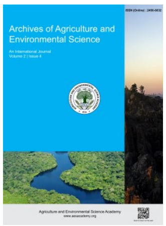
Archives of Agriculture and Environmental Science 9(4): 761-767 (2024)
https://doi.org/10.26832/24566632.2024.0904018

e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: journals.aesacademy.org/index.php/aaes



ORIGINAL RESEARCH ARTICLE

Performance of late sown wheat genotypes under drought stress at Khajura, Banke, Nepal

Prabhat K.C.[1*], Suman Bohara[2] and Bijaya Upadhayay[1]

[1]Faculty of Agriculture, Agriculture and Forestry University, Rampur, Chitwan, Nepal
[2]Directorate of Agricultural Research, Lumbini Province, Khajura, Banke, Nepal
[*]Corresponding author's E-mail: khatri.prabhat9@gmail.com

ARTICLE HISTORY

Received: 08 October 2024
Revised received: 29 November 2024
Accepted: 10 December 2024

Keywords

Breeding programs
Drought resilience
Drought stress
Genotypes
Tolerance
Wheat

ABSTRACT

This study aimed to identify wheat genotypes tolerant to drought and terminal heat stress under late-sown conditions using stress tolerance indices. A field experiment was conducted with 18 genotypes, including checks, at the Directorate of Agricultural Research, Lumbini Province, Khajura, Banke. The trials were arranged in a randomized complete block design (RCBD) with three replications under two conditions: normal irrigated and simulated drought (via rainout shelter). Grain yield was recorded, and stress susceptibility and tolerance indices were estimated. The research showed that the average grain yield of all tested genotypes decreased by 58.8% under stress conditions $(\bar{Y}_s)$ compared to normal irrigated condition $(\bar{Y}_p)$. There was a highly significant difference (p<0.01) in grain yield across genotypes when grown under both irrigated and stress conditions. The genotype NL 1488 produced the highest grain yield of 3725 kg/ha, followed by Banganga (3693.67 kg/ha), NL 1447 (3550.33 kg/ha), NL 1423 (3454.67 kg/ha), NL 1444 (3426 kg/ha), and NL 1445 (3224.67 kg/ha) under normal irrigated conditions. Similarly, the genotype NL 1447 produced the highest grain yield of 1547.33 kg/ha, followed by NL 1415 (1541.67 kg/ha), NL 1444 (1442.33 kg/ha), NL 1345 (1349.33 kg/ha), NL 1446 (1338.33 kg/ha), and NL 1451 (1328.33 kg/ha) under drought conditions. The highest values of MP, GMP, and STI were obtained in genotype NL 1447, followed by NL 1444, NL 1415, NL 1451, and NL 1446. Thus, these genotypes exhibit high yield potential under both irrigated and drought conditions, making them suitable candidates for breeding programs aimed at improving drought resilience in wheat.

Citation of this article: K.C., P., Bohara, S., & Upadhayay, B. (2024). Performance of late sown wheat genotypes under drought stress at Khajura, Banke, Nepal. *Archives of Agriculture and Environmental Science*, 9(4), 761-767, https://dx.doi.org/10.26832/24566632.2024.0904018

