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EFFECT OF SEED INVIGORATION ON GROWTH, YIELD AND ECONOMICS OF SUNFLOWER (*Helianthus annuus* L.)

RUPA DAS[1] AND SAIKAT BISWAS[2]*
[1]Department of Seed Science and Technology, [2]Department of Agronomy,
Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal - 741252, INDIA
e-mail: sbsaikatbiswas27@gmail.com

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***Corresponding author**

ABSTRACT

The study was conducted by treating various sized sunflower seeds with invigoration treatments to evaluate growth, yield and economics of the crop. Results revealed that seed invigoration with various powders improved growth and yield of sunflower over control or dry seeds. Specifically, large sized seeds treated with red chilli powder when sown in the field, produced highest plant growth (plant height, 113.90 cm), yield attributes (seed set, 84.27%) and consequently, seed yield (2439.87 kg ha^{-1}), stalk yield (5316.84 kg ha^{-1}), oil yield (1051.75 kg ha^{-1}) and harvest index (31.44 %). However, crop grown from large sized seeds treated with bleaching powder exhibited statistically similar plant growth (plant height, 111.76 cm), yield attributes (seed set, 84.15 %) and thereby, seed yield (2390.77 kg ha^{-1}), stalk yield (5280.87 kg ha^{-1}), oil yield (1029.62 kg ha^{-1}) and harvest index (31.16 %) as observed in large seeds treated with red chilli powder. In consequence of high yield, crops grown from large seeds showed high and statistically similar profitability when treated with either red chilli powder (net return, INR. 76,885.03 ha^{-1}; B:C, 3.01) or bleaching powder (net return, INR. 74,643.36 ha^{-1}; B:C, 2.95) and therefore, both these seed invigoration options can be recommended for ideal sunflower cultivation.

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is an important photo-insensitive oilseed crop in the world (Sujatha *et al.*, 2012). Apart from providing healthy edible oil, sunflower is cherished for its aesthetic beauty. Worldwide, it is a good source of snacks, oilcake, natural dye, bird food, animal feed etc (Shin *et al.*, 2000). India has produced 0.19 million tonnes from 0.33 mha with a productivity of 590 kg ha^{-1} in 2017-18 (NFSM, 2018). However, in order to make parity between its demand and supply, productivity of this oilseed needs to be elevated at this hour. Setback in sunflower productivity is a major issue today.

Availability of healthy seeds is one of the prime concerns for the sunflower growers of India. Moreover, poor germination, sub optimum plant stand and weak seedling vigour are some issues associated with poor quality seeds, which directly imparts negative effect on field performance and ultimate produce of this crop (Das *et al.*, 2020). In West Bengal, sunflower is mostly grown in winter and storage of sunflower seeds is done routinely for sowing in the next season. Seed quality deterioration is therefore, an unavoidable incident inside the storage. It is hypothesised that seed storage causes deterioration of seed quality due to poor atmospheric conditions, insect and disease infestations, irradiation etc (Kapoor *et al.*, 2010; Seiadat *et al.*, 2012; Kumar *et al.*, 2014; Saha and Mandal, 2016). Further, oilseed crops like sunflower are truly sensitive to seed quality deterioration inside the storage. For instance, Kausar *et al.* (2009) observed oxidation of oil content of the seeds inside the storage. Ghassemi-Golezani *et al.* (2010) further, reported that oxidative damages contribute strongly on seed deterioration inside the storage. To overcome the seed quality loss to an extent, various interventions are being proposed by the researchers. Seed invigoration is one of them, which is gaining popularity now-a-days.

Seed invigoration is a value added, pre-sowing treatment of seeds, which improves germination and seedling growth and thereby, helps the plants in achieving good field performance (Taylor *et al.*, 1998). Various chemical powders, pharmaceutical drugs as well as crude plant materials have been studied earlier as seed invigoration materials and observed positive results (Mandal *et al.*, 2000; Basra *et al.*, 2003; Guha *et al.*, 2012; Layek *et al.*, 2012; Guha and Mandal, 2013; Saha and Mandal, 2014; Bhattacharya *et al.*, 2015 and Saha and Mandal, 2016). Although many studies proved the efficacy of seed invigoration on germination and seedling quality, there are only a few numbers of research work that evaluated field performance of the crops grown from the treated seeds. Pallavi *et al.* (2003) practiced seed invigoration on sunflower and observed improvement of physiological and bio-chemical properties of the seeds, which on sowing, showed optimum germination, growth and yield of crop. Umarani *et al.* (1997) did treatment of *Casuarina* seeds with leaf powders of *Albizzia amara*, *Vitex negundo* and *Azadirachta indica* and found beneficial impacts of seed treatment.

