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EVALUATION OF ADVANCED POTATO (*SOLANUM TUBEROSUM* L.) GENOTYPES FOR SALINITY TOLERANCE BASED ON YIELD AND AGRONOMIC TRAITS

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ABSTRACT: Salinity stress is a major constraint on potato (*Solanum tuberosum* L.) production, particularly in salinity-prone regions such as the Indo-Gangetic plains. This study evaluated 58 potato genotypes, including 54 advanced breeding lines and 4 released varieties, under control (ECe < 1 dS/m) and saline (ECe ~ 6.8-7.05 dS/m) environments. Genotypes were assessed for key agronomic traits, including marketable tuber yield (MTY), non-marketable tuber yield (NMTY), total tuber yield (TTY), marketable and non-marketable tuber no. and dry matter content (DM%). Salinity stress significantly reduced MTY and TTY, with yield reductions ranging from 1.86% to 65.74% and an average reduction of 31.70%. Genotypes such as WS/19-911 (yield reduction – 1.86%), WS/17-321 (2.39%) and WS/18-407 (3.16%) demonstrated superior tolerance, exhibiting minimal yield reductions, while others, including WS/17-717 (65.74%), WS/19-701 (63.64%) and WS/17-813 (60.43%), showed high susceptibility. Among released varieties, Kufri Bahar exhibited the lowest yield reduction (7.32%) in the current investigation. The Stress susceptibility index (SSI) varied across genotypes, with tolerant lines maintaining stable yields under stress. These findings highlight the potential of salinity-tolerant genotypes for breeding programs aimed at improving potato productivity in saline environments. This research underscores the importance of selecting genotypes that combine high marketable yields with resilience to salinity stress for sustainable cultivation.

KEYWORDS: Salinity, marketable yield, stress susceptibility index, yield reduction.

INTRODUCTION

The potato is the third most important food crop in the world after rice and wheat in terms of human consumption. It is a vital contributor to food security and nutrition due to its adaptability and high nutritional value. It thrives in diverse environments, ranging from the Arctic Circle to tropical regions, at altitudes from sea level to over 4000 meters, and under extreme weather and soil conditions (Ramirez *et al.*, 2019). Its tuber yield depends on sucrose synthesis via photosynthesis, its translocation, and starch conversion in stolons, processes that are highly sensitive to abiotic stress during tuber initiation, affecting yield and quality (Sanwal *et al.*, 2022). For potatoes, which are moderately sensitive to salinity (Abu Zeid *et al.*, 2021), even low salinity levels (1.7–3.5 dS/m) can cause substantial yield reductions, making it a critical constraint in many regions (Chourasia *et al.*, 2021).

Salinity stress disrupts plant growth and tuber development by inducing ionic imbalance, osmotic stress, and oxidative damage, leading to significant yield losses (Li *et al.*, 2022). Plant growth is suppressed, tuber yield declines and alterations are observed in the levels of dry matter, soluble solids, and secondary metabolites within the tubers (Levy and Tai, 2013). Along with this it also restricts water uptake by roots, accelerates

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plant senescence, and leads to browning and cracking of the tuber surface (Levy *et al*., 2013). Physiological and biochemical traits, including Na^+/K^+ homeostasis, osmotic adjustment through proline accumulation, and antioxidant defence mechanisms, are critical determinants of salinity tolerance in potatoes. Recent advancements in molecular and physiological research have identified many key genes which regulate salt tolerance pathways in potatoes (Li *et al*., 2022).

The Indo-Gangetic plains and coastal regions, such as the Ganges Delta, are particularly vulnerable to salinity stress due to unsustainable agricultural practices and increasing soil salinization caused by climate change (Sarangi *et al*., 2020). In these areas, salinity not only limits crop productivity but also exacerbates challenges in resource use efficiency and soil health. Salinity-induced yield losses vary significantly among potato genotypes, with reductions of up to 60% reported under severe stress conditions (Sanwal *et al*., 2022). Genetic variability among cultivars offers opportunities for breeding salt-tolerant varieties that can sustain high yields and quality under adverse conditions (Han *et al*., 2023). Genotypes that exhibit high marketable yield and low non-marketable yield under saline stress are particularly desirable for breeding programs and commercial cultivation.

This study evaluates the performance of diverse potato genotypes under natural saline conditions, focusing on their marketable and non-marketable yields. By identifying genotypes with superior salinity tolerance and yield stability, the findings contribute to breeding efforts for developing stress-resilient potato varieties, ensuring sustainable production in salinity-affected regions.

MATERIAL AND METHODS

This study evaluated 58 potato genotypes (Table 1), comprising of 54 advanced breeding lines and 4 released varieties, derived from various breeding programs. The parental lineages of potato genotypes represented a diverse genetic base, including released varieties, HT series clones (heat-tolerant clones), and exotic accessions, ensuring a wide range of traits for salinity tolerance studies. Only genotypes that had demonstrated superior performance in prior breeding evaluations were selected for this study. The check varieties included Kufri Thar-2, derived from CIP397006.18 (Luthra *et al*., 2020); Kufri Surya, recognized for its heat tolerance (Minhas *et al*., 2006); Kufri Daksh, known for water-use efficiency (Kumar *et al*., 2024); and Kufri Bahar, a leading and widely cultivated variety due to its adaptability.

All the genotypes were planted in saline and control (normal) environments replicated thrice in a randomized complete block design (RCBD) in 2nd week of November 2023. Five sprouted tubers of size 30–40 mm of each genotype was planted at a distance of 60 cm × 30 cm in ICAR-IIWBR farm Hisar, Haryana. Salinity stress was created by applying natural saline ground water (ECiw ~ 6 dS m^{-1}) while for the control treatment, the best available water of ECiw ~ 0.72 dS m^{-1} was used. The treatment-wise irrigation was started just after planting and a total of 6 irrigations were applied during the whole cropping period based on 100% evapotranspiration (ET). As per standard recommendation, half a dose of nitrogen and a full dose of phosphorus and potassium were applied at the time of planting and the remaining dose of nitrogen was applied at the earthing up stage (30 days after planting). Dehaulming was performed

Table 1. List of potato genotypes and their parental lineages used in the study.