INTRODUCTION

Wheat (*Triticum aestivum* L.), a member of the Gramineae family and the tribe Hordeae, ranks as the third most important cereal crop in Nepal, following rice and maize (Bhatta *et al*., 2020; Subedi *et al*., 2019). This strategic crop is vital to the economy of emerging nations (Yassin *et al*., 2019), offering significant nutritional value as a source of protein, minerals, B-group vitamins, and dietary fiber (Kandel *et al*., 2018). Wheat is the third most cultivated cereal in Nepal, but its productivity is significantly reduced by drought and high temperatures, especially during critical growth stages such as anthesis and grain filling. Wheat grains are widely used to produce bread, pasta, cakes, noodles, biscuits, and other food products, making it a staple for global food security. In Nepal, wheat is cultivated on 716,978 hectares, producing 2,144,568 metric tons with a productivity of 2.99 metric tons per hectare (MOALD, 2023). However, its production is heavily influenced by climatic and environmental factors. Global climate change, increasing water scarcity, and deteriorating environmental conditions pose significant challenges to wheat production, threatening food and nutritional security for the growing population (Sahani *et al.*, 2021). Drought stress (DS), in particular, is a major limitation for wheat production, affecting plant morphology, physiology, and development. It reduces spike density, grains per spike, and the grain-filling period, ultimately leading to yield loss (Poudel *et al.*, 2020). DS during the reproductive stage is especially harmful, as it severely impacts photosynthesis, reproductive development, and grain yield (Chowdhury *et al.*, 2021). Historical records indicate increasing drought incidences in Nepal, particularly in the western region, where drought often coincides with the wheat cropping period, exacerbating production challenges (Hamal *et al.*, 2020). Nepal has 35 developed cultivars, 540 landraces, and 10 wild relatives of wheat (Joshi *et al.*, 2006), yet the lack of drought- and heat-tolerant varieties remains a critical issue. While modern agricultural practices have enhanced productivity, current wheat varieties are increasingly vulnerable to climate-induced stresses. Marker-assisted selection (MAS) and stress tolerance indices have shown promise in identifying drought-tolerant genotypes globally (Mollasadeghi *et al.*, 2011; Bennani *et al.*, 2017), but these tools remain underutilized in Nepal. There is a pressing need to evaluate wheat genotypes under drought and heat stress conditions to address the growing demand for wheat while mitigating yield losses caused by environmental stressors. This study aims to address the research gap by evaluating wheat genotypes for drought and terminal heat stress tolerance under late-sown conditions in the western Terai region of Nepal. By utilizing stress tolerance indices such as TOL, SSI, RSI, YSI, MP, GMP, and STI, this research seeks to identify genotypes that perform well under both stress and non-stress conditions (Poudel *et al.*, 2021). The findings will contribute to the development of resilient wheat varieties that can sustain productivity despite increasing climatic challenges. The primary aim of this research is to identify wheat genotypes tolerant to drought and terminal heat stress under late-sown conditions in the western Terai region of Nepal, using stress tolerance indices as a screening tool. This work will pave the way for breeding programs focused on climate-resilient wheat varieties, ensuring food security and agricultural sustainability in Nepal.

MATERIALS AND METHODS

Experimental site

The research was conducted at Directorate of Agricultural Research (DoAR), Lumbini Province, Khajura, Banke. Geographically, it lies between $81^{0}37"$ East longitudes and $28^{0}06"$ North latitude and an altitude of 181 meters above sea level. The research area has a humid subtropical climate where summers are hot and winters are cold. The location receives 1000-1500 mm of rain on average each year. The station's maximum and minimum temperatures are 46 °C and 5.4°C, respectively, and its relative humidity ranges from 27 to 94 %. For the majority of the year, the humidity is minimal. The station's soil is sandy to silty loam, with low levels of available organic carbon and nitrogen but moderate levels of phosphate and potassium. Soil pH varies from 7.2- 7.5 (DoAR, 2022).

Planting materials

The study included 18 genotypes, including check varieties, and the complete list of genotypes is provided in Table 1.

Experimental design and treatment combination

Eighteen wheat genotypes selected from rain-fed trials of the previous season were evaluated using RCBD with three replications. The wheat crop was sown late (4^{th} January, 2023) to subject the crop to heat stress during its critical stages. Each genotype was planted in a plot size of $2m^2$ (5 rows of 2m length) at the seed rate of 120 kg per hectare. Each plot had rows with a spacing of 25 cm between them and continuous sowing using the line sowing method. No gap was given between the plots within the same replication whereas a 0.5 m gap was maintained between the replication. The trials were conducted in non-stress (irrigated condition) and drought condition (inside rainout shelter) simultaneously. Total experimental field was 157.5 m^2.

Table 1. List of the genotypes used for the experiment.

S. No.	Genotypes	Source	Origin
1.	NL 1488	DoAR	CYMMIT
2.	NL 1444	DoAR	CYMMIT
3.	NL 1445	DoAR	CYMMIT
4.	NL 1446	DoAR	CYMMIT
5.	NL 1447	DoAR	CYMMIT
6.	GAUTAM (released)	DoAR	NWRP
7.	BHRIKUTI (released)	DoAR	NWRP
8.	NL 1451	DoAR	CYMMIT
9.	NL 1506	DoAR	CYMMIT
10.	NL 1415	DoAR	CYMMIT
11.	NL 1437	DoAR	CYMMIT
12.	KHAJURA DURUM 2	DoAR	NWRP
13.	BL 4951	DoAR	NWRP
14.	NL 1202	DoAR	CYMMIT
15.	NL 1345	DoAR	CYMMIT
16.	NL 1423	DoAR	CYMMIT
17.	NL 1349	DoAR	CYMMIT
18.	Banganga (released)	DoAR	NWRP

Land preparation

The soil was prepared for sowing by performing one round of disc harrowing followed by two crisscross ploughings using a rotavator (rotary tiller). Seeds of each genotype were treated with Vitavex @ of 2 gm/kg.