It is, therefore, assumed that seed invigoration exhibits checking of sunflower seeds' quality deterioration inside the storage, which impacts positively on germination and field performance of this crop. However, the extent of seed quality maintenance and thereby, improvement of field performance by seed invigoration need to be evaluated. Therefore, the present study was planned with the objective to study the possible effect of invigoration of various sized seeds on growth, yield and economics of sunflower crop.

MATERIALS AND METHODS

The field experiment was conducted at Calcutta University Experimental Farm, Baruipur, South 24 Parganas, West Bengal, India during winter season of 2015. Freshly harvested sunflower seeds (cv. Morden) from previous year collected during April of 2015 were graded in to various size categories (large, medium and small) along with composite seeds (ungraded) and seed invigoration ingredients were applied on them. The experiment was carried out in split plot design comprising 4 levels of seed size (S_1: composite, S_2: large, S_3: medium and S_4: small) in main plots and 4 levels of seed invigoration treatment (T_0: control or dry seeds, T_1: finely powdered aspirin (ortho acetyl salicylic acid) @ 50 mg kg^{-1} of seed, T_2: bleaching powder (calcium hypochlorite) @ 2 g kg^{-1} of seed and T_3: red chilli powder (capsaicin) @ 1g kg^{-1} of seed) in sub plots and replicated thrice. For seed invigoration, protocols given by Basu (1976) and De *et al.* (2003) were followed. Seed invigoration was done inside rubber stoppered glass bottles at room temperature (28 ± 1 °C) under ambient conditions and then, stored in perforated paper packets separately and transferred in to cloth bags under normal room condition. Seeds were periodically shaken without causing physical damage. Finally, those seeds were sown at a spacing of 40 cm × 25 cm during third week of December, 2015 as per the treatment combinations on each individual plot size of 4 m × 3 m.

The recommended fertilizer dose of 80: 40: 40 kg N: P_2O_5: K_2O/ha (50% N and full dose of P_2O_5 and K_2O at basal; 50% N in two equal splits at 30 DAS and at flower initiation stage) was applied. Pest protection and other agronomic practices were carried out as per the standard package of practices for sunflower cultivation. Observations covered plant height, number of leaves plant^{-1}, capitulum diameter, total number of seeds capitulum^{-1}, number of filled seeds capitulum^{-1}, seed set (%), 1000 seeds weight, seed yield, stalk yield, harvest index, oil content (%) and oil yield. Oil content was estimated using soxhlet apparatus (AOAC, 1960). Seed set (%) and oil yield (kg ha^{-1}) were calculated based on the following formulas:

$$\text{Seed set}(\%) = \frac{\text{Number of filled seeds capitulum}^{-1}}{\text{Total number of seeds capitulum}^{-1}} \text{X}100$$

(Nellikoppa, 2002)

Oil yield (kg ha^{-1}) = Oil content (%) × Seed yield (kg ha^{-1})

(Nkafamiya *et al.*, 2010)

For estimation of production economics, cost of cultivation, gross return, net return and benefit cost ratio (B:C) were calculated. All the recorded data were finally subjected to statistical analysis using analysis of variance method (Panse and Sukhatme, 1985) and treatment means were compared at 5% level of significance using critical difference (C.D.) (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Growth attributes

Experimental results expressed that different seed size showed significant variations on plant height and number of leaves plant^{-1} at harvest (Table 1). Plants grown from large sized seeds (S_2) showed tallest stature (110.08 cm), which was next followed by plants grown from medium sized seeds (S_3) (104.72 cm). Plants grown from small sized seeds (S_4) became shortest at harvest (99.32 cm). Similarly, maximum and minimum numbers of leaves plant^{-1} were exhibited by the plants grown from S_2 (19.67) and S_4 (15.46) respectively. The present finding might be due to the fact that large sized seeds contained higher food reserves in cotyledons for faster and greater root growth (Harper, 1977). Improved root growth helped the plants to uptake water and nutrients in a better way and thus, improved photosynthetic activity and overall growth of the plants. Thiyam *et al.* (2017) also observed better growth of pea from large sized seeds.

