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Research Article

Evaluation of stress tolerant indices and yield of barley landraces under drought condition

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ABSTRACT

Barley landraces serve as important genetic resources for enhancing drought tolerance in crop development programs. This study aimed to assess drought tolerance genotype among fourteen barley landraces using CRD replicated thrice, under controlled poly-house conditions at College of Natural Resource Management (CNRM), Bardibas, Nepal. Plants were exposed to water-deficit stress (60 centibars for 7 days) at the crown root initiation, tillering, and grain filling stages, while controls were maintained under optimal moisture. Physiological traits (chlorophyll content, flowering and maturity duration) and yield components were recorded, and drought tolerance indices (STI, MP, GMP, SSI, TOL, YSI) were computed. Significant genotypic variation was observed for drought response. Landrace AFU 202501 exhibited moderate growth reduction (9.2%) and high chlorophyll retention (93.2% of control), indicating sustenance under water-deficit condition with stable yield. Saptari Local demonstrated early maturity with minimal yield reduction (TOL = 0.86; SSI = –0.068) as a drought-escape mechanism, whereas NGRC 6010 was highly sensitive with severe growth inhibition. Based on stress indices, AFU 202501 and Gaushala Local depicts high-yielding potentiality under both stress and non-stress conditions (STI > 1.3), while Saptari Local exhibited superior yield stability (YSI = 0.943). The finding suggests chlorophyll retention and phenological plasticity as reliable indicators of drought adaptation, and identify AFU 202501 and Saptari Local as promising parental lines for breeding drought-tolerant barley, warranting further validation under multi-environment field conditions.

Keywords: Barley landraces, drought tolerance, stress indices, chlorophyll retention, phenological adaptation, yield stability.

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INTRODUCTION

Global population growth and increasing food possess major challenges on sustainable crop production due to limited land and water resources (Foley *et al.*, 2011). Additionally, agriculture productivity and food security is more vulnerable because of degraded soil condition, extreme drought, flood, and temperature extremes, major impact of climate change,

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because of climate change (Lichtfouse *et al.*, 2009; Wezel *et al.*, 2014). Therefore, the United Nations' 2030 Agenda for Sustainable Development emphasizes the need to enhance crop resilience and maintain agrobiodiversity for sustainable food systems (FAO, 2018). Crop landraces and wild relatives are vital components of agrobiodiversity, providing unique alleles for stress tolerance and adaptation. Though Nepalese barley (*Hordeum vulgare* L.) landraces exhibit high morphological and genetic diversity (Pandey *et al.*, 2006; Sharma *et al.*, 2013), these resources are rapidly extinction due to the adoption of modern cultivars and loss of traditional ecological knowledge. Despite being marginalized or underutilised crops in Nepal, Barley poses high nutritional value due to its β-glucan content which is beneficial for human health (Zhao *et al.*, 2003). It is typically cultivated under rainfed, low-input conditions and is frequently exposed to water deficits during the winter growing season. Therefore, yield reduction due to drought stress is major challenges reducing up to 80% in yield primarily through impaired photosynthesis and reduced reproductive success (Ahuja *et al.*, 2010). Study shows modern barley cultivars with a narrow genetic base and limited drought tolerant ability (Zhao *et al.*, 2010) while local and wild barley populations displaying wide ecological adaptability (Nevo & Chen, 2010). Identification of drought tolerant landraces and quantification of physiological and agronomic responses of those landraces is essential for developing drought resilient varieties, therefore this study aimed to evaluate the drought tolerant ability of barley landraces from Nepal using physiological traits, yield performance, and stress tolerance indices under controlled water-deficit conditions to identify promising genetic resources for future breeding programs.

MATERIALS AND METHODS

Experiment site: The experiment was conducted under polyhouse conditions at College of Natural Resource Management (CNRM), Bardibas in controlled environment Polyhouse where rainfall were maintained consistently to minimize external variability.

Plant materials: Fourteen (*Hordeum vulgare* L.) genotypes were initially used to assess drought tolerance (Table 1), but only eight landraces completed a full growth cycle to harvest. The landraces included both local cultivars (e.g., Saptari Local, Gaushala Local) and germplasm from the Gene Bank of Nepal and HCRP Dolakha.