Fertilizer and irrigation

The fertilizer dose was applied at the rate of 60:30:30 kg N: P_2O_5: K_2O/ha for both stress and non- stress conditions at basal dose. Only a single pre-sowing irrigation was given to the soil of stress trial (rainout shelter) whereas Irrigation was provided on all important stages, that is, CRI stage, flowering stage and milking stage of the non- stress trial based on soil moisture conditions. Rainfall and all forms of precipitation was avoided with the use of an automatic rainout shelter during the stress testing because no irrigation was given after sowing until harvest. Pendimethalin 30% EC was applied at a rate of 2 ml per liter of water as a pre-emergence herbicide, 48 hours after sowing, to manage weed competition during the early stages of crop growth. Harvesting was done manually using traditional sickle. The center $1m^2$ area was marked and harvested separately. Harvested wheat plants were left and sun dried and threshed manually. Threshed grain was cleaned by winnowing action.

Data collection and analysis

Field data such as days to heading, days to maturity, Plant height, Spike length, Number of grain per spike, Harvest index, Grain yield and Thousand grain weight were recorded. All the data were collected from the $1m^2$ area of each plot except grain yield which was measured from the whole plot. The well-matured plants were harvested manually by sickle and left in the field to dry for two days followed by manual threshing. Grain yield ton $ha^{-1}$was measured at a 12% moisture level by using the formula. Several drought tolerance indices were computed based on a mathematical relationship between yield under drought stress and non-stressed conditions. Analysis of variance was done by using ADEL-R developed by CIMMYT, Mexico. The analysis of variance (ANOVA) test was conducted to see the significant difference between the genotypes and the least significant difference (LSD) was computed at a 5% level of significance. The correlation between the drought indices and yield during stress and non-stress was carried out by SPSS version 25. The data was analyzed.

Grain yield (ton/ ha) = [Plot yield (kg) × (100 − grain moisture content%) × 10, 000 (m^2) / (100 − 12) × net plot area (m^2)]

The stress tolerance indices were calculated by the following relationships:

Tolerance Index (TOL) = Yp – Ys (Ramirez-Vallejo & Kelly, 1998)

Stress Susceptibility Index (SSI) = $\frac{1-(\frac{Ys}{Yp})}{1-(\frac{\bar{Ys}}{\bar{Yp}})}$ (Hossain *et al.*, 1990)

Mean Productivity (MP) = $\frac{Y_s+Y_p}{2}$ (Bouslama & Schapaugh Jr, 1984)

Geometric Mean Productivity (GMP) = √(Yp × Ys) (Khan & Kabir, 2014)

Stress tolerance index (STI) = $\frac{Ys\times Yp}{(\bar{Y}_p)^2}$ (Khan & Kabir, 2014)

Yield stability index (YSI) = $\frac{Ys}{Yp}$ (Bouslama & Schapaugh Jr, 1984)

Where, Ys, Yp, $\bar{Y}_s$ and $\bar{Y}_p$ represent yield under stress, yield under non-stress for each genotype, yield mean in stress and non-stress conditions for all genotypes, respectively.

RESULTS AND DISCUSSION

The results obtained during research were analyzed and presented in the section with the help of table and figure wherever necessary. The results obtained are discussed with possible results and literature support.

Days to heading and days to maturity

The ANOVA showed a highly significant ($p<0.01$) difference between the genotypes for days to heading and days to maturity to the genotypes under irrigated as well as drought conditions. Similar result was obtained by (Bohara *et al.*, 2023). The genotypes NL 1444 headed earliest in 63 days followed by NL 1488, NL 1447 (67 days) and the genotypes NL 1445 and NL 1349 headed late (71 days) in irrigated condition. Similarly, the genotypes NL 1444 headed earliest in 63 days followed by NL1488 (64 days), NL 1447 (65 days) and the genotype NL 1445 has headed late (71 days) in drought conditions. In case of maturity, the genotype NL 1444 matured earliest in 93 days followed by NL 1447, Banganga (96 days) and the genotype NL 1445 matured late (102 days) in irrigated condition. Similarly, the genotype Banganga matured earliest in 95 days followed by NL 1202 (96 days), NL 1447 (97 days) and the genotype NL 1445 mature late (105 days) in drought condition (Table 2).