Like seed size, different seed invigoration treatments also exerted significant and better influence on plant height and number of leaves plant^{-1} at harvest over control or dry seeds (T_0) (Table 1). Seed invigoration with red chilli powder (T_3) recorded tallest plant (108.29 cm) and maximum number of leaves plant^{-1} at harvest (19.61), which was next followed and shown statistical similarity by bleaching powder (T_2) (plant height: 106.28 cm, number of leaves plant^{-1}: 19.46). Among the combinations, S_2T_3 produced highest plant height (113.90 cm) and number of leaves plant^{-1} (21.80), which was next followed and shown statistical similarity by S_2T_2 (plant height: 111.76 cm; number of leaves plant^{-1}: 21.64). Seeds during storage deteriorated due to changes of various physiological, bio-chemical and enzymatic activities (Patra, 2017), production of free radicals, lipid auto oxidation (Basu and Rudrapal, 1980), electrolyte leakage, increased levels of electrical conductivity (Das *et al.*, 2020) *etc.* It was speculated that when seeds were treated with those powders, those

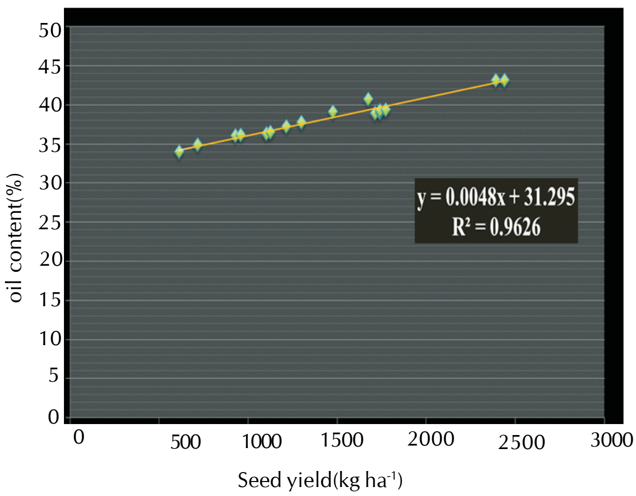

Figure 1: Linear relationship between seed yield and oil content

Table 1: Growth and yield of sunflower under invigoration of various sized seeds

Treatments	Plant height (cm)	Number of leaves plant^{-1}	Capitulum diameter (mm)	Total number of seeds capitulum^{-1}	Number of filled seeds capitulum^{-1}	Seed set (%)	1000 seeds weight (g)	Seed yield (kg ha^{-1})	Stalk yield (kg ha^{-1})	Harvest index (%)
Seed sizes (S)										
Composite (S_1)	103.89	17.67	146.58	564.50	451.33	79.77	46.89	1442.67	4016.26	26.17
Large (S_2)	110.08	19.67	151.80	659.83	546.50	82.70	48.92	1995.84	4744.71	29.31
Medium (S_3)	104.74	18.04	148.66	588.17	475.92	80.80	45.68	1484.00	4069.75	26.48
Small (S_4)	99.32	15.46	142.32	487.33	382.75	78.45	32.54	803.83	2477.15	24.32
SE(m)	0.58	0.07	0.64	2.84	2.14	0.10	0.14	19.77	28.43	0.15
C.D.(5%)	2.05	0.24	2.25	10.03	7.55	0.37	0.50	69.73	100.30	0.54
Powdered ingredients (T)										
Control (T_0)	100.98	15.19	141.13	519.50	405.92	77.98	40.70	1079.10	3400.29	23.80
Aspirin (T_1)	102.47	16.58	143.70	551.25	439.00	79.47	41.58	1226.30	3575.99	25.24
Bleaching powder (T_2)	106.28	19.46	151.51	610.92	502.58	82.10	45.71	1692.72	4150.46	28.47
Red chilli powder (T_3)	108.29	19.61	153.01	618.17	509.00	82.17	46.04	1728.23	4181.13	28.76
SE(m)	0.69	0.05	0.63	2.88	2.20	0.10	0.15	13.58	22.88	0.17
C.D.(5%)	2.02	0.16	1.84	8.45	6.45	0.29	0.43	39.87	67.17	0.51
Seed sizes × powdered ingredients										
S_1T_0	101.33	15.03	140.60	508.67	392.33	77.13	44.58	1102.23	3613.71	23.38
S_1T_1	103.34	16.41	142.77	528.00	413.00	78.22	44.96	1214.71	3882.77	23.83
S_1T_2	104.24	19.57	150.78	607.67	497.33	81.84	48.93	1712.64	4271.51	28.62