S.No.	Genotype	Parents	S.No.	Genotype	Parents
1	WS/19-728	HT/10-1559 × Kufri Mohan	30	WS/17-712	HT/12-932 × HT/7-220
2	WS/19-701	HT/10-1559 × Kufri Mohan	31	WS/17-209	MOP/11-147 × HT/7-804
3	WS/19-439	NA	32	WS/19-2008	Innovator × Kufri Pukhraj
4	WS/19-1715	Innovator × JEX/A-122	33	WS/17-1009	HT/10-1907 × HT/7-804
5	WS/19-720	HT/10-1559× Kufri Mohan	34	WS/17-814	Kufri Lalit × HT/7-804
6	WS/19-911	NA	35	WS/14-10-6	NA
7	WS/18-602	CP4197 × Kufri Mohan	36	WS/16-904	NA
8	WS/17-717	HT/12-932 × HT/7-220	37	WS/17-802	Kufri Lalit × HT/7-804
9	WS/18-432	Kufri Jawahar × HT/7-321	38	Kufri Daksh	CP1748 × LT-1
10	WS/19-733	HT/10-1559 × Kufri Mohan	39	WS/18-622	CP4197 × Kufri Mohan
11	WS/17-813	Kufri Lalit × HT/7-804	40	WS/17-1727	NA
12	WS/19-2012	Innovator × Kufri Pukhraj	41	SL/20-519	Kufri Frysona × Kufri Sutlej
13	WS/19-1907	Innovator × CP4242	42	SL/20-1001	UDS60 × Kufri Sutlej
14	Kufri Thar 2	CIP397006.18 (CP4175)	43	SL/20-410	Kufri Himsona × Kufri Jyoti
15	WS/19-1706	Innovator × JEX/A-122	44	SL/20-801	CP4517 × Kufri Sutlej
16	WS/19-1914	Innovator × CP4242	45	SL/20-206	Kufri Kuber × Kufri Sutlej
17	Kufri Surya	Kufri Lauvkar × LT-1	46	SL/20-607	Kufri Mohan × Kufri Jawahar
18	WS/18-1619	NA	47	SL/20-705	Kufri Swarna × Kufri Sutlej
19	WS/19-102	CP4512 × Kufri Mohan	48	SL/20-1502	CP4496 × CP3486
20	WS/19-502	CP3379 × HT/7-321	49	SL/20-707	Kufri Swarna × Kufri Sutlej
21	WS/18-407	Kufri Jawahar × HT/7-321	50	SL/20-511	Kufri Frysona × Kufri Sutlej
22	WS/18-403	Kufri Jawahar × HT/7-321	51	SL/20-412	Kufri Himsona × Kufri Jyoti
23	WS/19-512	CP3379 × HT/7-321	52	SL/20-720	Kufri Swarna × Kufri Sutlej
24	WS/17-321	Kufri Jawahar × HT/7-804	53	SL/20-207	Kufri Kuber × Kufri Sutlej
25	WS/18-412	Kufri Jawahar × HT/7-321	54	SL/20-111	CP4175 × Kufri Sutlej
26	WS/18-405	Kufri Jawahar × HT/7-321	55	SL/20-406	Kufri Himsona × Kufri Jyoti
27	WS/19-721	HT/10-1559 × Kufri Mohan	56	SL/20-1009	UDS60 × Kufri Sutlej
28	WS/17-806	Kufri Lalit × HT/7-804	57	SL/20-408	Kufri Himsona × Kufri Jyoti
29	WS/18-618	CP4197 × Kufri Mohan	58	Kufri Bahar	Kufri Red × Gineke

*NA - Information not available

90 days after planting and harvesting was performed after one week to ensure proper curing. Treatment-wise soil samples were collected just after harvesting to measure the soil salinity build-up and it was found that the final salinity was found in the range of 6.8-7.05 dS m^{-1} in saline treatment.

Traits measured

Data were collected from three plants of each genotype under both conditions, and mean values were used for analysis. The traits measured included marketable tuber yield (MTY), the weight of tubers over 20 g meeting market standards (MTN), and non-marketable tuber yield (NMTY), the weight of tubers under 20 g (NMTN). Total tuber yield (TTY) was the sum of marketable and non-marketable yields. Dry matter content (DM%) was calculated as the percentage of dry weight in tubers after drying at 70°C to constant weight, providing insights into tuber quality.

Statistical analysis

A paired t-test was conducted to determine the significance of differences in traits between control and saline treatments, with a significance threshold set at $p<0.001$. Statistical analysis and data visualization were performed using the R programming environment (R Core Team, 2020).

Stress Susceptibility Index (SSI)

The Stress Susceptibility Index (SSI) was calculated to assess the sensitivity of each genotype to salinity stress using the formula:

$$SSI = 1 - (Yws/Yns) \ / \ DII$$

Where:

Yws: Yield of a genotype under saline treatments.

Yns: Yield of a genotype under control treatments.

DII (Stress Intensity Index): Calculated as:

$$DII = 1 - (\text{Mean } Yws \ / \ \text{Mean } Yns)$$

RESULTS

The yield parameters of 58 potato genotypes, including four check varieties, were evaluated under natural field conditions in both control (non-saline) and saline treatments.

Marketable tuber number per plant (MTNPP)

The mean MTNPP under control treatments was 3.95, while under saline, it was lower at 2.66. The ranges for this trait were 0.90 to 6.13 in control and 0.40 to 4.87 in saline treatments. The coefficient of variation (CV) was 30.04% under control and 38.11% under saline treatments, indicating higher relative variability under saline stress (Table 2). The genotype SL/20-206 recorded the minimum MTNPP under control (0.90), while WS/17-814 exhibited the maximum (6.13) followed by WS/19-1907 (5.93) and WS/19-2012 (5.73) (Table 3). Under saline treatments, the minimum MTNPP was observed in genotype SL/20-801 (0.40), and the maximum in WS/19-2012 (4.87) followed by WS/19-911 (4.80) and WS/17-1009 (4.33). Most of the genotypes exhibited reduced tuber numbers under saline treatments except WS/19-911 and SL/20-1001 where more tuber numbers were observed. Maximum tuber number reduction was observed in genotype SL/20-801 (66.67%), WS/17-717 (65.28%), WS/19-701 (64.10%) and WS/19-102 (61.11%). Statistical analysis revealed a highly significant difference between control and saline treatments ($t = 11.40$, $p < 0.001$) (Fig 1).

Marketable tuber yield (MTY)

The mean MTY under control treatments was 175.6 g/plant, while under saline treatments, it was significantly lower at 106.20 g/plant. The ranges of MTY were 22.80 to 305.20 g/plant in control and 9.60

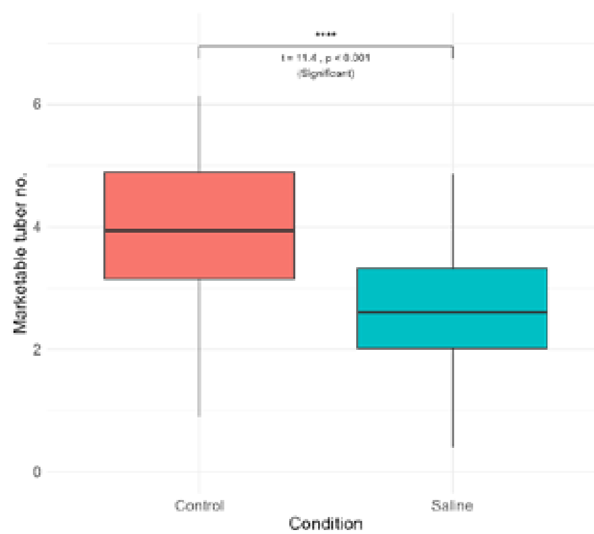

Fig. 1. Variation in marketable tuber no. of potato genotypes under control and saline treatments

Table 2. Comparative Analysis of Traits in Potato Genotypes Under Control and Saline treatments.