Plant height and spike length

The ANOVA showed a highly significant ($p<0.01$) difference between the genotypes for plant height and spike length to the genotypes under irrigated as well as drought conditions. The genotype khajura Durum 2 has a minimum plant height of 65.7 cm followed by NL 1446 (66.1 cm), NL 1345(69.1 cm) and the genotype NL 1444 has a maximum plant height of 85.4 cm in irrigated condition. Similarly, the genotype NL 1446 has a minimum plant height of 51.7 cm followed by Khajura Durum 2 (53.8 cm), NL 1437 (54.6 cm) and the genotype NL 1447 has a maximum plant height of 69.9 cm in drought conditions. In case of spike length, the genotype NL 1345 has a minimum spike length of 7.5 cm followed by Khajura Durum 2 (7.7 cm), NL 1444 (7.8 cm) and the genotype NL 1445 has a maximum spike length of 11.5 cm in irrigated condition. Similarly, the genotype Khajura Durum 2 has a minimum spike length of 4.9 cm followed by NL 1415 (5.5 cm), NL 1445 (5.8 cm) and the genotype NL 1447 has a maximum spike length of 8 cm in drought conditions (Table 2).

Table 2. Performance of wheat genotypes under stress and non-stress conditions.

S.N.	Genotype	DTH		DTM		SL		PH		GPS		GY		HI		TGW	
		Ir	Dr	Ir	Dr	Ir	Dr	Ir	Dr	Ir	Dr	Ir	Dr	Ir	Dr	Ir	Dr
1	NL 1488	67^{d}	64^{a}	97^{a}	97^{a}	10.3^{a}	42^{a}	67^{d}	64^{a}	97^{a}	97^{a}	3725^{a}	1243^{a}	0.45^{a}	0.41^{a}	44.47^{a}	50.53^{a}
2	NL 1444	63^{e}	63^{b}	93^{b}	97^{b}	7.8^{b}	36^{a}	63^{e}	63^{b}	93^{b}	97^{b}	3426^{a}	1442.33^{a}	0.43^{ab}	0.49^{ab}	34.16^{a}	40.51^{ab}
3	NL 1445	71^{a}	71^{b}	102^{b}	105^{bc}	11.5^{b}	41^{ab}	71^{a}	71^{b}	102^{b}	105^{bc}	3224.67^{a}	1159^{ab}	0.4^{abc}	0.34^{abc}	40.29^{ab}	43.73^{abc}
4	NL 1446	69^{b}	67^{c}	98^{b}	97^{bcd}	8.2^{bc}	40^{ab}	69^{b}	67^{c}	98^{b}	97^{bcd}	2896.67^{ab}	1338.33^{abc}	0.43^{abcd}	0.44^{abc}	39.45^{ab}	44.33^{abcd}
5	NL 1447	67^{d}	65^{c}	96^{b}	97^{bcde}	9.9^{cd}	41^{ab}	67^{d}	65^{c}	96^{b}	97^{bcde}	3550.33^{ab}	1547.33^{abc}	0.46^{abcd}	0.43^{abc}	38.74^{b}	46.03^{abcd}
6	GAUTAM	69^{bc--}	67^{c}	99^{bc}	98^{bcde}	10.7^{cd}	36^{ab}	69^{bc--}	67^{c}	99^{bc}	98^{bcde}	2946^{abc}	1059^{abc}	0.42^{abcd}	0.36^{abc}	40.78^{bc}	43.89^{abcd}
7	BHRIKUTI	69^{bc}	67^{c}	97^{bc}	97^{cdef}	10.7^{cd}	42^{ab}	69^{bc}	67^{c}	97^{bc}	97^{cdef}	2417.67^{abc}	1246^{abc}	0.44^{abcd}	0.42^{abc}	34.22^{bcd}	37.44^{abcde}
8	NL 1451	69^{b}	67^{c}	99^{bc}	101^{cdef}	8.1^{cd}	35^{abc}	69^{b}	67^{c}	99^{bc}	101^{cdef}	3098.67^{abc}	1328.33^{abc}	0.44^{abcd}	0.36^{bc}	35.49^{bcd}	35.52^{abcde}
