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Genotypic variations in morphological and yield attributes in flax (*Linum usitatissimum* L.) under salt stress

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Abstract

Flax is one of the most ancient and beneficial crops for its high-quality fibre and edible oil. However, increasing soil salinity due to global warming is one of the main obstacles of agricultural productivity. To investigate the effects of salt stress on seed germination, growth and yield of 40 flax genotypes, two experiments were conducted in the growth chamber and field laboratory of the Department of Crop Botany, Bangladesh Agricultural University. In germination and seedling growth experiments, four salt levels such as 0 (control), 40, 80 and 120 mM were applied. The second experiment was carried out to evaluate the growth and yield performances of the selected ten flax genotypes with two salinity levels: i) Control (0 mM NaCl) and ii) Salinity (100 mM NaCl). Salt stress notably retarded seed germination, seedling growth, yield and yield-attributing descriptors in all flax genotypes. The salt tolerance index (STI) values of all studied parameters in the first experiment were used to construct the hierarchical clustering of genotypes. Cluster II comprised of 16 genotypes with higher STI scores showing greater salt tolerance. Among them, the genotypes BD-10710, Faridpur, BD-10700 and BD-10703 performed better in relation to salt tolerance. In the second experiment, a greater extent of salt tolerance was observed in BD-10710 and BD-7145 genotypes considering the traits plant height, stem diameter, branch (no.) plant^{-1}, filled capsule plant^{-1}, seed (no.) capsule^{-1}, 1000-seed weight, seed yield plant^{-1} and yield stability index. Therefore, these two genotypes can be suggested for the cultivation in coastal areas of Bangladesh with further field trials and investigations.

Keywords

flax; salt tolerance; yield attributes; hierarchical clustering; plant biomass

Introduction

Flax (*Linum usitatissimum* L.; Family: Linaceae), often known as linseed, is one of the oldest utilitarian fibre-producing and oilseed crops (1). It is a self-pollinating annual herb that grows 60-100 cm tall and has a slender, upright and wiry stem; flax is native to Europe and Asia (2). Flax is a multipurpose crop grown in many environments for fibre, food, industrial, feed and medicinal purposes (3); each component of the plant possesses a distinct economic worth, rendering it a profitable crop (4). It is one of the 5 most important oil crops in the world and the third-largest natural fibre crop (5). Flax oil has a high concentration of α-linolenic acid, an omega^{-3} fatty acid (6). The hardening oil is used to prepare leather, linoleum, putty and varnishes (7) as well as to make paints, oilcloth, printer ink, enamels, stickers, tarpaulins, soaps and other products (8). It is taken orally for

bronchial infection and diarrhoea and is utilized in local medicines as a demulcent, emollient and laxative (7). The flax stem, which is used to make several valuable items, may also be utilized to produce fibres of high quality. After removing fibre, the leftover material can be processed into pulp and used to make premium writing paper, parchment paper and currency notes (4). As a food, flax may be used to produce bread, morning cereals, muesli bars and other food items (9); eaten with wot (a stew), particularly in northern Ethiopia and used to make a beverage for fasting days (10). Even though flax has many advantages, it is one of the most underexploited crops in underdeveloped nations, produced mostly on poor, marginal soil (11). This crop's low yield is attributable to the lack of improved cultivars that would be suitable for various agro-climatic conditions.

Salinity is the process through which soluble salts accumulate and form saline soils. Because of the effects of climate change, soil salinization is increasing, diminishing the amount of arable land available for crop cultivation. Soil salinity is a serious global threat, affecting 1100 M ha of soil, representing approximately 7 % of the earth's land surface (12), due to its negative influence on biodiversity, agricultural productivity and sustainability. The sharp rise in soil salinity in recent years has been caused by several factors, such as heavy irrigation, minimal precipitation, high surface evaporation, rock weathering, ion exchange and inadequate cultural practices (13). Agriculture in dry and semi-arid areas is greatly affected, with significant yields being reduced by more than 50 % (14). Soil salinity reduces soil quality and thus, weakens the base of resources. It can happen as a result of natural disasters or excessive abuse and poor management that compromises the integrity of the soil's ability to self-regulate. More than 100 countries in the world have seen a gradual rise in soil salinity due to its dynamic nature (15). Future climate change scenarios are expected to result in an increased soil salinization because of rising sea levels, their effects on coastal areas and rising temperatures. Salt stress inhibits plant development, photosynthesis, nutrition balance, water relations and yield of crops, similar to many other abiotic stresses (16). A complex syndrome involving osmotic stress, ion toxicity, mineral deficiencies, physiological and biochemical disturbances and combinations of these stresses is the result of the salinity effect on plant growth (17). Higher saltiness hinders seed germination and root development (18) and leads to poor crop establishment (19) which is detrimental and restricts plants from maintaining the proper nutritional requirements necessary for their optimal growth (20). In general, salinity dramatically slowed down the germination velocity, which resulted in a markedly higher ultimate germination percentage under high NaCl concentrations. Species differences occurred in tolerance to salt in the soil, even within the same species (21). Thus, the goal of the current study was to assess how well a large pool of flax genotypes responded to salinity stress throughout the seed germination and seedling growth stages as well as to look into the impact of saline water irrigation on the reproductive stage and yield characteristics of diverse flax genotypes.

Materials and Methods

Experimental area

The experiments were conducted at the Plant Physiology and Field Laboratories, Department of Crop Botany, Bangladesh Agricultural University (BAU), which is located at 24°75' N latitude and 90°50' E longitude and 19 m above sea level (22). Summer (Kharif; March to June), rainy (July to October), and winter (Rabi; November to February) are the three main crop seasons in this region having a monsoon climate (Appendix 1).

Experimental materials

Forty flax genotypes were collected from different sources and used for the seed germination and seedling growth study (Table 1). Based on the performance of germination and seedling growth, 10 flax genotypes, *viz*. BD-10703, BD-10701, Chilmari, Hatibandha, Faridpur, BD-10700, BD-10710, BD-10696, BD-7145 and BARI Tishi^{-1} were selected for the pot experiment to evaluate yield and yield contributing descriptors under salinity conditions. Seeds of all the flax genotypes were available in the Laboratory of Plant Systematics, Department of Crop Botany, BAU. Seeds were stored in dry condition till used for experimental purposes.

Experimentations

The first experiment was conducted maintaining a completely randomized design with three replications. The seeds of all genotypes were treated with a seed-treating fungicide named Knowin 50WP (Carbendazim) for 10 min following repeated washing with re-distilled water and then sown in petri dishes. Each petri dish contained 25 seeds of a single genotype and was treated as a single replicate. Sterilized filter paper in petri dishes was moistened with approximately 0, 40, 80 and 120 mM NaCl solutions prepared by dissolving NaCl in the respective solutions. The growth chamber was maintained at a temperature of 25 °C. Until the tenth day of the germination phase, a daily count of germinated seeds (2 mm emergence radicle) was conducted. Following the experiment's conclusion, 10 seedling samples from each

Table 1. List of studied linseed genotypes and their sources of collection

Source	Genotype
PGRC, BARI*	BARI Tishi-1, BD-10699, BD-7147, Lin 1903, BD-10706, BD-10702, BD-10703, BD-10708, BD-10711, BD-10701, BD-7142, BD-7140, BD-7143, BD-10705, BD-10707, BD-10709, BD-7146, BD-10697, BD-10700, BD-10710, BD-7141, BD-10696, BD-10698, BD-7145, BD-10704, BD-9944 and BD-7144.
Local Collection	Barishal, Ulipur, Tangail, Bandarban, Hobigonj, Chilmari (Black), Sirajgonj, Chilmari, Hatibandha, Faridpur
Foreign Collection	Vietnam, China and Canada

*Plant Genetic Resources Centre, Bangladesh Agricultural Research Institute

petri dish were removed to measure the length of the shoots and roots with a ruler against a dark background. Using precise scales, the fresh weight of the roots and shoots was determined. The fresh samples were then oven -dried for 72 h at 80 °C to get root and shoot dry weight. The germination % (GP) and salt tolerance index (STI) were calculated on the 10th day according to the following equations:

$$\text{Germination percentage (\% GP)} = \frac{\text{Total no.of germinated seeds}}{\text{Total no.of seeds taken for germinated seeds}} \times 100 \quad \text{(Eqn. 01)}$$

$$\text{Stress tolerance indices (STIs)} = \frac{\text{Stress value}}{\text{Control value}} \text{ X } 100 \quad \text{(Eqn. 02)}$$