Experimental design and treatment details: The experiment was laid out in a two-factorial completely randomized design (CRD) with two factors: barley genotype and drought treatment. Each genotype was grown in three individual 5 L pots containing a sand-soil-FYM mixture in a 1:1:1 ratio. Drought stress was imposed at three critical growth stages: crown root initiation (CRI), tillering, and grain filling. Stress was maintained for seven days when the tensiometer readings reached 60 centibars. Well-irrigated plants served as the control.
Cultural practices: Standard polyhouse management practices were followed, including pot preparation, sowing, and routine maintenance to ensure uniform growth. Fertilizer, pest, and disease management were applied uniformly across all treatments.

Data collection: During the experiment, the following observations were recorded:

Morphological and physiological traits: shoot fresh and dry weights, chlorophyll content (SPAD-502 Plus, Konica Minolta, Japan) of oldest and youngest fully expanded leaves, days to flowering, and days to maturity.

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Yield and yield components: grain yield, spike characteristics, and other relevant parameters at harvest.

Stress tolerance indices: values were used to calculate STI, MP, GMP, SSI, TOL, YSI, and modified STI according to standard formulas (Fischer & Maurer, 1978; Rosielle & Hamblin, 1981; Fernandez, 1992;

1. Stress Tolerance Index (STI) – Fischer and Maurer (1978)

Formula:

$STI=(Yp\times Ys)/(\bar{Yp})^2$ ………………eq.(1)

Where:

Yp = Yield under non-stress (control) conditions

Ys= Yield under stress conditions

$\bar{Yp}$= Mean yield of all genotypes under non-stress conditions

2. Mean Productivity (MP) – Rosielle and Hamblin (1981)

Formula:

$MP=(Yp+Ys)/2$ ……………………………..eq. (2)

3. Geometric Mean Productivity (GMP) – Fernandez (1992)

Formula:

$GMP=Yp\times Ys$ ……………………………eq. (3)

4. Stress Susceptibility Index (SSI) – Fischer and Maurer (1978)

Formula:

$SSI=1-(Ys/Yp)$ ……………………………eq. (4)

Where: SI (Stress Intensity) = $\frac{1-(Ys/Yp)}{1-(\bar{Ys}/\bar{Yp})}$

5. Tolerance Index (TOL) – Rosielle and Hamblin (1981)

$TOL=Yp-Ys$ ………………………………………eq. (5)

6. Yield Stability Index (YSI) – Bouslama and Schapaugh (1984)

Formula:

$YSI=Ys/Yp$ ……………………………………………eq. (6)

7. Modified Stress Tolerance Index (STI) – Moosavi *et al.*, (2008)

Formula:

$STI=(Yp\times Ys)/(\bar{Ys})$ ……………………………………eq. (7)

8. Harmonic Mean (HM)- Schneider *et al.* (1997)

Formula:

$HM=\frac{2(Yp X Ys)}{Yp+Ys}$ ……………………………………..eq. (8)

9. Drought Index (DI)- Fischer and Maurer (1978)

Formula:

$DI=1-(\frac{Ys}{Yp})$ ……………………………………….eq. (9)

10. Relative Drought Index (RDI)- Fischer and Maurer (1978)

Formula:

$RDI=\frac{Ys}{Yp}/(\frac{\bar{Ys}}{\bar{Yp}})$ ………………………………………………eq. (10)

11. Stress Susceptibility Percentage Index- Moosavi *et al.*, (2008)

Formula:

$SSPI=\frac{(Yp-Ys)x100}{2\bar{Yp}}$ ………………………………………eq. (11)

12. Yield Index (YI)- Gavuzzi, P., *et al.* (1997)

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Formula

YI=$Ys/\bar{Y}s$)………………………………………….. eq. (12)