9	NL 1506	69^{b}	68^{c}	97^{bcd}	98^{defg}	9.7^{cd}	41^{abc}	69^{b}	68^{c}	97^{bcd}	98^{defg}	2495^{abc}	1190.67^{abc}	0.45^{abcd}	0.41^{bc}	38.68^{bcd}	43.30^{abcde}
10	NL 1415	69^{b}	68^{c}	99^{bcd}	99^{efg}	8.3^{cd}	34^{abcd}	69^{b}	68^{c}	99^{bcd}	99^{efg}	2928^{abc}	1541.67^{abc}	0.44^{abcd}	0.43^{bc}	36.2^{bcd}	39.04^{bcde}
11	NL 1437	69^{bc}	68^{c}	99^{bcd}	100^{efg}	9.5^{d}	41^{abcd}	69^{bc}	68^{c}	99^{bcd}	100^{efg}	2934.33^{abc}	1153^{abc}	0.47^{abcd}	0.38^{bc}	38.16^{bcde}	42.99^{bcde}
12	KHAJURA DURUM 2	69^{b}	70^{c}	99^{cde}	101^{efg}	7.7^{e}	33^{bcd}	69^{b}	70^{c}	99^{cde}	101^{efg}	1720.67^{abc}	483.67^{abc}	0.41^{abcd}	0.37^{bc}	39.46^{bcde}	40.61^{bcde}
13	BL 4951	68^{c}	68^{c}	99de	97^{fg}	9.9^{ef}	33^{cd}	68^{c}	68^{c}	99de	97^{fg}	3183.67^{abc}	1222^{bc}	0.39^{abcd}	0.36^{bc}	39.7^{cde}	43.81^{bcdef}
14	NL 1202	67^{d}	65^{d}	98de	96^{fgh}	9.6^{ef}	40^{cd}	67^{d}	65^{d}	98de	96^{fgh}	2876.33^{bc}	1251.67^{bc}	0.44^{bcd}	0.41^{bc}	36.96^{de}	45.08^{bcdef}
15	NL 1345	67^{d}	67de	97de	99^{fgh}	7.5^{efg}	33^{d}	67^{d}	67de	97de	99^{fgh}	2521.67^{cd}	1349.33^{bc}	0.4^{cd}	0.39^{c}	35.41^{de}	40.07^{cdef}
16	NL 1423	67^{d}	68de	98^{e}	99^{fgh}	9.7^{fg}	41^{d}	67^{d}	68de	98^{e}	99^{fgh}	3454.67^{cd}	1177.67^{bc}	0.43^{cd}	0.39^{c}	40.84^{e}	44.39^{def}
17	NL 1349	71^{a}	70^{e}	99^{e}	99^{gh}	8.7^{fg}	31^{d}	71^{a}	70^{e}	99^{e}	99^{gh}	2632.33^{cd}	1085.67^{c}	0.39^{cd}	0.35^{c}	34.38^{e}	43.10^{ef}
18	BANGANGA	67^{d}	66^{f}	96^{f}	95^{h}	9.7^{g}	34^{d}	67^{d}	66^{f}	96^{f}	95^{h}	3693.67^{d}	1312.67^{d}	0.45^{d}	0.40^{c}	44.81^{e}	47.13^{s}
	Mean	68.111	67.074	97.889	98.37	9.298	37.389	68.111	67.074	97.889	98.37	2984.741	1229.52	0.43	0.396	38.456	42.862
	CV	0.537	1.09	0.97	1.27	4.743	9.99	0.537	1.09	0.97	1.27	18.036	17.57	8.381	13.112	6.356	9.658
	StdMSE	0.366	0.731	0.95	1.249	0.441	3.735	0.366	0.731	0.95	1.249	538.342	216.00	0.036	0.052	2.444	4.140
	LSD(5%)	0.607	1.214	1.576	2.073	0.732	6.198	0.607	1.214	1.576	2.073	893.282	358.41	0.06	0.086	4.056	6.869
	P-value	<0.001	<0.001	<0.001	<0.001	<0.001	0.0029	<0.001	<0.001	<0.001	<0.001	0.0068	0.0011	0.2257	0.1183	<0.001	0.0233

Note: Ir=Irrigated condition, Dr=Drought condition, DTH= Days to heading from sowing, DTM= Days to maturity from sowing, PH= Plant height in cm, GPS= Grain per spike, SL= Spike Length, HI= Harvest Index, GY= Grain Yield, TGW= Thousand Grain Weight.