Trait	Control						Saline						Paired t-test (t-value)	P value
	Range	Min.	Max.	SD	SE	CV (%)	Range	Min.	Max.	SD	SE	CV (%)		
DM (%)	14.74 – 20.32	WS/19-733	K Thar-2	1.31	0.17	7.55	14.48 – 21.22	SL/20-720	SL/20-408	1.51	0.20	8.63	-0.51	0.611
MTN	0.90 – 6.13	SL/20-206	WS/17-814	1.19	0.16	30.04	0.40 – 4.87	SL/20-801	WS/19-2012	1.02	0.13	38.11	11.39	<0.001
MTY (g)	22.8 – 305.2	SL/20-206	K Thar-2	63.30	8.31	36.05	9.60 – 208.60	SL/20-801	Kufri Thar-2	45.30	5.95	42.66	13.58	<0.001
NMTN	2 – 10.2	WS/19-2012 & WS/19-102	WS/17-813 & WS/18-403	1.92	0.25	41.14	1.8 – 9.67	SL/20-707	WS/17-1009	1.82	0.24	39.69	0.316	0.753
NMTY	19.73 - 104	SL/20-1001	WS/18-403	18.88	2.48	38.97	17.27 – 84.20	WS/19-701	WS/16-904	15.99	2.10	35.94	1.47	0.146
TTY (g)	75.3 – 343.8	SL/20-801	Kufri Thar-2	66.74	8.76	29.79	51.2 – 241.3	WS/19-701	WS/19-2008	49.66	6.52	32.95	11.88	<0.001

to 208.60 g/plant in saline treatments (Table 2). The genotype SL/20-206 recorded the minimum MTY under control treatments (22.80 g/plant), while Kufri Thar-2 exhibited the maximum (305.20 g/plant) followed by WS/19-2008 (301.13 g/plant) and WS/19-1907 (299.73 g/plant). Under saline treatments, the minimum MTY was observed in SL/20-801 (9.60 g/plant), and the maximum in Kufri Thar-2 (208.60 g/plant) followed by WS/19-2008 (205.80 g/plant) and WS/19-1907 (128.33 g/plant). The SD under control (63.30) and under saline treatments (45.30), reflects higher variability in the control environment. The CV (36.05% under control and 42.66% under saline) also indicate greater relative variability under saline stress. Statistical analysis using a paired t-test revealed a highly significant difference between control and saline conditions ($t=13.58$, $p<0.001$) (Fig. 2). This indicated that salinity stress significantly reduced the marketable tuber yield. Most of the genotypes exhibited MTY reduction under saline conditions except one genotype i.e. WS/17-321 which exhibited a 3.12% yield advantage under saline conditions. Maximum yield reduction was

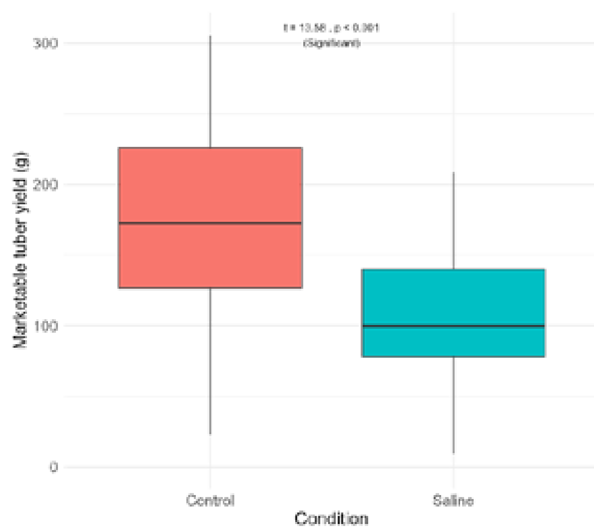

Fig. 2. Variation in marketable tuber yield of potato genotypes under control and saline treatments

Table 3. Performance of different potato genotypes under control and saline treatments.