Table 1: List of landraces and genotypes used in experiment 2025

S.N.	Landraces	Source
1	Saptari Local	Saptari Framer
2	AFU 202501	Nearby Mahottari border
3	NGRCO 7576	Gene Bank, Nepal
4	NGRCO 6004	Gene Bank, Nepal
5	NGRC 7730	Gene Bank, Nepal
6	NGRC 7724	Gene Bank, Nepal
7	NGRC 7581	Gene Bank, Nepal
8	NGRC 7571	Gene Bank, Nepal
9	NGRC 6010	Gene Bank, Nepal
10	NGRC6002	Gene Bank, Nepal
11	NGRC 5999	Gene Bank, Nepal
12	Muktinath	HCRP, Dolakha
13	Gaushala Local	Mahottari farmers
14	Bonus	HCRP, Dolakha

Data analysis and interpretation

The data was entered in excel 2007 and interpreted in MS word 2007. The data was analyzed with Gen-stat version 2015 and DMRT for the mean separation.

RESULTS

Phenological Responses

Barley genotypes exhibited significant variation in flowering and maturity under both control and drought conditions. Days to flowering ranged from 74.5 (Saptari Local) to 101.5 days (NGRC 5999) under optimal conditions. Drought stress accelerated flowering by 5–22%, with AFU 202501 showing minimal reduction (9.2%) and NGRC 6010 exhibiting the highest reduction (22%), reflecting differences in genotypic drought adaptation. Days to maturity varied from 105.7 to 122.5 days, with drought advancing maturity by an average of 7.1%. Saptari Local matured earliest, demonstrating a drought-escape strategy, whereas NGRC 5999 showed the greatest delay under stress. These results indicate marked phenological plasticity among landraces, supporting their potential role in breeding for terminal drought environments (Table 2).

Physiological Responses

Drought stress significantly affected chlorophyll content, measured as SPAD values. At 79 DAS, SPAD values ranged from 52.39 to 66.45 units, decreasing further by 86 DAS (45.6–64.9 units), indicating cumulative stress impact on photosynthetic machinery. Genotypes differed in maintaining photosynthetic capacity under stress: AFU 202501 retained 93.2% of control SPAD values, Saptari Local 88.4%, while NGRC 6010 showed only 72.3% retention. These trends correlate with growth reduction and yield stability, suggesting that chlorophyll maintenance is a key physiological trait for drought tolerance (Table 2).

Stress Tolerance Indices and Yield Performance

Significant variation ($p < 0.001$) was observed among genotypes for all stress tolerance indices (STI, SSI, TOL, YSI, GMP, MP, HM) and yield components (Tables 3–4).

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Table 2: Phenological and Physiological characters of barley landraces under different water regimes in 2025

Condition (A)	DF(days)	DM (days)	SPAD 79 DAS (Chl)	SPAD@ 86 DAS (Chl)
Normal	100.3^{a}	118.4 ^{a}	61.59 ^{a}	61.1+
Drought	84.3^{b}	110 ^{b}	56.88 ^{b}	50.6^{b}
SEM(±)	2.07	0.74	1.013	1.77
LSD(0.05)	1.03***	2.23***	3.036***	5.32**
Genotypes (B)				
Gausala Local	77 ^{c}	107.2^{d}	65.69^{a}	62.7^{ab}
Muktinath	95.7 ^{ab}	116.7^{bc}	58.3^{bc}	58.1 ^{ab}
AFU 202501	91.5 ^{b}	109.2^{d}	60.62^{ab}	64.9^{a}
NGRC 5999	101.5^{a}	122.5^{a}	54.91^{bc}	52.3^{bc}
NGRC 6002	101^{a}	121^{ab}	55.17^{bc}	52.9^{bc}
NGRC 6010	100^{a}	115.5^{c}	52.39^{c}	45.6^{c}
NGRCO 7576	97.5^{ab}	115.7^{c}	60.35^{ab}	55.1^{abc}
Saptari Local	74.5^{c}	105.7^{d}	66.45^{a}	55.4^{abc}
SEM(±)	6.22	1.49	2.025	3.55
LSD(0.05)	3.11***	4.47***	6.071***	10.64***
AXB	Ns	Ns	Ns	Ns
CV(%)	4.5	2.6	6.8	12.7
Grand mean	92.3	114.2	59.23	55.9

level of significance at 5%, ** level of significance at 1%, * level of significance at 0.1%,* mean value sharing same letter represent are not statistically different, *df-days of flowering, dm-days of maturity*