S_1T_3	106.67	19.66	152.16	613.67	502.67	81.91	49.08	1741.10	4297.07	28.83
S_2T_0	107.00	17.05	143.44	590.33	474.67	80.41	44.88	1476.72	4173.37	26.13
S_2T_1	107.67	18.20	145.70	634.33	520.00	81.98	45.87	1676.03	4207.77	28.49
S_2T_2	111.76	21.64	158.77	702.67	591.33	84.15	52.21	2390.77	5280.87	31.16
S_2T_3	113.90	21.80	159.30	712.00	600.00	84.27	52.71	2439.87	5316.84	31.44
S_3T_0	102.10	15.37	142.10	534.33	418.33	78.29	42.87	1125.38	3668.05	23.48
S_3T_1	104.37	16.82	145.92	569.00	454.33	79.85	44.09	1298.33	3908.90	24.93
S_3T_2	105.80	19.94	152.60	621.33	512.67	82.51	47.70	1738.99	4337.03	28.61
S_3T_3	106.70	20.04	154.00	628.00	518.33	82.54	48.08	1773.32	4365.02	28.89
S_4T_0	93.50	13.30	138.39	444.67	338.33	76.09	30.45	612.08	2146.06	22.20
S_4T_1	94.53	14.88	140.42	473.67	368.67	77.84	31.39	716.13	2304.50	23.70
S_4T_2	103.33	16.71	143.90	512.00	409.00	79.90	34.01	928.50	2712.44	25.50
S_4T_3	105.90	16.96	146.59	519.00	415.00	79.97	34.30	958.62	2745.60	25.89
Interaction	S×T T×S	S×T T×S	S×T T×S	S×T T×S	S×T T×S	S×T T×S	S×T T×S	S×T T×S	S×T T×S	S×T T×S
SE(m)	1.16 1.32	0.14 0.11	1.27 1.26	5.69 5.74	4.28 4.36	0.21 0.20	0.28 0.29	39.53 30.72	56.87 48.77	0.30 0.33
C.D.(5%)	4.19 4.04	0.33 0.36	3.87 3.89	17.73 17.68	13.52 13.44	0.61 0.62	0.90 0.89	86.38 97.73	143.54 153.0	0 1.05 1.02

Table 2: Oil content and oil yield of sunflower under invigoration of various sized seeds

Oil content (%)						Oil yield (kg ha^{-1})					
Seed sizes × powdered ingredients	Control (T_0)	Aspirin (T_1)	Bleaching powder (T_2)	Red chilli powder (T_3)	Mean	Seed sizes × powdered ingredients	Control (T_0)	Aspirin (T_1)	Bleaching powder (T_2)	Red chilli powder (T_3)	Mean
Composite (S_1)	36.3	37.23	38.92	38.97	37.85	Composite (S_1)	400.11	452.28	666.48	678.55	549.36
Large (S_2)	39.1	40.67	43.07	43.11	41.49	Large (S_2)	577.41	681.7	1,029.62	1,051.75	835.12
Medium (S_3)	36.52	37.72	39.27	39.33	38.21	Medium (S_3)	410.93	489.7	683.12	697.38	570.28
Small (S_4)	33.97	34.89	35.99	36.08	35.23	Small (S_4)	207.95	249.84	334.16	345.87	284.45
Mean	36.47	37.63	39.31	39.37		Mean	399.1	468.38	678.35	693.38	
			SE(m)	C.D.(5%)					SE(m)	C.D.(5%)	
Seed sizes			0.06	0.22		Seed sizes			8.18	28.86	
Powdered ingredients			0.07	0.22		Powdered ingredients			5.49	16.13	
Seed sizes × Powdered ingredients			0.12	0.45		Seed sizes × Powdered ingredients			16.36	35.03	
Powdered ingredients × Seed sizes			0.14	0.43		Powdered ingredients × Seed sizes			12.55	40.01	

powders entered through the cracks and crevices of the seed outer coating and checked those harmful physiological, enzymatic and biochemical changes (Guha *et al.*, 2012). Seeds' repair through pre-sowing powder treatments probably reflected directly to the plant growth performance in the field.