In the second experiment, the selected 10 flax genotypes from the first experiment were sown in pots to examine the morphological and yield responses to salt stress. The experiment was set following a Completely Randomized Design with 3 replications (single pot with 2 plants treated as a single replicate) during the Rabi season. Before sowing, the seeds were disinfected with Knowin 50WP (Carbendazim) @ 1 g/kg seed. The plastic pots(13 L; Bengal Company, Dhaka, Bangladesh) were prepared with 9 kg of well-pulverized soil with 3 kg of well-decomposed cow dung in each. Proper moisture was maintained in the soil at the time of sowing for good germination of seeds. In this experiment, 2 salinity levels, *viz*. 0 mM NaCl and 100 mM NaCl, were imposed through saline water irrigation at the age of 40 days and 60 days of flax seedling. The leaf greenness was measured every day starting from 2 days to 15 days after the imposture of salt stress by a chlorophyll meter (SPAD-502, Konica Minolta, Osaka, Japan). At 100 DAS, morphological descriptors like plant height, stem diameter and number of branches per plant were measured. The yield attributing descriptors that were collected at harvest time include the length of the inflorescence, the number of primary branches inflorescence^{-1}, the number of capsules plant^{-1}, the length and diameter of the capsules, the number of seeds capsule $^{-1}$, the thousand seed weight and the seed yield plant $^{-1}$.

Statistical analysis

All data were subjected to two-way analysis of variance (ANOVA) using Statistix 10 software to identify the main effects and interactions in response to salinity treatments. The multiple comparisons of treatment means were performed by the Tukey test at a 5 % level of probability.

Results and Discussions

Seed germination and seedling growth experiment

Since the life cycle of a plant begins with the germination of seeds, it is imperative to determine the plants' susceptibility to salinity during this stage (23). Better crop growth, development, yield and financial benefits result from fast, reliable seed germination and good seedling establishment. Table 2 displays a significant decrease in the germination % (GP), root length (RL), shoot length (SL), root fresh weight (RFW), shoot fresh weight (SFW), root dry weight (RDW) and shoot dry weight (SDW) of 40 flax genotypes due to an increase in salt content. The reduction inclination followed the concentration of NaCl supplied exactly (Fig. 1) (24). For each trait, the ANOVA revealed substantial variations in the salt concentrations (data not shown). The highest germination % (96.67 %) was attained from the control (0 mM NaCl) in genotype BD-10710. An increase in salt concentration caused a decrease in GP in all genotypes. Under stressful conditions, genotype BD-10710 showed the maximum GP of 94.67 % at 40 mM NaCl, while BARI Tishi^{-1} showed the lowest value (24 %) at 120 mM NaCl (Table 2). In general, salinity considerably reduced the rate of germination, which resulted in a much lower final germination % under high

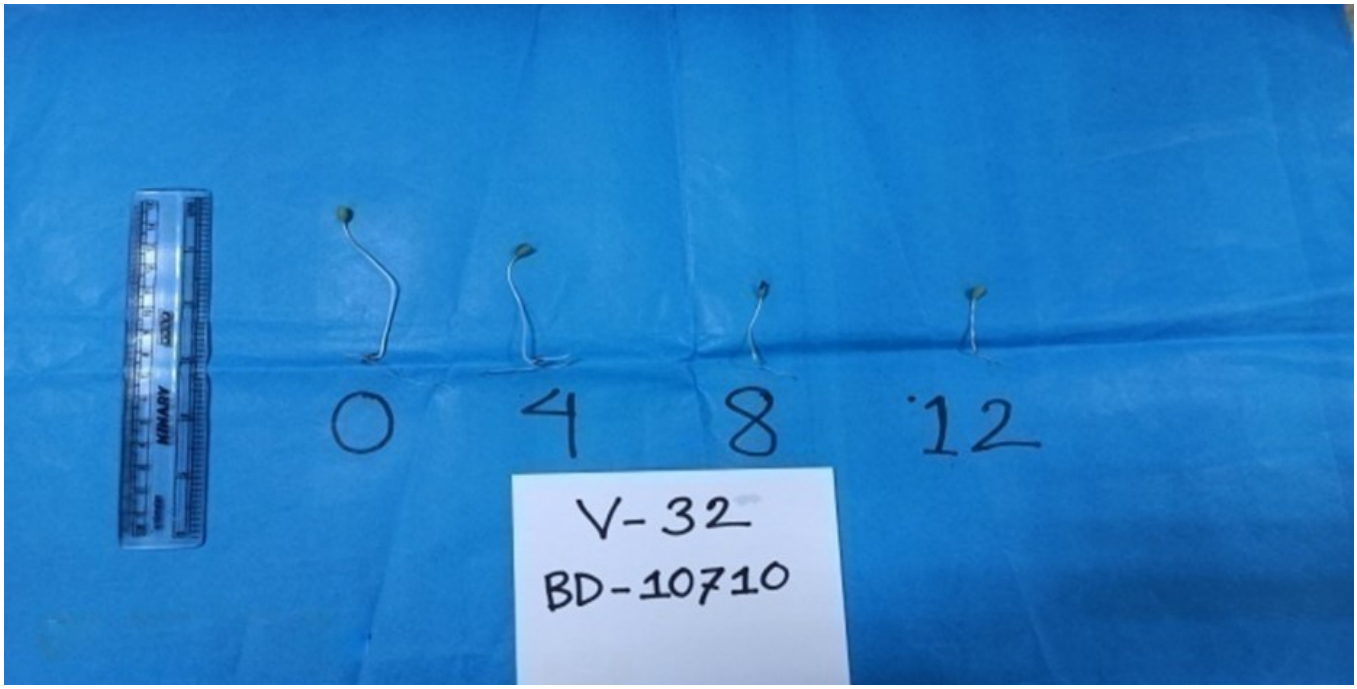

Fig. 1. Pictorial view of flax seedlings (root and shoot) affected by salinity stress (0, 40, 80 and 120) in flax genotypes at 10 days old seedlings.

Table 2. Germination and seedling growth descriptors of forty flax genotypes influenced by four salinity levels (0, 40, 80 and 120 mM)