Grains per spike and grain yield

The ANOVA showed significant (p<0.05) difference between the genotypes for grains per spike under irrigated condition which is in agreement with the findings of (Bohara *et al.*, 2023) while testing late sown wheat genotypes under high temperature stress conditions. While ANOVA showed no significant difference between the genotypes for grains per spike under drought conditions. The highest grains per spike was observed in the genotypes NL 1488 / Bhrikuti (42) followed by NL 1445/ NL 1447/ NL 1506/ NL1437/ NL 1423 (41) and NL 1446/ NL 1202 (40) under irrigated conditions. Similarly, the highest grains per spike was observed in the genotypes NL 1488 (29) followed by NL 1444/ NL 1451/ NL 1345/ NL (26) and NL 1447 (25) under drought conditions (Table 2). The ANOVA showed significant (p<0.05) difference between the genotypes for grain yield to the genotypes under irrigated as well as drought conditions. The genotype NL 1488 gave the highest grain yield of 3725 kg/ha followed by Banganga (3693.67 kg/ha), NL 1447 (3550.33 kg/ha), NL 1423 (3454.67 kg/ha) and NL 1444 (3426 kg/ha) under irrigated condition. Similarly, the genotype NL 1447 gave the highest grain yield of 1547.33 kg/ha followed by NL 1415 (1541.67 kg/ha), NL 1444 (1442.33 kg/ha), NL 1345 (1349.33 kg/ha) and NL 1446 (1338.33 kg/ha) under drought condition (Table 2).

Thousand grain weight and harvest index

ANOVA showed highly significant (p<0.01) difference between the genotypes for thousand grain weight (TGW) to the genotypes under irrigated condition which is in agreement with the findings of (Bohara *et al.*, 2023) while testing late sown wheat genotypes under high temperature stress conditions. ANOVA showed significant (p<0.05) difference between the genotypes for thousand grain weight (TGW) under drought conditions. Similar result was obtained by (Bohara *et al.*, 2023) while testing late sown wheat genotypes in drought stress environments.

The highest TGW was observed in the genotypes Banganga with 44.81 g followed by NL 1488 (44.47 g), NL 1423 (40.84 g), Gautam (40.78 g) and NL 1445 (40.29 g) in irrigated condition. Similarly, the highest TGW was observed in the genotypes NL 1488 with 50.53 g followed by Banganga (47.13 g), NL 1447 (46.03 g), NL 1202 (45.08 g) and NL 1423 (44.39 g) in drought condition. There was no significant difference between the genotypes for harvest index in both conditions (Table 2).

Drought tolerance indices

Drought tolerance indices were determined on the basis of the grain yield of the wheat genotypes under irrigated condition and drought condition. Many researchers had used stress tolerance indices of grain yield to identify stress tolerance genotypes (Poudel *et al.*, 2021; Puri *et al.*, 2015; Singh *et al.*, 2011). Drought stress has been found to reduce wheat grain yield by 58.8% compared to irrigated conditions. Similar results were obtained by (Bohara *et al.*, 2023; Poudel *et al.*, 2021). The greater value of TOL shown by NL 1488 (2482 kg/ha), Banganga (2381 kg/ha), NL 1423 (2277 kg/ha) and NL 1445 (2065.67 kg/ha) suggest that their grain yield is highly decreased by drought when compared to other genotypes, thus they are the most susceptible genotypes to drought among the tested genotypes. (Nouri *et al.*, 2011) suggested that a lower TOL value is preferable for selecting high-yielding genotypes under stress conditions. The genotypes NL 1345 and Bhrikuti exhibit low TOL values and high YSI values, indicating their drought tolerance. Additionally, their low SSI values of 0.82 and 0.79, respectively, suggest their ability to perform well in both favorable and drought conditions. The lower SSI value suggests higher yield stability. Similar results were reported by (Bohara *et al.*, 2023), genotypes having lower SSI have high drought- tolerant capacity.