Genotype	DM (%)		NMTN (No./plant)		NMTY (g/plant)		MTN (No./plant)		MTY (g/plant)		TTY (g/plant)	
	Control	Saline	Control	Saline	Control	Saline	Control	Saline	Control	Saline	Control	Saline
WS/19-728	16.04	17.93	5.27	4.40	58.80	45.13	4.90	2.60	191.40	101.00	250.20	146.13
WS/19-701	15.97	16.46	3.73	2.07	35.87	17.27	2.60	0.93	104.93	33.93	140.80	51.20
WS/19-439	17.66	16.73	4.87	3.80	49.07	36.60	3.13	2.00	152.73	76.33	201.80	112.93
WS/19-1751	17.30	18.18	4.13	3.60	48.53	41.00	5.20	4.20	236.27	166.20	284.80	207.20
WS/19-720	17.47	17.37	5.60	3.93	56.07	45.27	3.73	2.60	148.07	98.13	204.13	143.40
WS/19-911	19.33	18.67	3.87	5.40	41.87	49.07	4.27	4.80	166.27	155.20	208.13	204.27
WS/18-602	16.49	17.96	6.13	4.80	70.20	49.40	5.27	2.73	221.00	119.00	291.20	168.40
WS/17-717	17.12	15.95	6.00	1.87	58.87	17.40	4.80	1.67	225.27	79.93	284.13	97.33
WS/18-432	17.10	15.52	6.07	6.13	63.07	61.00	3.93	3.20	178.00	117.13	241.07	178.13
WS/19-733	14.74	14.61	5.80	4.33	69.47	45.80	5.33	2.47	229.40	92.53	298.87	138.33
WS/17-813	16.56	14.85	10.20	4.13	88.93	33.60	5.27	2.27	226.13	91.07	315.07	124.67
WS/19-2012	16.36	16.46	2.00	5.00	21.40	47.93	5.73	4.87	247.27	187.53	268.67	235.47
WS/19-1907	18.80	20.16	3.47	5.07	39.53	50.67	5.93	3.27	299.73	128.33	339.27	179.00
Kufri Thar 2	20.32	20.15	3.13	3.00	38.60	30.27	5.47	3.33	305.20	208.60	343.80	238.87
WS/19-1706	16.60	16.98	6.00	6.80	62.67	64.47	3.80	2.20	138.00	77.93	200.67	142.40
WS/19-1914	16.15	16.32	3.47	1.93	38.07	24.00	3.07	1.33	150.60	72.53	188.67	96.53
Kufri Surya	18.21	18.69	3.40	2.40	35.73	28.87	3.93	3.07	171.33	131.87	207.07	160.73
WS/18-1619	17.69	17.37	3.60	3.47	45.33	27.80	3.13	2.00	164.33	95.13	209.67	122.93
WS/19-102	17.71	16.75	2.00	2.27	22.53	22.80	3.60	1.40	164.07	65.73	186.60	88.53
WS/19-502	17.56	16.8	3.60	3.47	37.67	31.40	2.73	1.67	110.40	50.20	148.07	81.60
WS/18-407	18.91	18.33	5.80	7.40	59.67	60.73	3.20	2.87	115.60	109.00	175.27	169.73
WS/18-403	16.14	17.24	10.20	4.50	104.00	48.80	5.40	3.00	207.87	119.50	311.87	168.30
WS/19-512	20.03	18.54	2.33	2.20	27.07	27.07	3.87	2.87	262.67	165.27	289.73	192.33
WS/17-321	17.51	18.83	6.47	5.47	59.73	52.53	2.80	2.70	104.73	108.00	164.47	160.53
WS/18-412	18.03	16.81	4.47	3.13	43.93	32.07	3.33	2.27	163.47	89.73	207.40	121.80
WS/18-405	16.22	15.9	4.47	4.47	45.67	45.13	4.33	2.13	215.20	83.27	260.87	128.40
WS/19-721	16.89	15.42	4.00	5.00	49.40	51.20	5.33	3.80	197.67	163.47	247.07	214.67
WS/17-806	19.12	17.13	4.33	4.07	39.93	43.07	4.27	3.40	241.67	169.80	281.60	212.87
WS/18-618	16.36	18.78	3.00	2.53	30.60	26.33	3.93	2.00	225.60	89.90	256.20	116.23
WS/17-712	18.48	19.02	4.60	5.67	54.27	59.20	4.33	4.07	194.07	166.33	248.33	225.53
WS/17-209	15.81	16.14	4.07	4.53	42.87	51.53	4.60	4.20	230.27	141.67	273.13	193.20
WS/19-2008	17.03	17.52	2.93	3.40	35.47	35.53	5.07	3.87	301.13	205.80	336.60	241.33
WS/17-1009	17.25	17.95	4.53	9.67	50.40	67.13	5.47	4.33	228.33	170.13	278.73	237.27
WS/17-814	17.42	18.41	5.60	3.80	65.13	36.73	6.13	3.67	268.73	162.73	333.87	199.47
WS/14-10-6	15.20	17.3	3.73	3.67	40.93	33.00	5.73	3.53	256.80	148.47	297.73	181.47
WS/16-904	15.30	15.25	8.80	9.00	93.93	84.20	4.60	2.40	187.60	87.60	281.53	171.80
WS/17-802	18.84	17.36	6.53	5.73	69.93	59.00	4.87	3.67	268.27	144.67	338.20	203.67
Kufri Daksh	17.38	16.92	5.07	6.13	41.73	57.20	4.33	3.13	185.20	109.20	226.93	166.40
WS/18-622	17.04	15.2	4.40	3.87	48.73	37.13	3.60	3.00	181.47	104.07	230.20	141.20

Genotype	DM (%)		NMTN (No./plant)		NMTY (g/plant)		MTN (No./plant)		MTY (g/plant)		TTY (g/plant)	
	Control	Saline	Control	Saline	Control	Saline	Control	Saline	Control	Saline	Control	Saline
WS/17-1727	16.98	18.66	8.80	5.13	93.07	55.60	3.80	3.80	177.53	121.70	270.60	177.30
SL/20-519	19.70	19.54	2.53	2.47	23.93	23.00	2.10	1.27	117.30	43.53	141.23	66.53
SL/20-1001	16.93	18.53	2.33	9.00	19.73	79.30	2.00	2.50	173.50	86.10	193.23	165.40
SL/20-410	17.98	18.88	5.47	7.73	44.87	74.60	4.07	2.40	131.07	89.87	175.93	164.47
SL/20-801	16.78	17.2	4.40	5.20	39.60	49.53	1.20	0.40	35.70	9.60	75.30	59.13
SL/20-206	18.70	19.88	7.60	5.53	71.00	34.87	0.90	0.80	22.80	21.00	93.80	55.87
SL/20-607	15.19	15.71	2.80	5.53	22.73	58.47	4.40	3.10	152.50	90.00	175.23	148.47
SL/20-705	17.08	17.96	4.00	2.60	52.80	28.60	3.20	2.87	152.60	134.20	205.40	162.80
SL/20-1502	18.22	19.42	2.80	4.87	31.70	44.47	3.80	1.67	111.90	66.27	143.60	110.73
SL/20-707	16.65	17.9	3.07	1.80	30.27	20.33	3.00	2.60	125.27	110.20	155.53	130.53
SL/20-511	18.97	19.42	3.40	3.67	31.20	37.67	3.00	1.33	114.90	40.80	146.10	78.47
SL/20-412	19.72	17.42	4.50	3.73	51.20	28.53	2.40	1.60	92.30	51.40	143.50	79.93
SL/20-720	15.50	14.48	3.33	3.67	30.13	33.27	2.47	1.20	87.80	45.40	117.93	78.67
SL/20-207	17.81	16.62	2.20	2.73	27.33	29.07	3.27	2.33	170.80	119.40	198.13	148.47
SL/20-111	18.99	19.24	4.53	6.53	43.13	64.27	4.20	2.07	167.20	78.47	210.33	142.73
SL/20-406	18.02	15.67	6.73	6.60	65.20	64.73	3.27	2.47	101.47	81.07	166.67	145.80
SL/20-1009	16.27	17.43	7.87	6.60	71.67	66.53	2.33	2.13	78.73	66.67	150.40	133.20
SL/20-408	19.32	21.22	3.20	4.53	33.30	49.93	3.60	2.33	124.70	74.40	158.00	124.33
Kufri Bahar	16.23	16.66	3.40	5.53	40.93	61.47	5.13	4.20	179.40	142.73	220.33	204.20

exhibited by genotype SL/20-801 (73.11%) followed by WS/19-701 (67.66%), WS/17-717 (64.52%) and SL/20-511 (64.50%). Out of 4 check varieties minimum MTY reduction was observed by variety Kufri Bahar (20.44%) and maximum reduction by variety Kufri Daksh (41.04%). Ten genotypes were found that exhibited lower yield reduction under saline treatments as compared to check Kufri Bahar.