Genotype	Salinity levels (mm	Germination (%)	Root length (cm)	Shoot length (cm)	Seedling length (cm)	Root FW (mg)	Shoot FW (mg)	Total FW (mg)	Root DW (mg)	Shoot DW (mg)	Total DW (mg)
Barishal	0	86.67	2.71	6.43	9.14	74.00	264.91	338.91	6.67	34.00	40.67
	40	85.33	2.16	5.71	7.87	73.35	260.00	333.35	5.79	32.79	38.58
	80	81.33	1.49	3.77	5.26	32.61	195.91	228.52	5.00	25.00	30.00
	120	25.33	0.20	0.31	0.51	24.73	108.00	132.73	2.00	18.73	20.73
Vietnam	0	98.67	3.55	6.22	9.77	62.60	261.10	323.70	5.78	27.55	33.33
	40	98.67	2.89	5.62	8.51	71.46	250.00	321.46	5.65	23.43	29.08
	80	92.00	1.61	3.01	4.61	51.00	187.29	238.29	3.57	17.70	21.27
	120	16 .00	0.23	0.36	0.59	0.00	0.00	0.00	0.00	0.00	0.00
Ulipur	0	92.00	3.81	6.05	9.86	49.22	255.24	304.45	4.51	22.00	26.51
	40	80.67	2.51	4.81	7.33	42.63	177.00	219.63	3.81	21.37	25.18
	80	44.67	1.00	2.55	3.55	16.62	143.33	159.96	1.11	19.22	20.33
	120	2.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BD-10699	0	58.67	2.99	5.13	8.12	57.27	234.33	291.60	3.33	27.73	31.06
	40	49.33	2.06	4.27	6.33	38.27	174.44	212.71	3.00	21.31	24.31
	80	29.33	1.23	2.33	3.56	21.00	142.33	163.33	2.22	17.67	19.89
	120	2.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tangail	0	94.67	4.21	6.15	10.35	67.41	222.37	289.77	6.67	24.24	30.91
	40	81.33	2.63	4.43	7.05	51.04	217.05	223.08	3.16	18.34	21.50
	80	49.33	1.33	0.95	2.28	11.00	132.48	183.52	0.00	18.23	18.23
	120	26.67	0.22	0.67	0.88	6.03	114.00	120.03	0.00	18.07	18.07
China	0	76.00	2.74	4.59	7.33	59.39	227.16	286.55	5.63	19.26	24.89
	40	69.33	2.37	4.37	6.74	48.69	207.63	256.32	4.67	19.12	23.79
	80	45.33	1.11	1.83	2.94	33.55	158.73	192.28	3.64	16.32	19.96
	120	10.67	0.47	0.96	1.42	0.00	0.00	0.00	0.00	0.00	0.00
Bandarban	0	94.67	4.34	5.56	10.01	88.37	237.16	315.52	9.44	32.89	42.34
	40	94.67	4.01	4.97	8.99	60.52	225.20	285.71	6.92	19.10	26.02
	80	85.33	1.57	3.11	4.68	62.73	35.28	98.01	3.81	17.70	21.51
	120	5.33	0.12	0.40	0.52	0.00	0.00	0.00	0.00	0.00	0.00
BARI Tishi^{-1}	0	89.33	3.96	4.98	8.94	66.30	282.56	348.86	7.51	41.48	48.99
	40	78.67	2.11	4.92	7.03	61.58	243.03	304.61	6.68	27.76	34.44
	80	53.33	1.05	2.89	3.93	27.38	162.74	190.12	3.33	22.37	25.70
	120	24.00	0.95	2.00	2.95	25.58	109.00	134.58	2.86	18.50	21.36
Bd-7147	0	74.67	3.50	3.94	7.44	57.40	244.44	301.84	5.84	34.59	40.43
	40	54.67	1.91	3.59	5.51	34.93	212.30	247.23	5.45	23.39	28.84
	80	33.33	1.24	2.03	3.27	31.75	175.49	207.24	2.74	20.86	23.60
	120	1.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Hobigonj	0	98.67	5.45	6.33	11.79	65.63	317.79	383.42	5.88	25.00	30.88
	40	76.67	3.64	4.88	8.52	62.00	272.20	334.2	3.33	23.18	26.51
	80	30.67	1.35	1.80	3.15	32.00	184.44	216.44	3.13	18.42	21.55
	120	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chilmari (Black)	0	98.67	4.04	4.83	8.80	81.50	323.78	405.28	6.52	24.64	31.16
	40	97.33	3.97	4.76	8.79	64.44	246.55	310.99	5.29	22.63	27.92
	80	53.33	2.87	4.55	7.43	41.34	167.38	208.72	4.29	22.26	26.55
	120	5.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sirajgonj	0	86.67	2.87	5.45	8.32	46.65	266.59	313.24	6.67	38.72	45.39
	40	70.67	2.37	3.49	5.86	45.61	212.00	257.61	6.11	31.99	38.10
	80	30.67	0.81	2.37	3.58	26.72	201.67	228.39	5.63	21.07	26.70
	120	08.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lin 1903	0	78.67	2.59	7.09	9.69	52.58	233.67	286.25	7.50	32.06	39.56
	40	61.33	1.93	4.80	6.61	53.31	225.18	278.49	5.00	28.16	33.16
	80	54.67	1.81	3.83	5.75	52.10	176.61	228.71	4.67	26.42	31.09
	120	24.67	0.72	3.42	4.13	21.69	150.00	171.69	3.64	23.32	26.96
BD-10706	0	73.33	3.95	7.13	10.59	52.00	214.00	266.00	10.00	29.55	39.55
	40	69.33	3.45	6.42	10.37	38.64	204.16	242.80	5.88	27.61	33.49
	80	52.67	2.01	3.75	5.77	38.52	191.78	230.30	3.85	22.20	26.05
	120	29.33	1.25	3.23	5.32	32.00	182.20	214.20	3.33	21.80	25.13
BD-10702	0	85.33	4.61	4.29	8.91	50.81	236.25	287.06	6.25	28.38	34.63
	40	58.67	4.06	3.57	7.63	45.77	206.20	251.97	4.22	23.69	27.91
	80	33.33	2.53	2.52	5.99	35.52	190.02	225.53	3.62	23.64	27.26
	120	24.00	1.70	1.68	4.51	32.40	155.22	187.62	3.32	22.34	25.66
BD-10703	0	94.67	3.99	6.89	10.89	94.67	232.32	326.99	13.85	22.39	36.24
	40	72.00	3.44	5.58	8.29	80.92	220.25	301.17	10.00	21.94	31.94
	80	67.33	2.71	4.85	7.19	70.71	215.19	285.90	7.14	21.39	28.53
	120	63.33	2.35	3.74	7.18	63.52	181.14	244.66	6.19	20.66	26.85
BD-10708	0	44.00	2.44	5.47	7.73	71.24	205.63	276.87	8.88	41.37	50.25
	40	29.33	2.26	4.39	6.83	57.15	172.00	229.15	5.71	26.74	32.45
	80	16.67	1.16	2.27	3.43	21.00	146.89	167.89	0.00	25.07	25.07
	120	9.33	0.49	1.48	1.98	13.35	140.33	153.68	0.00	21.00	21.00
Canada	0	68.67	4.05	5.00	9.05	62.30	235.67	297.97	5.71	34.60	40.31
	40	60.00	3.57	3.64	7.21	60.91	234.00	294.90	5.38	26.46	31.83
	80	36.00	2.27	2.10	4.37	28.31	215.38	243.69	1.11	23.56	24.67
	120	20.00	0.67	1.18	2.12	27.73	177.55	205.28	0.00	20.58	20.58
BD-10701	0	74.00	3.64	6.84	10.48	71.00	233.36	304.36	7.27	30.73	38.00
	40	68.67	3.43	5.75	9.19	43.55	208.48	252.03	5.56	22.62	28.18
	80	63.33	2.74	4.32	7.06	39.09	194.32	233.41	4.62	22.58	27.20
	120	49.33	1.99	2.77	4.76	35.09	153.31	188.40	2.87	19.29	22.16