Yield attributes and yield

Like the growth attributes, plants grown from various sized seeds showed significant variations among yield attributes and yield of sunflower (Table 1). Plants grown from S_2 produced highest capitulum diameter (151.80 mm), total number of seeds

Table 3: Correlation matrix of growth, yield attributes and yield of sunflower

	PH	LNP	CD	FS	SS	TW	SY
PH	1						
LNP	0.959**	1					
CD	0.902**	0.949**	1				
FS	0.884**	0.934**	0.982**	1			
SS	0.808**	0.874**	0.903**	0.950**	1		
TW	0.789**	0.848**	0.882**	0.921**	0.979**	1	
SY	0.775**	0.843**	0.870**	0.917**	0.974**	0.993**	1

PH: Plant height, LNP: Number of leaves plant-1, CD: Capitulum diameter, FS: Number of filled seeds capitulum-1, SS: Seed set, TW: 1000 seeds weight, SY: Seed yield ;** Highly significant

Table 4: Economics of sunflower cultivation under invigoration of various sized seeds

Treatments Seed sizes × powdered ingredients		Cost of cultivation (INR /ha)	Gross return* (INR /ha)	Net return (INR /ha)	B:C
Composite (S_1)	Control (T_0)	37,287.41	53,213.91	15,926.50	1.43
	Aspirin (T_1)	37,287.86	58,544.72	21,256.86	1.57
	Bleaching powder (T_2)	37,288.85	81,340.46	44,051.61	2.18
	Red chilli powder (T_3)	37,292.27	82,646.72	45,354.45	2.22
Large (S_2)	Control (T_0)	38,220.41	70,625.62	32,405.21	1.85
	Aspirin (T_1)	38,220.91	79,628.97	41,408.06	2.08
	Bleaching powder (T_2)	38,222.01	1,12,865.37	74,643.36	2.95
	Red chilli powder (T3)	38,225.81	1,15,110.84	76,885.03	3.01
Medium (S_3)	Control (T_0)	38,130.41	54,310.00	16,179.59	1.42
	Aspirin (T_1)	38,130.81	62,333.90	24,203.09	1.63
	Bleaching powder (T_2)	38,131.69	82,591.58	44,459.89	2.17
	Red chilli powder (T_3)	38,134.73	84,164.42	46,029.69	2.21
Small (S_4)	Control (T_0)	37,818.41	29,689.66	-8,128.75	0.79
	Aspirin (T_1)	37,818.71	34,530.35	-3,288.36	0.91
	Bleaching powder (T_2)	37,819.37	44,494.94	6,675.57	1.18
	Red chilli powder (T_3)	37,821.65	45,883.35	8,061.70	1.21
Interaction		S×T T×S	S×T T×S	S×T T×S	S×T T×S
SE(m)		- -	1826.16 1406.6	1825.57 1406.43	0.05 0.04
C.D.(5%)		- -	3935.56 4480.65	3935.54 4479.97	0.1 0.12

*Seed rates used: 9, 10, 8 and 6 kg ha^{-1} for composite, large, medium and small size categories, respectively; Price of aspirin:INR. 1000.00 kg^{-1}, Price of bleaching powder:INR.80.00 kg-1, Price of red chilli powder:INR. 540.00 kg^{-1}, Price of sunflower seed:INR. 45.00 kg^{-1}, Price of sunflower stalk:INR.1.00 kg^{-1}

capitulum^{-1} (659.83), number of filled seeds capitulum^{-1} (546.50), seed set (82.70 %) and 1000 seeds weight (48.92 g), which was next followed serially by plants grown from S_3, S_1 and S_4. Consequently, highest seed yield (1995.84 kg ha^{-1}), stalk yield (4744.71 kg ha^{-1}) as well as harvest index (29.31%) were also recorded from the plants grown from S_2. Greater photosynthetic activity and thereafter, partitioning of dry matter and its translocation towards reproductive part of the plant might be some reasons behind such high yield attributes and yield of sunflower. Conversely, plants grown from S_4 showed lowest seed yield (803.83 kg ha^{-1}), stalk yield (2477.15 kg ha^{-1}) and harvest index (24.32%). The present finding was earlier supported by Dharmalingam and Basu (1987) in mung bean, Sadeghi *et al.* (2011) in Jute and safflower and Saha and Mandal (2016) in sunflower as they also observed that plants grown from large sized seeds produced better yield attributes and yield than the small ones.