Non-marketable tuber number per plant (NMTNPP)

The mean NMTNPP under control treatments was 4.67, while under saline treatments, it was 4.58. The ranges of NMTNPP were 2.00 to 10.20 in control and 1.80 to 9.67 in saline treatments (Table 2). The genotype WS/19-2012 exhibited the minimum under control treatments (2.0), while WS/17-813 recorded the highest (10.2) NMTNPP. Under saline treatments, the minimum NMTNPP was observed in SL/20-707 (1.8), and the maximum in WS/17-1009 (9.67). The box plot visually represents the distribution of NMTNPP under control and saline treatments. Statistical analysis revealed no significant difference between control and saline treatments ($t = 0.317$, $p = 0.753$). This result suggests that salinity had no significant impact on the number of non-marketable tubers per plant (Fig 3).

Non-marketable tuber yield (NMTY)

The mean NMTY under control treatments was 48.44 g/plant, while under saline treatments, it was slightly lower at 44.51 g/plant. The ranges of NMTY were 19.73 to 104.00 g/plant in control and 17.27 to 84.20 g/plant in saline treatments (Table 2). The genotype SL/20-1001 recorded the minimum NMTY under control treatments (19.73 g/plant), while WS/18-403 exhibited

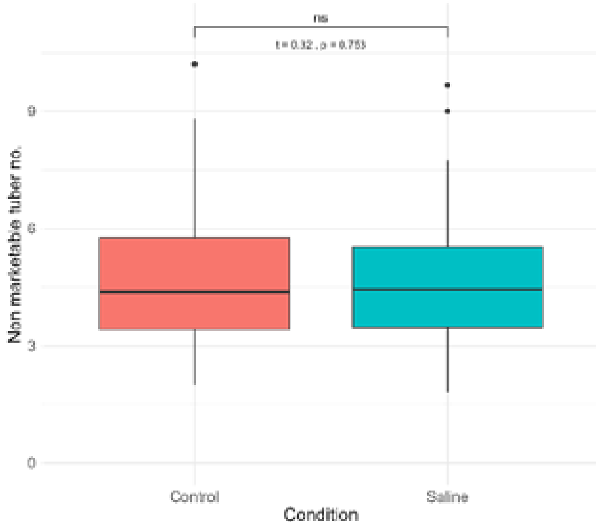

Fig. 3. Variation in non-marketable tuber no. of potato genotypes under control and saline treatments

the maximum (104.00 g/plant). Under saline treatments, the minimum NMTY was observed in WS/19-701 (17.27 g/plant), and the maximum in WS/16-904 (84.20 g/plant). Statistical analysis revealed no significant difference between control and saline treatments (t = 1.474, p = 0.146) (Fig. 4). This result suggests that salinity did not significantly impact the non-marketable tuber yield.

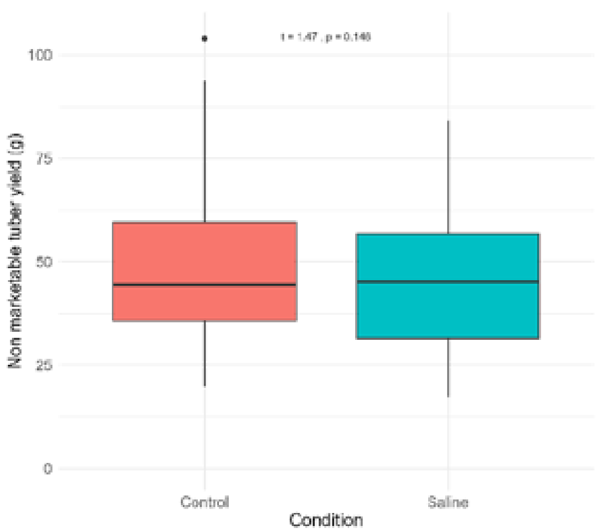

Fig. 4. Variation in non-marketable tuber yield of potato genotypes under control and saline treatments

Total tuber yield (TTY)

The total tuber yield (TTY) was significantly affected by salinity stress, as evident from the statistical analysis conducted on potato genotypes. Under control treatments, the mean TTY was 224.00 g/plant, with an SD of 66.74, SE of 8.76, and a CV of 29.79%. The range of TTY under control varied from 75.30 g/plant (SL/20-801) to 343.80 g/plant (K. Thar-2) (Table 2). After Kufri Thar-2 maximum TTY under control treatments was exhibited by genotype WS/19-1907 (339.27 g) followed by WS/17-802 (338.20 g) and WS/19-2008 (336.60 g) (Table 3). In comparison, under saline treatments, the mean TTY decreased significantly to 150.70 g/plant, with an SD of 49.66 g/plant, SE of 6.52 g/plant, and a CV of 32.95%. The range under saline treatments spanned from 51.20 g/plant (WS/19-701) to 241.30 g/plant (WS/19-2008). Under saline treatments after WS/19-2008 maximum TTY was shown by Kufri Thar-2 (238.87 g), WS/17-1009 (237.27 g) and WS/19-2012 (235.47 g). So out of all check varieties, Kufri Thar-2 performed better under both the control and saline treatments. The paired t-test revealed a highly significant difference between control and saline treatments ($t=11.881$, $p<0.001$), confirming the adverse impact of salinity on TTY (Fig 5).

Dry Matter Content (DM)

The results showed that the mean dry matter under control treatment was 17.40%, while under saline treatments, it was slightly higher at 17.48%. The genotype WS/19-733 recorded the minimum dry matter under control (14.74%), whereas variety Kufri Thar-2 exhibited the highest (20.32%) followed by WS/19-512 (20.03%) and SL/20-412 (19.72). Under saline treatments, the minimum DM was observed in SL/20-720 (14.48%), and the maximum in SL/20-408 (21.22%) followed by WS/19-1907 (20.16%) and Kufri Thar-2

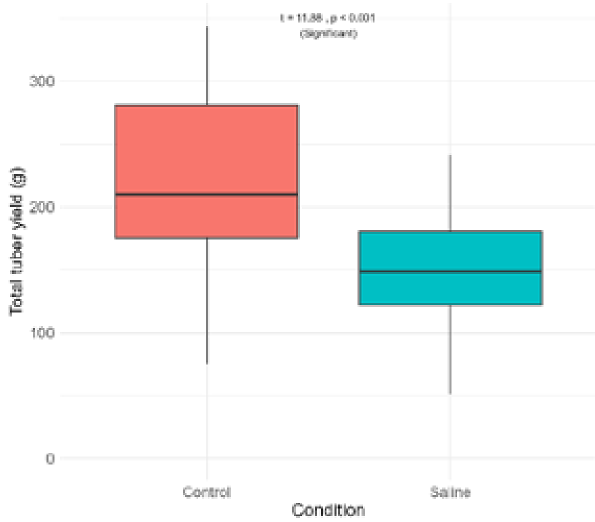

Fig. 5. Variation in total tuber yield of potato genotypes under control and saline treatments