BD-7142	0	52.00	2.96	5.11	8.07	41.74	207.63	249.37	10.00	31.84	41.84
	40	32.67	1.75	2.43	4.45	41.14	205.15	246.29	5.45	27.36	32.82
	80	26.67	1.35	1.99	3.33	26.58	135.39	161.97	4.44	23.32	27.77
	120	6.00	0.24	0.62	1.14	24.43	103.24	127.67	0.00	13.33	13.33
BD-7140	0	17.33	0.55	2.23	3.15	54.10	206.67	260.77	6.00	41.67	47.67
	40	6.67	0.09	1.25	1.88	46.66	190.00	236.66	0.00	31.37	31.37
	80	4.00	0.19	0.75	0.98	15.10	175.67	190.77	0.00	16.00	16.00
	120	1.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BD-7143	0	97.33	3.16	5.47	8.63	70.61	256.18	326.79	15.83	42.10	57.93
	40	84.67	3.80	4.26	8.06	69.42	237.26	306.67	5.56	26.24	31.80
	80	37.33	0.91	1.47	2.45	20.40	187.67	208.07	0.00	22.50	22.50
	120	32.67	0.83	0.79	1.94	16.07	131.15	147.22	0.00	17.43	17.43
BD-10705	0	96.67	5.51	6.95	12.46	43.35	217.98	261.33	5.00	33.31	38.31
	40	77.33	5.29	6.01	11.31	29.23	207.02	236.25	5.00	27.71	32.71
	80	52.67	3.73	4.11	7.84	20.65	161.49	182.14	2.22	18.49	20.71
	120	8.00	0.06	0.57	0.87	3.38	137.00	140.38	0.00	17.22	17.22
BD-10707	0	70.67	5.70	6.95	12.65	53.64	212.20	265.84	4.71	38.20	42.91
	40	58.67	4.37	5.54	9.91	43.89	204.00	247.89	2.78	25.20	27.98
	80	41.33	3.05	3.27	6.31	36.07	184.70	220.77	0.00	17.69	17.69
	120	24.00	0.68	1.86	2.64	21.32	104.58	125.90	0.00	15.31	15.31
BD-10709	0	94.67	3.84	5.58	8.98	82.14	284.10	366.24	6.84	32.50	39.34
	40	84.67	3.62	4.19	7.81	59.66	243.19	302.85	6.67	29.31	35.98
	80	65.33	3.38	3.10	7.20	49.28	227.63	276.90	6.43	28.51	34.94
	120	29.33	0.95	1.35	2.36	5.00	205.83	210.83	0.00	25.24	25.24
BD-7146	0	67.33	5.07	6.06	11.21	47.82	272.56	320.37	6.67	34.32	40.99
	40	65.33	4.19	5.56	9.75	58.31	207.33	265.64	5.00	24.27	29.27
	80	44.67	2.40	3.23	5.63	30.73	187.67	218.40	5.00	16.42	21.42
	120	15.33	0.57	1.39	2.43	22.50	143.03	165.53	0.00	0.00	0.00
BD-10697	0	71.33	4.06	4.35	8.41	45.34	215.16	260.50	4.17	25.40	29.57
	40	48.67	2.96	3.25	6.21	39.20	197.72	236.92	3.33	21.00	24.33
	80	37.33	2.11	2.13	4.23	41.33	186.52	227.85	1.33	21.00	22.33
	120	15.33	0.52	1.34	2.43	10.73	134.17	144.90	0.00	20.56	20.56
Chilmari	0	94.67	6.79	7.20	13.99	65.20	245.00	310.20	7.00	27.67	34.67
	40	92.00	4.83	5.85	10.68	61.00	213.50	274.50	6.00	24.10	30.10
	80	74.00	1.79	3.19	4.98	34.15	166.35	200.51	5.50	18.59	24.09
	120	58.67	1.13	1.27	2.41	46.40	117.00	163.40	4.71	13.50	18.21
Hatibandha	0	92.67	4.98	6.11	11.08	69.66	152.67	222.33	6.67	24.10	30.77
	40	90.67	4.43	6.10	10.55	64.58	152.14	216.72	6.67	18.23	24.90
	80	64.67	2.91	3.71	6.61	32.21	127.86	160.07	2.00	15.27	17.27
	120	53.33	1.09	1.21	2.30	23.40	70.00	93.40	1.43	14.15	15.58

Faridpur	0	94.67	4.78	7.63	12.41	111.53	205.00	316.53	12.63	31.47	44.10
	40	92.00	4.37	5.86	10.23	69.60	196.11	265.71	8.89	18.53	27.42
	80	78.67	3.55	4.14	7.69	64.77	164.13	228.90	8.00	17.41	25.41
	120	70.67	1.27	1.91	3.17	51.11	145.56	196.67	7.30	16.31	23.61
BD-10700	0	90.67	5.15	7.04	12.19	91.08	177.12	268.20	13.33	30.64	43.97
	40	86.67	3.23	4.81	8.03	90.40	176.12	266.52	9.58	30.46	40.04
	80	78.67	2.98	3.29	6.27	37.38	147.22	184.59	5.29	21.51	26.80
	120	69.33	1.35	1.74	3.09	31.15	142.44	173.59	3.67	13.18	16.86
BD-10710	0	96.67	4.79	6.27	11.06	74.18	232.56	306.73	8.75	21.53	30.28
	40	94.67	2.15	4.41	6.57	91.17	186.25	277.41	8.70	21.32	30.02
	80	82.67	2.08	2.99	5.07	37.38	146.09	183.46	5.91	19.26	25.17
	120	74.67	1.97	2.19	4.15	51.81	112.45	164.26	3.16	16.39	19.55
BD-7141	0	65.33	2.35	3.61	5.96	61.53	195.39	256.92	8.46	34.80	43.26
	40	55.33	2.08	2.96	4.90	42.12	182.94	225.06	7.14	18.80	25.94
	80	38.67	1.94	1.46	4.03	40.00	172.69	212.69	0.00	18.43	18.43
	120	35.33	0.90	1.24	2.59	36.68	165.54	202.23	0.00	18.40	18.40
BD-10696	0	96.00	2.18	4.72	6.90	41.27	175.72	216.99	5.42	27.24	32.66
	40	93.33	2.18	4.18	6.19	43.68	156.12	199.80	4.21	22.15	26.36
	80	90.67	2.01	3.51	5.69	36.15	147.44	183.59	3.85	21.27	25.11
	120	49.33	0.32	0.71	1.03	26.00	126.29	152.29	2.00	14.41	16.41
BD-10711	0	66.67	2.93	4.55	6.77	65.00	201.42	266.42	9.17	36.20	45.37
	40	53.33	2.22	3.24	6.17	51.76	197.67	249.43	8.82	27.50	36.32
	80	53.33	1.61	2.80	4.51	41.88	194.64	236.52	6.00	24.47	30.47
	120	29.33	0.79	2.24	3.56	32.00	155.07	187.07	5.63	18.76	24.39
BD-10698	0	93.33	2.01	4.45	6.45	26.00	214.28	240.28	3.50	27.70	31.20
	40	65.33	1.67	3.14	4.85	43.68	165.54	209.22	3.07	25.53	28.59
	80	44.67	0.95	1.96	3.14	36.83	164.83	201.67	2.11	20.50	22.61
	120	19.33	0.33	0.93	1.49	2.18	108.00	110.18	0.00	18.79	18.79

BD-7145	0	89.33	6.06	5.67	11.17	79.50	255.33	334.83	10.00	34.25	44.25
	40	85.33	5.50	4.59	10.65	68.89	243.83	312.72	6.00	25.57	31.57
	80	74.67	3.86	3.64	7.50	71.18	186.08	257.26	5.00	21.47	26.47
	120	62.67	1.61	2.17	4.36	40.59	182.78	223.37	4.71	17.27	21.98
BD-10704	0	79.33	4.78	5.97	9.27	71.18	255.88	327.06	6.92	20.33	27.25
	40	77.33	2.59	4.49	8.56	64.71	227.16	291.87	4.21	18.56	22.77
	80	55.33	1.36	2.61	3.97	51.00	197.84	248.84	4.12	17.66	21.78
	120	42.67	0.77	1.59	2.36	47.68	152.26	199.94	2.67	17.63	20.30
BD-9944	0	65.33	4.74	6.39	11.00	64.29	205.27	269.56	7.14	21.00	28.14
	40	57.33	4.61	5.17	9.91	66.88	196.02	262.90	5.44	20.90	26.35
	80	51.33	1.56	4.01	5.99	69.09	177.83	246.92	4.00	18.53	22.53
	120	39.33	0.75	1.88	3.13	53.00	124.00	177.00	3.75	17.40	21.15
BD-7144	0	86.67	6.13	6.73	12.87	74.38	226.25	300.63	11.18	24.29	35.47
	40	79.33	4.05	5.23	9.27	78.78	213.73	292.51	7.50	23.31	30.81
	80	61.33	2.10	3.02	5.12	41.88	212.88	254.75	5.00	21.72	26.72
	120	26.67	1.01	1.95	2.96	41.00	181.04	222.04	3.33	16.16	19.49
Significance	Genotypes (A)	3478.4***	8.453***	9.283***	29.33***	2018.0***	8709***	13788***	42.098***	182.47***	263.3***
	Treatment (B)	65788.8***	201.499***	447.913***	1248.13***	46550.3***	350218***	648996***	784.645***	6171.63***	11311.7***
	A × B	446.4***	1.665***	1.397***	4.92***	328.6***	5163***	6598***	6.980***	78.53***	97.9***
	Error	1.6	0.234	0.222	0.54	2.0	30	36	0.027	0.93	1.0
	CV	2.16	19.29	13.07	12.07	3.12	3.03	2.66	3.59	4.37	3.67

FW Fresh weight; DW Dry weight; *** Significant at 0.1% level.

NaCl concentrations (13, 25, 26). Osmotic stress caused by salinity lowers the germination medium's water potential relative to the seed's interior and inhibits the seed's absorption of water. Germination may also be impacted by ionic stress brought on by the salt itself, which disrupts hormone signalling, metabolism, enzyme function and the utilisation of stored energy (27). Overall, salt-induced osmotic and ionic stress results in a delay and inhibition of seed germination. Different reactions of flax seeds and seedlings to different salt solutions may also be caused by the cell structural components of the seeds, namely the cell wall and membrane permeability (23).