Among the seed invigoration treatments, T_3 exerted highest positive influence on capitulum diameter (153.01 mm), total number of seeds capitulum^{-1} (618.17), number of filled seeds capitulum^{-1} (509.00), seed set (82.17 %), 1000 seeds weight (46.04 g) and consequently, on seed yield (1728.23 kg ha^{-1}), stalk yield (4181.13 kg ha^{-1}) and harvest index (28.76%), which was closely followed and shown statistical similarity by T_2 (capitulum diameter: 151.51 mm, total number of seeds capitulum^{-1}: 610.92, number of filled seeds capitulum^{-1}: 502.58, seed set: 82.10 %, 1000 seeds weight: 45.71 g, seed yield: 1692.72 kg ha^{-1}, stalk yield: 4150.46 kg ha^{-1} and harvest index: 28.47%). Guha *et al.* (2012) also similarly observed high yield attributes and yield in Okra.

Interaction effect between various seed size and seed invigoration materials as shown in Table 1 revealed significant variations among them on yield attributes and yield of sunflower. Among various interactions, S_2T_3 recorded highest capitulum diameter (159.30 mm), total number of seeds capitulum^{-1} (712.00), number of filled seeds capitulum^{-1} (600.00), seed set (84.27 %), 1000 seeds weight (52.71 g) and consequently, on seed yield (2439.87 kg ha^{-1}), stalk yield (5316.84 kg ha^{-1}) and harvest index (31.44%). However, it was closely followed and shown statistical similarity by S_2T_2 (capitulum diameter: 158.77 mm, total number of seeds capitulum^{-1}: 702.67, number of filled seeds capitulum^{-1}: 591.33, seed set: 84.15%, 1000 seeds weight: 52.21 g, seed yield: 2390.77 kg ha^{-1}, stalk yield: 5280.87 kg ha^{-1} and harvest index: 31.16%). Saha and Mandal (2016) also observed high yield attributes and yield of sunflower through treating large seeds with red chilli or bleaching powders.

Red chilli powder has the active ingredient named capsaicin. Nascimento *et al.* (2013) reported the antioxidant properties of capsaicin against free radicals (OH° and peroxyl). Saha and Mandal (2016) further reported its inhibitory action against pathogens inside the storage. Das *et al.* (2020) stated its radical scavenging properties through the transfer of hydrogen from phenolic hydroxyl group. Das *et al*. (2020) further mentioned the improvement of cell membrane integrity of seeds through red chilli powder treatment. Dey and Ghosh (1993) observed the inhibitory effects of capsaicin on lipid peroxidation and electrolyte leakage. Mandal *et al*. (2000) reported the aldehyde reduction ability of capsaicin. All these reports suggested the quality maintenance of seeds inside the storage through invigoration with red chilli powder, which directly reflected on plants growth and thereby, yield of crop when sown in the field.

Bleaching powder contains halogen compound chloride. Rudrapal and Basu (1981) earlier reported the role of chloride in stabilizing the lipid double bonding in seed membrane. Pryor and Lasswell (1975) and Farooq *et al*. (2008) further, found chloride as free radical scavenger. Altogether, thus, bleaching powder helped in checking seed quality deterioration, which directly reflected to better field performance in terms of growth and thereby, yield of crop. Earlier, Vidyadhar and Singh (2000) also mentioned the beneficial role of bleaching powder on maize and mustard seeds.

Oil content and oil yield

Various sized seeds exhibited significant influence on oil content and thereby oil yield of sunflower crop (Table 2). Highest oil content (41.49 %) and consequently, oil yield (835.12 kg ha^{-1}) were recorded by the produce of the plants grown from S_2. On a contrary, produce of the plants grown from S_4 showed lowest oil content (35.23%) and oil yield (284.45 kg ha^{-1}). Linear relationship between seed yield and oil content as shown in Fig 1 explained the high oil content in large sized seeds by stating that oil content improved with the improvement of seed yield as observed specially in large sized seeds. Likewise, various seed invigoration ingredients exerted significant and positive influence on oil content and oil yield of sunflower over control (Table 2). Highest oil content (39.37%) and thereby, oil yield (693.38 kg ha^{-1}) were exhibited by the produce of the plants grown from the seeds treated with T_3 which was next followed by the produce of the plants grown from the seeds treated with T_2 (oil content: 39.31%, oil yield: 678.35 kg ha^{-1}) and both remained statistically indifferent to each other. Among the combinations, S_2T_3 recorded highest oil content (43.11%) and oil yield (1051.75 kg ha^{-1}), which was next followed and shown statistical similarity by S_2T_2 (oil content: 43.07% and oil yield: 1029.62 kg ha^{-1}) (Table 2). Healthy and vigorous growth and yield of crop grown from good quality seeds maintained by the treatments with red chilli or bleaching powders might also influenced positively on oil content of the sunflower crop in this study. Further, production of various lipid synthetic enzymes under seed invigoration practices might influenced the oil contents of crop. Similar type of improvement in oil content of sunflower through various seed priming options was earlier observed by El-Saidy *et al*. (2011). However, exact mechanism of oil accumulation in case of crop grown from the primed seeds is still unknown (Ohlragge and Jaworski, 1997).