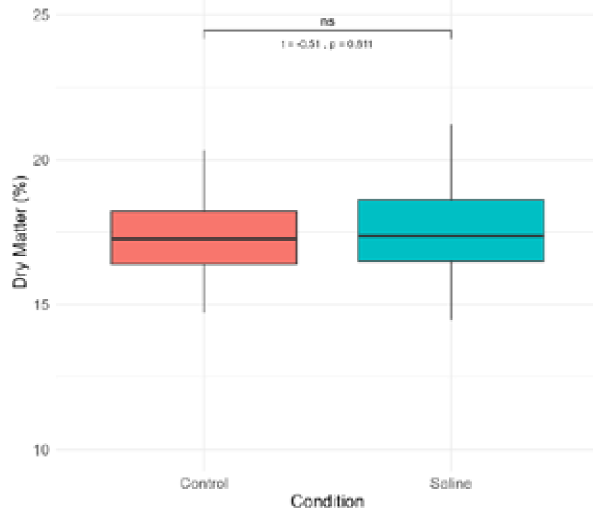

Fig. 6. Variation in dry matter (%) of potato genotypes under control and saline treatments

(20.15%). Statistical analysis using a paired t-test ($t = -0.51$, $p = 0.611$) indicated no significant difference between the DM content under control and saline treatments. The variability parameter (SD of 1.31 for control and 1.51 for saline) also suggested minor fluctuations in response to salinity. A comparison across the genotypes revealed that certain genotypes, such as WS/19-720, WS/19-733, WS/19-2012, Kufri Thar-2, WS/16-904 and SL/20-519 maintained almost stable DM content across both conditions, highlighting potential tolerance to salinity-induced stress. The box plot visually represents the distribution and variability of dry matter content under control and saline treatments, showing comparable medians and ranges (Fig 6).

Stress Susceptibility Index (SSI)

The analysis of the Stress susceptibility index (SSI) revealed significant variation among the potato genotypes, highlighting their differing responses to salinity stress (Fig 7). Genotypes with SSI values less than 1 were identified as tolerant, demonstrating smaller yield reductions under stress. Notable tolerant genotypes included WS/19-911 (0.06), WS/19-2012 (0.37), WS/17-712 (0.28), Kufri Bahar (0.22), and SL/20-1502 (0.69), which maintained stable yields despite the stress conditions. Genotypes with SSI values close to 1, such as WS/19-720 (0.90), WS/17-209 (0.89) and WS/19-2008 (0.86) exhibited moderate tolerance by experiencing yield reductions proportional to the overall stress intensity. Conversely, genotypes with SSI values greater than 1 were classified as sensitive, indicating higher susceptibility to salinity stress. Highly sensitive genotypes included WS/17-717 (1.99), WS/19-733 (1.63), SL/20-519 (1.60), and SL/20-720 (1.01), which showed significant yield declines under stress. These findings underscore the potential of tolerant genotypes, such as WS/19-911 and WS/18-407 (0.10), for cultivation in saline environments, while sensitive genotypes may require targeted breeding efforts or improved management practices to enhance their performance under stress.

DISCUSSION

The observed similarity in dry matter content between control and saline conditions

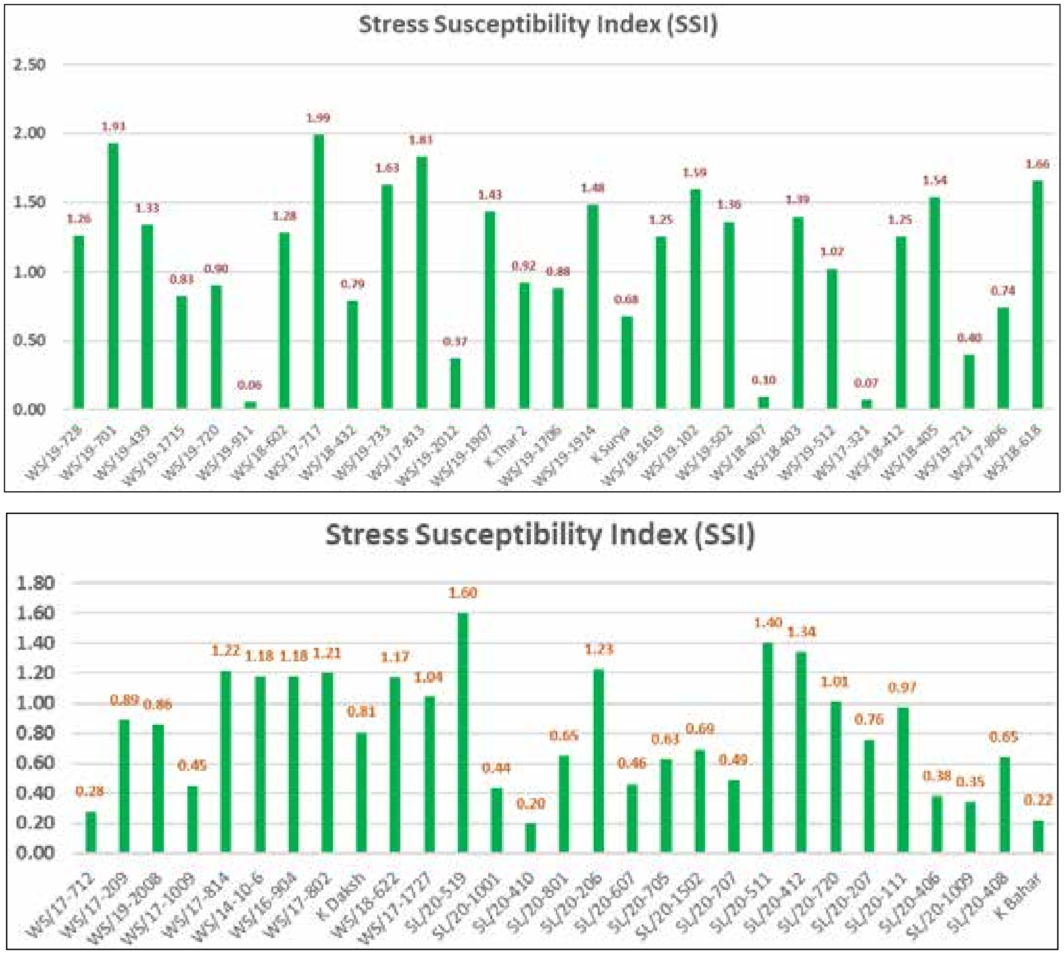

Fig. 7. Stress Susceptibility Index (SSI) of potato genotypes under salinity stress treatments

indicates that salinity did not significantly impact this trait across the evaluated genotypes. This stability in DM might suggest inherent physiological mechanisms enabling these genotypes to maintain carbohydrate synthesis and storage even under saline stress. Genotypes showing consistent dry matter content under saline treatments could be prioritized for further breeding programs targeting salinity resilience. For example, SL/20-408 and Kufri Thar-2 showed high dry matter content under both control and saline treatments, making them potential candidates for breeding. Conversely, genotypes like WS/19-733 and SL/20-720, which exhibited lower dry matter content, could be considered less tolerant. The findings align with previous studies that reported varying impacts of salinity on dry matter content, depending on the genetic background and environmental factors.