In salinity conditions, the highest RL and SL (6.79 and 7.20 cm, respectively) were observed in the genotype Chilmari under control condition (0 mM NaCl). At the germination stage, a stronger root system is an indicator of the extent of salt tolerance in genotypes (seeds) and these genotypes would have better growth at the later stages (26). The ability of a plant to withstand environmental stress can be determined by measuring its root and shoot lengths, which are thought to be the main indications of plant response to stress. The highest RFW was found in Faridpur (111.53 mg) while the highest SFW was observed in Hobiganj (317.79 mg) in control (0 mM NaCl). At the control, the highest RDW and SDW (15.83 and 42.10 mg respectively) were observed in genotype BD-7143 (Table 2). On the contrary, Faridpur (7.30 mg) and BD-10709 (25.24 mg) produced the maximum RDW and SDW respectively at the maximum saline condition (40 mM NaCl). The large variations among different morphological descriptors indicated that there is sufficient variability among tested genotypes. Hence, selection of these characteristics might be effective for the selection of genotypes in saline conditions.

The degree of stress tolerance of genotypes could be evaluated by the Stress Tolerance Index (STI) (28). The STIs for various measured characteristics of all forty flax genotypes at the seed germination and seedling stage are shown on the hierarchical clustering heatmap in Fig. 2. The genotypes were classified into 4 groups as shown in rows (Group^{-1} with 6 genotypes- BD-10707, BD-7141, Canada, BD -10700, BD-10705 and Hatibandha; Group^{-2} with 16 genotypes- BD-10698, BD-10702, Lin 1903, BD-10703, BD-9944, BD-7144, BD-10706, BD-10697, Chilmari (Black), Faridpur, BD-7145, BD-10711, Barishal, BD-10701, BD-10709 and BD-10696; Group-3 with 6 genotypes -BD-10708, BD-7140, BD-7143, Tangail, Ulipur and Hobigonj; and Group^{-4} with 12 genotypes – Bandarban, Sirajgonj, BD-7146, BARI Tishi^{-1}, BD-10699, BD-7147, BD-7142, BD-10710, China, BD-10704, Vietnam and Chilmari). The genotypes of Group^{-2} showed greater tolerance, scoring higher STI values (more greenish), whereas the genotypes of Group^{-3} exhibited susceptibility to salinity stress, having lower STI values and showing more reddish (Fig. 2). On the other hand, the traits were also grouped into 2 clusters (columns). Cluster^{-1} comprised the shoot and total fresh

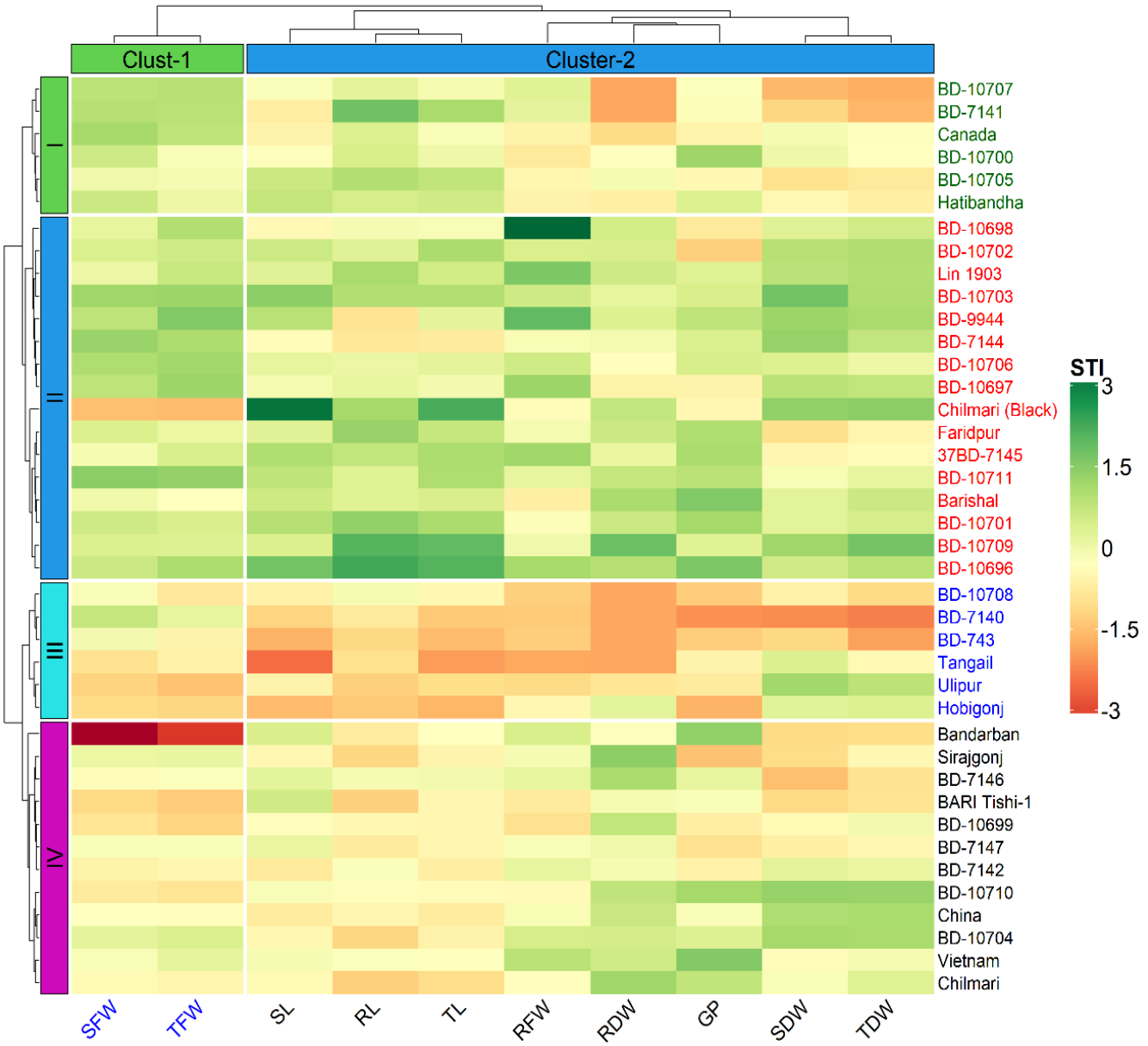

Fig 2. Hierarchical clustering heatmap (row and column-wise) showing the categorization of genotypes and traits. The 40 linseed genotypes and 10 measured traits were grouped into 4 (row) and 2 (column) clusters, respectively. The stress tolerance index (STI) values of traits are normalized and used to construct the heatmap (scaling from -3 to +3). The cell with more greenish shows greater salt tolerance with higher STI values. Traits description: SFW (shoot fresh weight), TFW (total fresh weight), SL (shoot length), RL (root length), TL (total length), RFW (root fresh weight), RDW (root dry weight), GP (germination percentage), SDW (shoot dry weight) and TDW (total dry weight).

weight and Cluster-2 comprised the most studied parameters such as shoot, root and total seedling length; germination %; fresh and dry weight of root and total dry weight of the shoot. Salt tolerance index can be effectively used to identify the susceptibility of genotypes to salt stress since it expresses the relative changes of all the parameters under salinity conditions when compared to the control treatments. The STI values have been utilized in several studies to identify the tolerant genotypes of various crops that are resistant to stress (24, 29, 30).

Yield and yield-attributing descriptors

The analysis of variance showed that all the morphological, yield and yield-attributing descriptors were greatly affected by salinity stress except unfilled capsule plant^{-1} (Table 3). Reduced water potential in the root zone of salinity-stressed plants results in a water deficit, phytotoxicity of ions such as Na^+ and Cl^- and nutrient imbalance through a decrease in uptake and shoot transport (24). Due to lack of available water and ion toxicity due to salinity stress may impair the photosynthetic pathway. For that reason, morphological and physiological variations occur and ultimately, these affect the yield of the genotype of flax. Furthermore, to maintain normal cellular conservation in saline conditions, a greater amount of energy (photosynthates) is required to neutralize osmotic and ionic stress (31); as a consequence, this leaves a smaller amount of photosynthates for growth and yield requirements. Salinity also causes alterations in anatomical features, for example, an increase in cutin synthesis on epidermal cells as well as alteration in the xylem structure and lignification in flax and stems that inhibit plant growth (24); subsequently, it serves as an adaptation mechanism to withstand the salinity stress (32).