Other drought indices like MP, GM and STI are used to identify the genotype that produces high yield under both stress and non-stress conditions. The highest value of MP, GMP, and STI was obtained in genotype NL 1447 followed by NL 1444, NL 1415, NL 1451 and NL1446. These genotypes are more productive under stress conditions compared to the other genotypes included in the study. Similar results were obtained by (Bohara *et al.*, 2023; Poudel *et al.*, 2021). The high value of STI implies that it shows an intensive tolerance to drought (Hooshmandi, 2019). Similarly, the high value of MP implies that it can perform

Table 3. Grain yield (kg/ha) of wheat genotypes under irrigated (Yp) and drought stress (Ys) conditions and stress tolerance indices.

Genotype	Yp	Ys	TOL	SSI	STI	MP	GMP	YSI
NL 1488	3725.00	1243.00	2482.00	1.13	0.52	2484.00	2151.78	0.33
NL 1444	3426.00	1442.33	1983.67	0.98	0.55	2434.17	2222.93	0.42
NL 1445	3224.67	1159.00	2065.67	1.09	0.42	2191.83	1933.23	0.36
NL 1446	2896.67	1338.33	1558.33	0.91	0.44	2117.50	1968.94	0.46
NL 1447	3550.33	1547.33	2003.00	0.96	0.62	2548.83	2343.83	0.44
GAUTAM	2946.00	1059.00	1887.00	1.09	0.35	2002.50	1766.30	0.36
BHRIKUTI	2417.67	1246.00	1171.67	0.82	0.34	1831.83	1735.63	0.52
NL 1451	3098.67	1328.33	1770.33	0.97	0.46	2213.50	2028.81	0.43
NL 1506	2495.00	1190.67	1304.33	0.89	0.33	1842.83	1723.58	0.48
NL 1415	2928.00	1541.67	1386.33	0.81	0.51	2234.83	2124.62	0.53
NL 1437	2934.33	1153.00	1781.33	1.03	0.38	2043.67	1839.37	0.39
KHAJURA DURUM 2	1720.67	483.67	1237.00	1.22	0.09	1102.17	912.27	0.28
BL 4951	3183.67	1222.00	1961.67	1.05	0.44	2202.83	1972.42	0.38
NL 1202	2876.33	1251.67	1624.67	0.96	0.40	2064.00	1897.42	0.44
NL 1345	2521.67	1349.33	1172.33	0.79	0.38	1935.50	1844.61	0.54
NL 1423	3454.67	1177.67	2277.00	1.12	0.46	2316.17	2017.04	0.34
NL 1349	2632.33	1085.67	1546.67	1.00	0.32	1859.00	1690.51	0.41
BANGANGA	3693.67	1312.67	2381.00	1.10	0.54	2503.17	2201.94	0.36
Mean	2984.74	1229.52	1755.22	1.00	0.42	2107.13	1909.73	0.41

Note: Yp = Grain yield of genotypes under normal condition, Ys = Grain yield of genotypes under drought stress condition, TOL= Tolerance index, YSI = Yield stability index, SSI = Stress susceptibility index, MP = Mean productivity, GMP = Geometric mean productivity, STI = Stress tolerance index.

Table 4. Correlation coefficient between grain yield (Yp and Ys) and drought stress tolerance indices.

	Yp	Ys	TOL	SSI	STI	MP	GMP	YSI
Yp	1							
Ys	0.6184**	1						
TOL	0.8962**	0.2056	1					
SSI	0.2004	-0.6343**	0.6077**	1				
STI	0.9002**	0.8786**	0.6250**	-0.1947	1			
MP	0.9634**	0.8065**	0.7444**	-0.0656	0.9771**	1		
GMP	0.8903**	0.9081**	0.5961**	-0.2600	0.9872**	0.9797**	1	
YSI	-.274	.490*	-.618**	-.898**	.064	-.040	.139	1

Note: **. Correlation is significant at the 0.01 level, *. Correlation is significant at the 0.05 level, Yp = Grain yield of genotypes under normal condition, Ys = Grain yield of genotypes under drought stress condition, TOL = Tolerance index, YSI = Yield stability index,SSI = Stress susceptibility index, MP = Mean productivity, GMP = Geometric mean productivity, STI = Stress tolerance index.

well under both conditions. Genotypes with high MP and STI values and low SSI values are considered tolerant to drought (Mohammadi *et al.*, 2008) (Table 3).