The results of the present investigation demonstrated that salinity stress had a significant negative impact on the MTNPP trait. The reduction in mean MTNPP under saline treatments, coupled with a higher CV, suggests that genotypes exhibit diverse responses to salinity stress. This highlights the need for targeted selection of genotypes with stable performance under saline environments. Genotypes such as WS/19-2012 and WS/17-814, which recorded high

MTNPP under saline and control treatments, respectively, could be prioritized for breeding programs aimed at improving marketable tuber yield under stress. Conversely, genotypes like SL/20-206 and SL/20-801, which exhibited low MTNPP, may be less suitable for such programs. The observed variability and significant reduction in MTNPP under saline treatments align with previous studies indicating that salinity adversely affects tuber development and marketability. Future studies should focus on identifying physiological and molecular mechanisms that enable certain genotypes to maintain higher MTNPP under saline stress, which could facilitate the development of stress-resilient potato varieties.

The results demonstrated that salinity stress had a pronounced negative impact on the MTY trait. The reduction in mean MTY under saline treatments, coupled with a higher CV, suggests that genotypes exhibit diverse responses to salinity. This diversity highlights the importance of selecting genotypes with stable and high yields under saline environments. Kufri Thar 2, which exhibited the highest MTY under both control and saline treatments, emerges as a promising candidate for breeding programs aimed at improving yield under salinity stress. Conversely, genotypes like SL/20-206 and SL/20-801, which showed consistently low MTY, may be less suitable for saline environments. These findings align with prior research, underscoring salinity detrimental effects on potato yield. Future research should focus on identifying the physiological and molecular mechanisms that enable salinity tolerance in high-performing genotypes, such as Kufri Thar 2, to facilitate the development of resilient potato cultivars.

The results indicated that salinity stress had no significant influence on the non-marketable tuber no and yield, as evidenced by the non-significant p-value from the paired t-test. Genotypes that exhibit high marketable yield and low non-marketable yield under saline treatments are highly desirable, as they ensure both economic viability and quality, even in stress-prone environments.

The reduction in mean TTY, along with the higher CV under saline treatments, underscores the variability in genotype performance under stress. Kufri Thar 2, which exhibited the highest TTY under control treatments, and WS/19-2008, which performed best under saline treatments, are robust candidates for breeding programs focused on salinity tolerance. Conversely, genotypes such as SL/20-801 and WS/19-701, which consistently showed low TTY, may be less suitable for saline environments. These findings align with previous studies highlighting salinity detrimental effects on potato tuber yield. In their study, Levy and Tai (2013), showed significant genotypic differences in response to salinity, with varieties such as Vivaldi and Almera demonstrating better adaptation under high salinity treatments compared to Mondial and Charlotte. They also reported that salinity reduced tuber yield but increased dry matter and soluble solids across all genotypes, underscoring the differential impact of saline conditions on potato traits. Rahman *et al*. (2013) evaluated CIP germplasm in saline conditions and observed that CIP-112 recorded the highest yield (21.07 t/ha), followed by CIP-111 (18.72 t/ha) and CIP-102 (17.55 t/ha), all of which outperformed local variety Diamant (15.78 t/ha). The range under saline conditions in our study spanned from 51.20 to 241.30 g/plant. In comparison, Ramírez *et al*. (2019) reported that despite extreme salinity, 40% of the genotypes survived, yielding between 0.3–5.2 g of fresh tuber per plant. The observed variability among genotypes provides opportunities for selecting high-performing genotypes to enhance resilience under salinity stress. Further research is warranted to understand the physiological and molecular mechanisms underlying salinity tolerance in promising genotypes like K. Thar 2 and WS/19-2008.

Yield reduction percentage and comparison with check varieties

The analysis of yield reduction percentage revealed significant differences in the responses of genotypes under saline treatments. The yield reduction in the present study ranged from 1.86% to 65.74%, with an average reduction of 31.70%, highlighting significant variability in genotypic responses to salinity stress. Among the check varieties, Kufri Bahar exhibited the lowest yield reduction of 7.32%, showcasing salinity tolerance and yield stability under stress treatments. Similarly, Kufri Surya, Kufri Daksh and Kufri Thar-2 showed yield reductions of 22.38%, 26.67% and 30.52%, respectively. These results highlight the variability in salinity responses among check varieties. When compared to the genotypes, several promising genotypes demonstrated better performance than some of the check varieties. Notably, WS/19-2008 recorded the highest yield under saline treatments (241.30 g/plant) with a yield reduction of 28.30%, surpassing even Kufri Thar-2. Similarly, genotypes such as WS/19-911 (yield reduction- 1.86%), WS/17-321 (2.39%), WS/18-407 (3.16%) and SL/20-410 (6.52%) exhibited lower yield reduction, outperforming Kufri Bahar (7.32% yield reduction). These genotypes, with minimal reductions and consistent performance under stress, represent excellent candidates for breeding programs targeting salinity tolerance. In contrast, genotypes like WS/17-717 (65.74%), WS/19-701 (63.64%) and WS/17-813 (60.43%) displayed the highest yield reductions, highlighting their susceptibility to salinity stress. It is well known that salinity is a major abiotic stress which affects plant growth and yield drastically by disrupting physiological, biochemical and metabolic processes. In this study, yield reductions under saline treatments can be caused by multiple factors. It may be due to osmotic stress, which limits water uptake, reduced cell expansion, tuber initiation and bulking. Additionally, ion toxicity, due to excessive accumulation of Na^{+} and Cl^{-} ions, can disrupt nutrient homeostasis which impacts the uptake of essential macronutrients like K^{+}, Ca^{2+}, and Mg^{2+}, thereby impairing enzymatic activities and plant metabolism. Furthermore, it can affect photosynthetic efficiency of potato plant which impacts biomass accumulation and tuber development. Salinity triggers oxidative stress through reactive oxygen species (ROS), responsible for cellular damage and disruption of metabolic pathways. So, all of these physiological constraints could be responsible for decline in tuber yield under saline treatments compared to the control treatment.