When exposed to salt stress, plant cells often constrict and immediately become dehydrated, although they gradually recover. The roots and shoots grow more slowly because, despite this improvement, there is still a reduction in cell division and elongation (16). Flax plants also showed a similar predisposition. Irrigation improved the SPAD values for all the genotypes studied however, saline water irrigation affects the SPAD values of different genotypes differently (Fig. 3). Initially, the SPAD value of the genotypes was decreased and thereafter, followed the increasing trend. The negative effect of saline water irrigation was the most prominent from 6 to 7 days after the saline water irrigation. After 13 days of saline water irrigation, almost all genotypes recovered from the stress and some cases performed better, at least expressed in SPAD values, compared to the initial condition (Fig. 3). At various salinity levels, salt stress may cause harm to the photosynthetic process, including pigments, stomata functioning and increased activity of the enzyme that breaks down chlorophyll (24).

The RL, SL and plant height of all 10 flax genotypes were significantly decreased due to salinity stress (Table 3 and 4). In the case of root length, the longest root was observed in genotype BD-7145 both in control and stress conditions (19.50 cm and 18.93 cm, respectively). The longer roots could be an indication of salt tolerance, which would eventually be reflected in the seed yield of this genotype later. In general, salinity in soils alters the architecture of agricultural plants' root systems and prevents the formation of primary roots. Therefore, for improved adaptation to saline soils, a steep, deep and cheap root ideotype for water and nitrogen acquisition has been proposed (21). The genotype Faridpur had the highest SL under both the control and stress settings. The shoot length of this genotype was statistically similar in both conditions, but its maximum value in terms of numbers was 75.83 cm under the control (Table 3). In all instances, the genotype Faridpur produced the longer plant (Table 4).

In the control condition, the highest RFW and RDW were found in BD-7145 (1.23 g and 0.91 g, respectively) and the lowest in BD-10701 (0.59 g and 0.32 g). In stress conditions, the maximum RFW and RDW were observed in BD-7145 (0.97 g and 0.83 g, respectively) and the minimum in genotype BD-10696 and genotype BD-10701 which were statistically similar but numerically genotype BD-10696 (0.28 g) had the lower value (Table 3). At 100 mM NaCl, the highest SFW was found in BD-7145 (12.33 g) and the lowest SFW was obtained from genotype BD-10701 (5.35 g). The highest SDW in the control condition was recorded in genotype BD-7145 (10.08 g) and the lowest in genotype BD -10696 (5.03 g). In stress conditions, the maximum SDW was observed in genotype BD-7145 (9.68 g) and the minimum in genotype BD-10701 (4.03 g) (Table 3).

Table 3. Morpho-physiological descriptors of ten flax genotypes influenced by two salinity levels (0 and 100)

Genotype	Treatment	Length (cm)		Fresh weight (g)		Dry weight (g)	
		Root	Shoot	Root	Shoot	Root	Shoot
BD-7145	0 mM	19.50 a	57.67 de	1.23 a	14.18 b	0.91 a	10.08 a
	100 mM	18.93 a	56.83 e	0.97 b	12.33 c	0.83 b	9.68 ab
BD-10710	0 mM	9.10 gh	60.10 bc	0.77 cd	10.81 de	0.47 e	6.48 fg
	100 mM	7.97 h	58.00 de	0.66 ef	9.30 f-h	0.45 ef	7.47 ef
Hatibandha	0 mM	12.33 b-e	49.60 h	0.83 c	10.44 d-f	0.45 ef	6.05 gh
	100 mM	10.33 c-h	44.93 j	0.54 g	6.85 i	0.42 e-g	4.99 i-l
BD-10700	0 mM	10.20 d-h	56.97 e	0.97 b	13.49 b	0.67 c	8.50 cd
	100 mM	9.60 f-h	54.90 f	0.81 c	12.03 c	0.62 c	8.22 c-e
Chilmari	0 mM	10.17 d-h	59.75 bc	0.96 b	17.16 a	0.55 d	9.66 ab
	100 mM	9.98 e-h	54.52 f	0.56 g	10.08 d-g	0.42 e-g	5.87 g-i
BARI Tishi-1	0 mM	11.08 b-g	60.67 b	0.66 ef	8.83 h	0.42 e-g	5.85 g-i
	100 mM	9.63 f-h	55.17 f	0.42 h	5.96 ij	0.33 h-j	4.66 j-l
BD-10703	0 mM	12.83 bc	51.00 h	0.66 ef	9.89 e-h	0.44 ef	5.67 g-j
	100 mM	11.42 b-g	47.58 i	0.41 h	6.23 ij	0.36 g-i	5.29 h-k
BD-10701	0 mM	10.58 c-g	50.25 h	0.59 fg	9.88 e-h	0.32 ij	5.25 h-k
	100 mM	11.83 b-f	45.83 j	0.37 h	5.35 j	0.29 j	4.03 l
BD-10696	0 mM	13.33 b	58.83 cd	0.71 de	8.99 gh	0.35 hi	5.03 i-l
	100 mM	10.33 c-h	52.67 g	0.52 g	6.06 ij	0.28 j	4.38 kl
Faridpur	0 mM	12.67 b-d	75.83 a	0.72 de	12.03 c	0.46 e	8.93 bc
	100 mM	10.00 e-h	75.33 a	0.58 g	11.20 cd	0.39 f-h	7.50 de
Significance	Genotype (A)	49.87***	388.65***	0.21***	38.74***	0.17***	19.70***
	Treatment (B)	20.77**	182.70***	0.76***	137.65***	0.06***	13.27***
	A × B	2.32^{NS}	6.07***	0.01***	5.06***	0.00	2.22***
	Error	2.45	0.87	0.00	0.48	0.00	0.37
	CV	13.49	1.66	6.64	6.90	7.99	9.14

** Significant at 1% level; *** Significant at 0.1% level; NS: Not Significant. Means with different letters within the treatments are significant at p=0.05 level.