AFU 202501 exhibited the highest STI (1.782) and GMP (25.07), reflecting strong performance under both stress and non-stress conditions. Saptari Local displayed the lowest SSI (-0.068) and highest YSI (0.943), highlighting its drought avoidance via early maturity and compact growth. Conversely, sensitive genotypes like Muktinath and NGRC 6010 showed low STI and YSI, coupled with severe yield reductions (TOL: 14.58–14.58) and high SSPI values, confirming vulnerability under water deficit.

Table 3: Stress tolerance index of different landrace of barley under different drought stress in Bardibas in 2025

Genotypes	DI	GMP	HM	MP	RDI	SDI
Gausala Local	0.784 ^{b}	22.12 ^{a}	20.78 ^{a}	23.57 ^{a}	0.916 ^{c}	0.504 ^{b}
Muktinath	0.092 ^{c}	8.87 ^{de}	6.86 ^{de}	11.49 ^{cd}	0.413 ^{d}	0.776 ^{a}
AFU 202501	1.567 ^{a}	25.36 ^{a}	25.07 ^{a}	25.65 ^{a}	1.365 ^{b}	0.260 ^{c}
NGRC 5999	0.600 ^{bc}	14.31 ^{bc}	13.75 ^{bc}	14.90 ^{bc}	1.051 ^{c}	0.430 ^{b}
NGRC 6002	0.082 ^{c}	5.55 ^{e}	4.59 ^{e}	6.70 ^{e}	0.518 ^{d}	0.719 ^{a}
NGRC 6010	0.119 ^{c}	6.85 ^{de}	5.84 ^{de}	8.04 ^{de}	0.577 ^{d}	0.687 ^{a}
NGRCO 7576	0.392 ^{bc}	10.35 ^{cd}	9.85 ^{cd}	10.89 ^{d}	0.975 ^{c}	0.472 ^{b}
Saptari Local	1.434 ^{a}	15.97 ^{b}	15.96 ^{b}	15.99 ^{b}	1.739 ^{a}	0.057 ^{d}
SEM(±)	**0.152**	**1.310**	**1.457**	**1.150**	**0.084**	**0.045**
LSD(0.05)	0.497***	4.27***	4.751***	3.750***	0.276***	0.149***
CV (%)	34.1	13.6	16	11.1	12.7	13.3
Grand mean	0.634	13.67	12.84	14.65	0.944	0.488

*level of significance at 5%, ** level of significance at 1%, *** level of significance at 0.1%, Ns-Non significant, mean value sharing same letter represent are not statistically different, DI-Drought index, GMP-Geometric Mean Productivity, HM-Harmonic Mean, MP-Mean Productivity, RDI- Relative Drought Index, SDI-Stress Susceptibility Index

Under optimal conditions, Gaushala Local and AFU 202501 achieved the highest yields (31.45 and 29.48), while under drought, AFU 202501 (21.81) and Saptari Local (15.55) maintained superior performance.

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These findings demonstrate substantial genetic variability in phenology, physiological traits, and stress indices among barley landraces.

Table 4: Stress tolerance index of different landrace of barley under different drought stress in Bardibas in 2025