Ramírez *et al*. (2019) observed CIP 397099.4, CIP 396311.1, and CIP 390478.9 demonstrated the highest tolerance, with 9.3%, 8.9%, and 5.8% yield relative to control conditions, respectively. Levy (1992) reported yield reductions of 0–17% under moderate salinity and 21–79% under high salinity, with early-maturing cultivars like Atica and Desirée performing better. Salinity affected tuber growth more than haulm growth, delaying emergence and accelerating senescence. Munira *et al*. (2015) analyzed the response of ten potato varieties to different salinity levels (0.5 to 8.90 dS/m) and observed Sagita and Felsina as the top-performing varieties, achieving the highest yields of 363.3 g at 0.5 dS/m and 121.7 g/118.3 g at 8.90 dS/m. Lady Rosetta and Provento showed moderate tolerance, while Shilbilati and Lalpakri were the most affected, displaying the lowest yields and severe membrane damage. Across all varieties, yield reductions surpassed 60% under 8.90 dS/m salinity. Shaterian *et al*. (2008) evaluated the effects of salinity (100–150 mM NaCl) on tuber yield in 22 diploid potato clones and revealed significant variability in yield under salinity, with clones 9506-04 and 9788-03 showing the highest relative yields, demonstrating strong tolerance. Sanwal *et al*. (2022) assessed 53 potato genotypes under saline (6 dS/m) and control conditions, observing an average tuber yield reduction of 38.75% due to salinity stress. The highest yield under saline conditions was recorded in Kufri Lalit (428.27 g/plant), while Kufri Sheetman (60.93 g/plant) had the lowest. Abdullah-Al-Mahmud *et al*. (2018) assessed five CIP potato clones and two check varieties under salinity levels of 0 to 16 dS/m. At 0 dS/m, tuber yields ranged from 276 to 366.75 g/plant, with Diamant yielding the highest. At 16 dS/m, yields dropped to 14.25–48 g/plant, with CIP-139 showing the best performance. Yield reductions at 8 dS/m were 50.64% for CIP-139, 55.25% for CIP-112, and 59.51% for CIP-102.

The comparison underscores the importance of selecting genotypes that combine high yields with minimal yield reductions under saline conditions. While Kufri Bahar and Kufri Thar-2 serve as reliable standards for evaluating salinity tolerance in our study, the outstanding performance of WS/19-2008, WS/19-911, and WS/17-321 demonstrates the potential of these genotypes for breeding programs. The variability in yield reduction percentages across genotypes emphasizes the need for further research to understand the physiological and molecular mechanisms of salinity tolerance, particularly in high-performing genotypes like WS/19-2008, to develop stress-resilient potato cultivars. Figure 9 shows the yield of potato genotypes under control and saline conditions, with consistent reductions observed across all genotypes under salinity stress. Genotypes exhibiting minimal yield differences, such as WS/19-911 and WS/17-321, indicate potential tolerance, while others like WS/17-717 showed pronounced sensitivity. Figure 8 shows the percentage yield reduction under saline conditions across potato genotypes, with substantial variability observed among genotypes.

CONCLUSION

This study highlighted the remarkable diversity among advanced potato genotypes

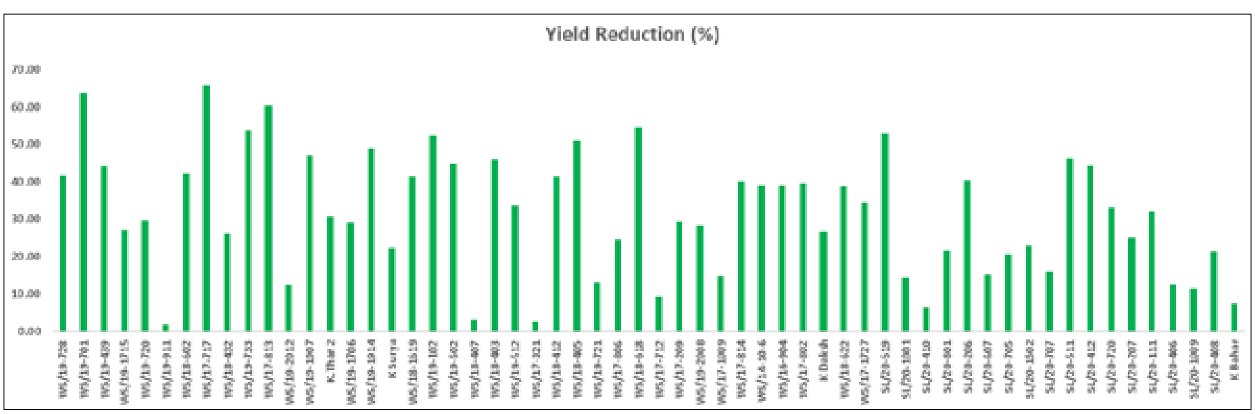

Fig. 8. Yield reduction (%) of potato genotypes under saline treatments

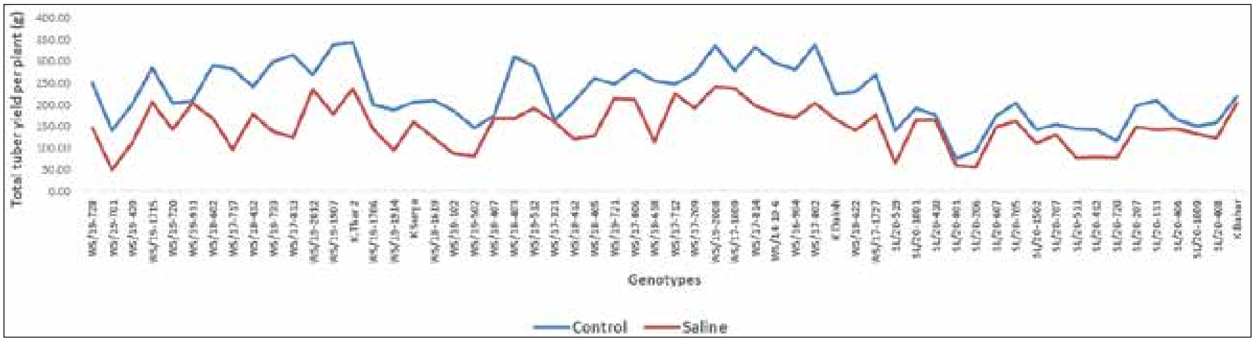

Fig. 9. Total tuber yield (g/plant) of potato genotypes under control and saline treatments

in their ability to tolerate salinity stress under natural field conditions. Genotypes such as WS/19-911 and WS/17-321, along with the variety Kufri Bahar, stood out for their resilience, maintaining high yields even under saline conditions. These genotypes were found superior for breeding efforts aimed at improving potato productivity in saline-prone areas. The results emphasize the importance of identifying and utilizing such robust genotypes to ensure sustainable cultivation and food security. Moving forward, a deeper understanding of the mechanisms driving salinity tolerance will be key to developing even more resilient potato varieties.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors

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