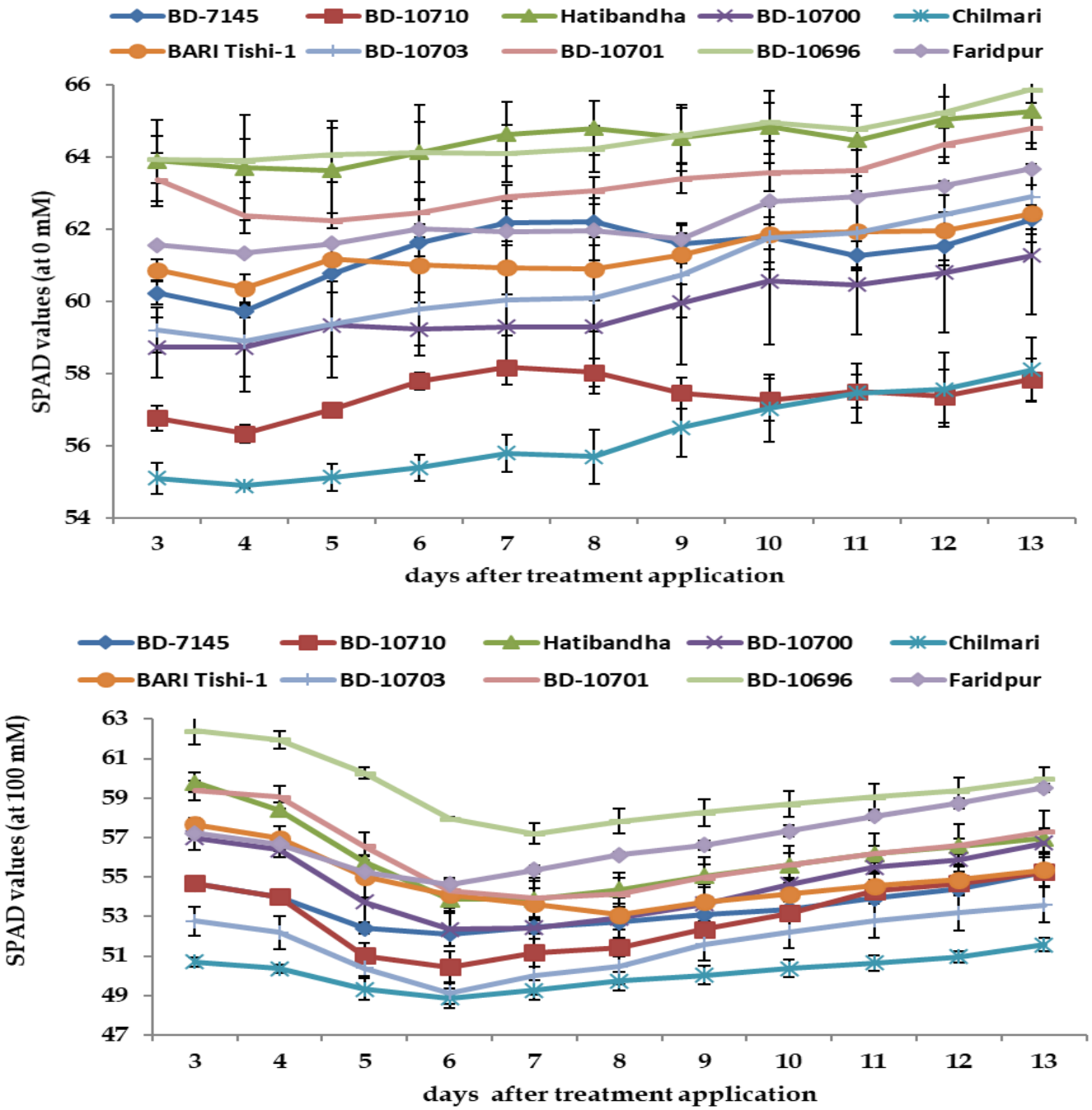

Fig. 3. Leaf greenness (SPAD values)of ten flax genotypes grown under 0 and 100 mM salinity levels. Vertical bars indicate the standard error (±) of the mean (n=3).

All the yield and yield attributing descriptors, *viz.* primary branch inflorescence^{-1}, filled capsule plant^{-1}, unfilled capsule^{-1}, length and diameter of the capsule, number of seed capsule^{-1}, thousand seed weight and seed yield plant^{-1} were evaluated after harvesting of the crop. In the case of primary branch inflorescence^{-1}, in the control condition, the highest value was observed in genotype BD-10710 (8.50) and the lowest in BD-10701 (5.00). Similar results in the number of primary branch inflorescence^{-1} were also observed in stressed conditions (Table 4).

In control condition, the highest filled capsule plant^{-1} was observed in genotype Chilmari (163.17) and the lowest in genotype BD-10696 (101.17). In stressed condition, genotype BD-10710 (134.33) showed a maximum number of filled capsule plant^{-1} and lowest in genotype BD-10696, BARI Tishi^{-1} and BD-10701, which were statistically similar but numerically genotype BD-10701 (94.33) had the lowest value (Table 4).

In case of unfilled capsule plant^{-1}, the highest value was observed in genotype Chilmari (33.30) and the lowest was in genotype Hatibandha (12.67) at 0 mM NaCl. In stressed condition, genotype Chilmari (25.67) had the maximum value and the minimum value was found in BARI Tishi^{-1} (11.33) (Table 4).

In both control and stress conditions, genotype Faridpur had the longest capsule (7.87 mm and 7.78 mm at 0 and 100 mM NaCl, respectively); genotype BD-10703 had the shortest in both control and stressed conditions (Table 4). In the case of capsule diameter (CD), in both control and stressed conditions, the highest CD was observed in genotype Faridpur (6.48 mm and 6.83 mm at 0 and 100 mM NaCl, respectively). In a control condition, the lowest CD was found in genotype BD-10696 (6.2 mm). Genotype

Hatibandha (5.58 mm) had the lowest CD in stressed conditions (Table 4).

Seed number capsule^{-1} and thousand seed weight are 2 of the important parameters (33) because they are directly related to seed yield in flax. In a control condition, the maximum number of seed capsule^{-1} was observed in genotype Hatibandha (9.80) and BD-7145 (9.80), both are statistically and numerically similar and the lowest value was found in genotype Faridpur (7.47). In stress conditions, the maximum number of seed capsule^{-1} was observed in genotype BD-10710 (9.73) and the lowest number was in genotype Faridpur (Table 4). In the case of thousand seed weight, genotype Faridpur had the maximum weight in both control and stress conditions. The genotype BD-10696 had the lowest value at 100 mM NaCl (Table 4).

In control condition, the highest seed yield plant^{-1} was observed in genotypes Chilmari, BARI Tishi^{-1}, BD-7145 and BD-10710 which were statistically similar. In stressed conditions, the highest value was seen in genotype BD-7145 (5.32 g) and the lowest yield was observed in genotype BD-10696 (3.78 g) (Table 4). Although the seed yield of BD-10710 was numerically comparatively lower than BD-7145, the yield stability index was highest (96 %) among the genotypes (Fig. 4). In addition to impeding plant development, salinity also affects cell signalling, energy metabolism and protein synthesis. The substantial metabolic cost linked to plant adaptation, growth maintenance and stress responses ultimately results in decreased agricultural output and yield (16). Furthermore, when the concentration of salt increased, so did the amounts of catalase and glutathione S-transferase (13).

Table 4. Yield attributing descriptors of ten flax genotypes influenced by two salinity levels (0 and 100)