Correlation of drought indices

The most suitable criterion for drought stress tolerance was identified through Pearson's correlation analysis between Yp, Ys, and heat tolerance indices (Table 3). The best drought indices are those which have a high correlation with yield under both stress and non-stress conditions (Hooshmandi, 2019). The correlation results from the table indicate that yield under stress conditions (Ys) has a highly positive and significant correlation with Yp, MP, GMP and STI. In contrast, SSI showed a negative and significant correlation with (Ys). Similarly, non-stress condition (Yp) showed a positive significant association with TOL, MP, GMP and STI while Yp showed negative and non-significant correlation with YSI. Table shows positive and non-significant correlation of TOL with Ys while it shows negative and significant correlation of SSI with Ys. Similarly, there is a positive and significant correlation between YSI and Ys. This Suggests that the appropriate criterion for the selection of drought tolerant genotypes is higher value of YSI and lower values of SSI and TOL. A significant positive correlation was observed between the grain yield (Yp and Ys) of genotypes and the indices MP, GMP, and STI, suggesting their potential use as selection criteria for identifying superior genotypes adaptable to both stress and non-stress environments. Similar results were obtained by (Puri *et al.*, 2020; Poudel *et al.*, 2021; Bohara *et al.*, 2023)). Selection based on these indexes results in the identification of genotypes with high yield stability in both environments and can be introduced as the best evaluation indexes for stress tolerance in wheat (Table 4).

Conclusion

The findings of the study revealed that drought stress can reduce wheat grain yield by more than 58.8% compared to irrigated conditions. Under drought conditions, agronomic traits such as spike length, plant height, and the number of grains per spike were significantly reduced. A strong, positive, and significant correlation was observed between grain yield (under both irrigated and drought conditions) and the indices MP, GMP, and STI, indicating their suitability as selection criteria for identifying genotypes with superior performance in both environments. Among the genotypes evaluated under irrigated conditions, NL 1488 recorded the highest grain yield (3725 kg/ha), followed by Banganga (3693.67 kg/ha), NL 1447 (3550.33 kg/ha), NL 1423 (3454.67 kg/ha), and NL 1444 (3426 kg/ha). Under drought conditions, NL 1447 achieved the highest grain yield (1547.33 kg/ha), followed by NL 1415 (1541.67 kg/ha), NL 1444 (1442.33 kg/ha), NL 1345 (1349.33 kg/ha), and NL 1446 (1338.33 kg/ha). The highest MP, GMP, and STI values were observed in genotype NL 1447, followed by NL 1444, NL 1415, NL 1451, and NL 1446. These genotypes demonstrated strong yield potential under both irrigated and drought conditions, making them promising candidates for breeding programs aimed at enhancing drought resilience in wheat.

DECLARATIONS

Author contribution statement

Conceptualization: P.K.C. and S.B.; Methodology: S.B.; Software and validation: P.K.C., S.B. and B.U.; Formal analysis and investigation: P.K.C and B.U.; Resources: S.B.; Data curation: P.K.C. and B.U.; Writing—original draft preparation: P.K.C. and B.U.; Writing—review and editing: P.K.C. and S.B.; Visualization: P.K.C.; Supervision: S.B.; Project administration: S.B.; Funding acquisition: S.B. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest: The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Ethics approval: This study did not involve any animal or human participant and thus ethical approval was not applicable.

Consent for publication: All co-authors gave their consent to publish this paper in AAES.

Data availability: The data that support the findings of this study are available on request from the corresponding author.

Supplementary data: No supplementary data is available for this paper.

Funding statement: No external funding is available for this paper.

Additional information: No additional information is available for this paper.

ACKNOWLEDGEMENTS

We sincerely acknowledge the Directorate of Agriculture Research (DoAR), Khajura, Banke, Nepal, for providing the necessary research support and facilities to conduct this experiment. We also extend our gratitude to Agriculture and Forestry University (AFU) for incorporating the Learning for Entrepreneurial Experience (LEE) Program into the curriculum, offering valuable opportunities for engaging in research. Furthermore, we appreciate the contributions of the personnel from the Plant Breeding Research Unit at DoAR, Khajura, Banke, Nepal, for their support and efforts in ensuring the success of this research.

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