Correlation between growth, yield attributes and yield

Correlation matrix (Table 3) expressed that there existed highly significant and positive correlations between various growth, yield attributes and yield of sunflower crop. Among them, strongest correlation occurred between 1000 seeds weight and seed yield (r = 0.993), which was next followed by correlation between capitulum diameter and number of filled seeds capitulum^{-1} (r = 0.982). On the other hand, positive but relatively weakest correlation occurred between plant height and seed yield (r = 0.775). However, all the positive and high correlations among growth, yield attributes and yield of sunflower crop indicated that invigoration of various sized sunflower seeds exerted significant impact on growth, yield attributes and thereby, yield of the crop. It also revealed that change in one variable caused significant changes in other variables.

Relationship between seed yield and oil content

It was depicted from Fig 1 that there existed linear regression relationship between seed yield and oil content of sunflower. Based on coefficient of determination value (R^2 = 0.9626), It was clear that the linear model was able to explain 96.26% variations between seed yield and oil content of sunflower grown from the various sized seeds treated with invigoration powdered ingredients. It was also found from the linear regression model that, slight change in the variable of X-axis caused significant change in the variable of Y-axis.

Economics

Data from Table 4 represented the production economics of sunflower cultivation. It was found that S_2T_3 incurred highest cost of cultivation (INR.38,225.81 ha^{-1}). It might be due to greater seed rates required for large size categories as well as higher price of red chilli powder. On the other hand, S_1T_0 required lowest cost of cultivation (INR.37,287.41 ha^{-1}). Apart from no seed invigoration treatment (and so, zero cost), as no sorting required for composites, there was no involvement of manual labour in that purpose, which saved the cost of cultivation for the composites. It was found that higher gross return (INR. 1,15,110.84 ha^{-1}), net return (INR. 76,885.03 ha^{-1}) and profit (B:C 3.01) were recorded from S_2T_3. However, gross return (INR. 1,12,865.37 ha^{-1}), net return (INR.74,643.36 ha^{-1}) and B:C (2.95) recorded from S_2T_2 showed statistical similarity with that under S_2T_3. The economic benefit was directly resulted from their high productions of crop yield. On the other hand, crop grown from small sized seeds specially, without any treatment caused highest economic loss. Poor performance of the crop in terms of production of yield was the reason behind such drastic economic loss.

Seed invigoration has been earlier reported by many scientists to complete all the bio-chemical and physiological processes prior to seed germination and therefore, after sowing, seeds imbibe soil moisture well and rejuvenate seed metabolisms. Srimathi *et al*. (2013) stated that seed treatment with crude plant leaf powder enhanced seed longevity by protecting insect and disease infestation. Dutta *et al*. (2015) also reported from their experiment that as compared to chemical seed treatment, seed invigoration with botanical crude material like neem leaf powder significantly checked seed deterioration and improved germination and seedling growth. Lone *et al*. (2014) observed checking of seed quality parameters and thereby improvement of germination of aged maize seeds and seedling growth under seed invigoration with bleaching powder or red chilli powder. Beside these similar line of works, the present result might also be due the fact that seed invigoration with botanical powder, upon sowing, improved rhizospheric region of soil which all together, improved crop growth, yield and thereby, profitability (Srimathi *et al*., 2013).

Overall, the present study confirmed the hypothesis and concluded that seed invigoration with various powdered ingredients significantly checked seed quality deterioration inside the storage to a high extent and thereby, maintained seed quality well, which finally reflected on improved field performances of the sunflower crop. Based on the results, invigoration of large sized seeds with either red chilli powder @ 1g/kg^{-1} of seed or bleaching powder @ 2 g/kg^{-1} of seed can be recommended to the sunflower growers of West Bengal for sowing and thereby, achieving high growth, yield and economic benefits.

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