Genotype	Treatment	Plant height (cm)	Stem diameter (mm)	Branch plant^{-1} (no.)	Inflores. length (cm)	1^{0} branch inflores.$^{-1}$	Capsule (no. Plant^{-1})		Capsule		Seeds capsule^{-1} (no.)	1000-seed weight (g)	Seed yield plant^{-1}(g)
							Filled	Unfilled	Length (mm)	Diameter (mm)			
BD-7145	0 mM	77.17 c	2.50 cd	9.83 ef	23.50 b	6.17 b-d	127.00 b-d	21.33 cd	7.40 b-d	6.62 a-d	9.80 a	1.09 b-d	5.66 a-c
	100 mM	75.77 c	2.41 ef	9.50 fg	20.57 de	6.00 b-d	124.00 c-e	22.33 cd	7.22 d-f	6.63 a-c	9.47 a-d	0.94 g-i	5.32 b-d
BD-10710	0 mM	69.20 fg	2.48 d	8.67 hi	19.63 e-g	8.50 a	138.67 b	31.67 ab	7.37 cd	6.51 a-e	9.47 a-d	1.05 c-f	5.50 bc
	100 mM	65.97 hi	2.40 ef	8.17 ij	19.40 e-g	8.33 a	134.33 bc	22.33 cd	7.12 d-g	6.34 c-g	9.73 ab	1.05 c-g	5.28 cd
Hatibandha	0 mM	61.93 kl	2.33 g	10.67 cd	18.83 f-h	6.67 b	120.83 d-f	12.67 e-g	7.33 de	6.29 c-g	9.80 a	1.06 c-e	4.93 d-f
	100 mM	55.27 o	2.22 i	7.83 j	12.33 k	5.33 d-f	119.83 d-f	18.00 d-g	7.01 fg	5.58 h	8.40 e	0.95 f-i	3.98 h-j
BD-10700	0 mM	67.17 gh	2.49 d	9.00 gh	22.43 bc	6.50 bc	103.50 g-j	15.67 d-g	7.33 de	6.22 d-g	9.20 a-d	1.09 b-d	4.80 d-f
	100 mM	64.50 ij	2.40 ef	8.50 h-j	19.27 e-g	5.67 c-e	102.00 h-j	17.33 d-g	7.31 de	6.21 e-g	9.00 c-e	0.95 f-i	4.02 g-j
Chilmari	0 mM	69.92 ef	2.80 b	12.50 a	21.83 cd	6.33 bc	163.17 a	33.33 a	7.01 fg	6.26 c-g	9.13 b-d	0.96 e-i	6.06 a
	100 mM	64.50 ij	2.55 c	9.83 ef	18.33 gh	6.33 bc	122.17 de	25.67 bc	6.90 gh	6.02 g	8.40 e	0.92 i	4.95 de
BARI Tishi-1	0 mM	71.75 de	2.48 d	6.33 k	22.67 bc	5.33 d-f	123.33 c-e	17.33 d-g	7.68 ab	6.48 a-f	9.60 a-c	1.14 a-c	5.83 ab
	100 mM	64.80 ij	2.32 gh	5.50 l	20.17 ef	5.00 ef	94.67 j	11.33 g	7.63 a-c	6.31 c-g	9.47 a-d	1.04 d-h	4.85 d-f
BD-10703	0 mM	63.83 jk	2.51 cd	12.33 a	14.00 ij	5.00 ef	114.17 e-g	19.00 c-f	6.64 hi	6.37 c-g	9.40 a-d	0.94 hi	4.85 d-f
	100 mM	59.00 mn	2.46 de	11.50 b	13.33 jk	5.00 ef	113.67 e-h	12.67 e-g	6.51 i	6.03 g	9.07 cd	0.91 i	4.00 h-j
BD-10701	0 mM	60.83 lm	2.27 hi	11.33 bc	17.33 h	5.00 ef	109.83 f-i	12.00 fg	7.38 cd	6.43 b-g	9.47 a-d	1.03 d-h	4.40 f-i
	100 mM	57.67 n	2.21 i	9.83 ef	14.33 ij	4.67 f	94.33 j	13.33 e-g	7.22 d-f	6.21 e-g	8.87 de	1.03 d-h	3.93 ij
BD-10696	0 mM	72.17 d	2.45 de	10.50 de	22.33 bc	6.67 b	101.17 ij	17.00 d-g	7.01 fg	6.20 e-g	9.60 a-c	1.06 c-e	4.54 e-g
	100 mM	63.00 jk	2.37 fg	9.83 ef	15.33 i	5.67 c-e	95.00 j	22.67 cd	7.07 e-g	6.09 fg	9.27 a-d	0.89 i	3.78 j
Faridpur	0 mM	88.50 a	3.32 a	6.33 k	29.83 a	5.33 d-f	103.33 g-j	17.33 d-g	7.87 a	6.84 a	7.47 f	1.21 a	4.46 e-h
	100 mM	85.33 b	3.30 a	5.67 kl	29.67 a	5.00 ef	102.83 g-j	20.00 c-e	7.78 a	6.83 ab	7.20 f	1.18 ab	3.98 h-j
Significance	Genotype (A)	428.97***	0.55**	24.10**	49.87**	6.46**	1431.41***	182.98***	0.73***	0.04**	2.72**	0.036**	2.10**
	Treatment (B)	326.67***	0.14**	19.27**	20.77**	3.04**	1565.70***	20.42^{NS}	0.23**	0.57**	2.48**	0.087**	7.23**
	A × B	8.55***	0.01**	1.24**	2.32**	0.31^{NS}	294.80***	46.94*	0.018^{NS}	0.068^{NS}	0.29^{NS}	0.006^{NS}	0.13^{NS}
	Error	1.52	0.001	0.22	2.45	0.26	50.48	19.874	0.029	0.061	0.15	0.004	0.101
	CV	1.82	1.51	5.11	13.49	8.63	6.16	23.28	2.38	3.89	4.24	6.22	6.69

Inflores: Inflorescence; * Significant at p=0.05 level; ** Significant at 1% level; *** Significant at 0.1% level; NS: Not Significant. Means with different letters within the treatments are significant at *p*=0.05 level.

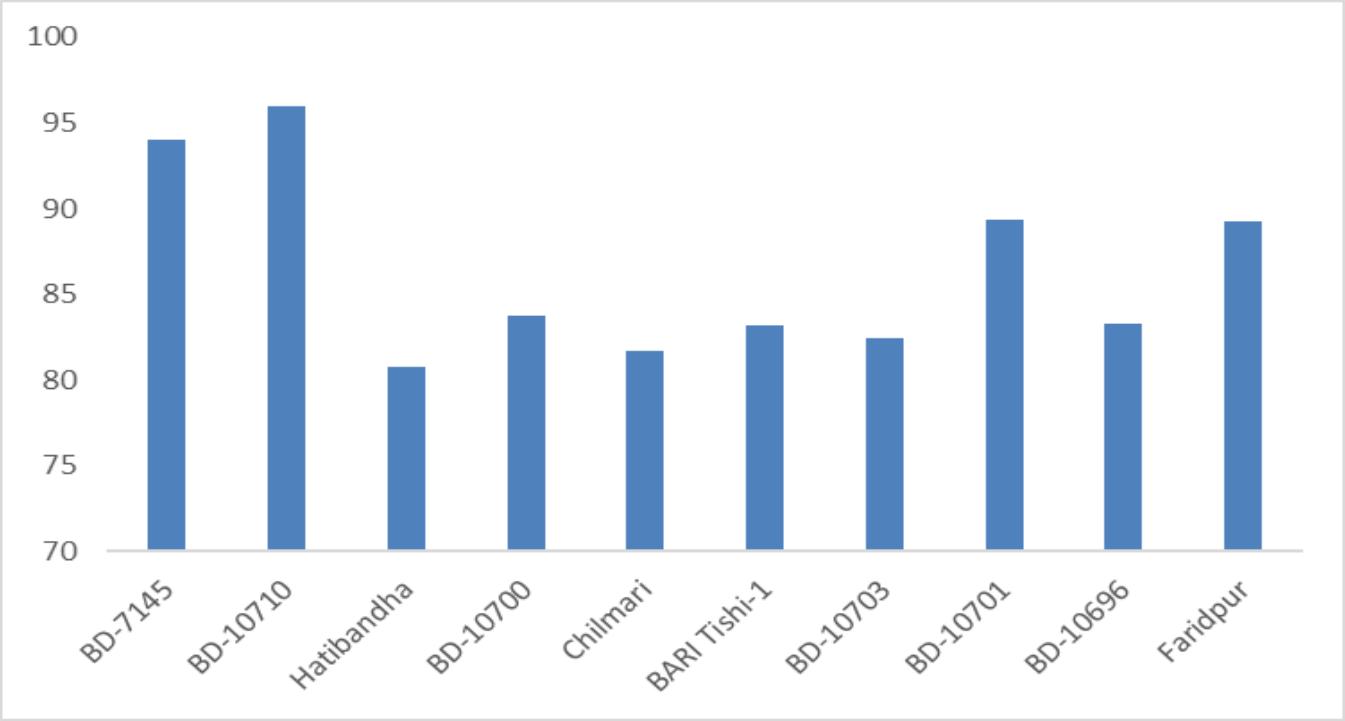

Fig. 4. Yield stability index of ten flax genotypes.

Salt-prone regions can have quite different stress patterns, demonstrating the connection between genotype and stress. Additionally, a significant genotype by stress interaction was discovered, demonstrating how each genotype reacted differently to 2 stressful circumstances in terms of seed output and other yield descriptors. The importance of the mean squared deviation for all stress parameters for seed yield across all genotypes illustrates the diversity of genotypes with salt stress resistance (24, 25). Plant breeders used a variety of approaches to identify and choose high-yielding genotypes under stressful conditions based on the variability in cultivars (30).

Conclusion

Salt stress hindered the germination and seedling growth in 40 flax genotypes by reducing water intake, which thwarts the imbibition process. The genotypes BD-10710, Faridpu, BD-10700, BD-10703 and BD-7145 performed better concerning germination and seedling growth descriptors under salt stress. However, in the pot experiment, all the studied parameters were significantly affected by salinity except unfilled capsule plant^{-1}. Considering all measured traits, a noticeable genotypic variation was observed in response to salinity stress. The seed yield plant^{-1} followed the trend- BD-7145> BD-10710> Chilmari> BARI Tishi^{-1}> BD-10700> BD10703> Faridpur> Hatibandha> BD-10701> BD-10696. In conclusion, BD-10710 and BD-7145, with a comparable (seed) yield with BARI Tishi^{-1}, could be considered as tolerant genotypes to salt stress and suggested for field trials at the saline-prone areas of Bangladesh.

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Authors' contributions

Study conception and design: AKMGS, MSH and MAH; Experimentation and data acquisition: KA and MMK; formal analysis: MMK and MSH; writing original draft preparation: KA and MMK; writing review and editing: AKMGS, MSH and MAH; supervision: AKMGS and MAH; project administration: AKMGS and MSH; funding acquisition: AKMGS. All authors have read and agreed to the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare no conflicts of interest related to this article.

Ethical issues: None.

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