}. However, seed priming through PEG 6000 @ -0.3 MPa100 ml water^{-1} 5 g seeds^{-1} also almost similarly influenced the performances of various rapeseed-mustard varieties, specially, Pusa Bold. Therefore, cultivation of Pusa Bold variety by seed priming through either KH_2PO_4 @ 0.15 mol 100 ml water^{-1} 5 g seeds^{-1} or PEG 6000 @ -0.3 MPa100 ml water^{-1} 5 g seeds^{-1} can be recommended to mustard growers of New alluvial zone of West Bengal, India for achieving better, growth, yield and seed and seedling quality parameters.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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