Genotypes	SSI	SSPI	STI	TOL	YI	YSI	Yp	Ys
Gausala Local	-0.596 c	41.45 a	1.375 a	15.75 a	1.523 b	0.496 c	31.45a	15.69b
Muktinath	-0.919 d	38.36 a	0.218 c	14.58 a	0.408 d	0.224 d	18.78bc	4.20d
AFU 202501	-0.308 b	20.17 b	1.782 a	7.67 b	2.118 a	0.740 b	29.48ab	21.81a
NGRC 5999	-0.509 c	21.58 b	0.567 bc	8.20 b	1.048 bc	0.570 c	19b	10.8c
NGRC 6002	-0.851 d	19.73 b	0.086 c	7.50 b	0.286 d	0.281 d	10.45d	2.95d
NGRC 6010	-0.814 d	22.06 b	0.132 c	8.38 b	0.374 d	0.313 d	12.23cd	3.85d
NGRCO 7576	-0.558 c	17.55 b	0.300 bc	6.67 b	0.733 cd	0.528 c	14.22c	7.55c
Saptari Local	-0.068 a	2.26 c	0.718 b	0.86 c	1.510 b	0.943 a	16.41c	15.55b
SEM(±)	0.0544	2.594	0.138	0.986	0.148	0.0459	0.882	1.534
LSD(0.05)	0.17***	8.461*88	0.4 ***	3.216***	0.48***	0.14***	2.87***	5.0***
CV (%)	13.3	16	30.2	16	21.1	12.7	6.6	21.1
Grand mean	-0.578	22.90	0.647	8.70	1	0.512	19	10.3

level of significance at 5%, ** level of significance at 1%, * level of significance at 0.1%, Ns-Non significant, mean value sharing same letter represent are not statistically different, SSI-Stress Susceptibility Index, SSPI-Stress Susceptibility Percentage Index, STI-Stress Tolerance Index, TOL- Tolerance Index, YI-Yield Index, YSI- Yield Stability Index, Yp-Yield at normal condition, Ys-Yield at stress condition*

DISCUSSION

This study presents the possibility of Nepalese barley landraces to combat drought stress displaying its genetic potentiality in breeding programs. The differential responses in flowering and maturity among genotypes demonstrate contrasting drought-adaptation strategies among several physiological and phenological strategies. For example, Saptari Local exhibited early flowering and minimal phenological shift, presenting a drought-escape mechanism, while NGRC 5999 displayed greater flexibility in maturity, indicating stress tolerance ability but at the potential cost of yield. These patterns align with previous reports on xerophytic barley landraces which shows the importance of phenological plasticity against terminal drought environments (Ludlow, 1989; Tavakkoli *et al.*, 2011; Turner *et al.*, 2014).

Physiological responses varied significantly among genotypes especially for chlorophyll retention ability. Among the genotypes, AFU 202501 maintained 93% of its chlorophyll under drought, whereas NGRC 6010 retained only 72%, indicating that photoprotective mechanisms and antioxidant capacity likely contribute to stress resilience (Zivcak *et al.*, 2014; Flexas *et al.*, 2016).

Genotype performance was further clarified through stress tolerance indices. AFU 202501 and Gausala Local exhibited high STI and GMP values, combining strong yield potential under both optimal and stressed conditions. Saptari Local showed the highest YSI and lowest SSI, confirming its ability to maintain yield under drought through early maturity and compact growth. However, Muktinath and NGRC 6010 showed severe yield reductions and poor stress-index performance, thereby highlighting the range of adaptive responses within the landraces. Thus, the findings emphasize the importance of integrating physiological and phenological traits with stress indices while selecting drought-resilient genotypes. Among the used genotypes and landraces, AFU 202501 and Saptari Local emerge as promising candidates for

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breeding programs targeting water-limited environments, particularly those prone to intermittent drought.

CONCLUSION

This study identifies AFU 202501 as the most promising barley genotype, combining high yield potential with moderate drought tolerance, while Saptari Local demonstrates strong drought-resistance traits, making it a valuable source of genes for breeding programs. Key physiological and phenological traits such as chlorophyll retention and early maturity can contribute to their superior performance under water-limited conditions.
Future research should:

- Investigate the physiological and molecular basis of drought tolerance in these genotypes.
- Validate performance under multi-location field conditions to ensure adaptability.
- Incorporate molecular markers associated with drought-related traits for marker-assisted breeding.
- Develop genotype-specific breeding strategies targeting drought-prone environments.

Overall, the identified landraces offer critical genetic resources for developing climate-resilient barley varieties, providing practical guidance for breeding programs aimed at sustaining productivity in water-limited regions.

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Authors' Contributions

All authors equally contributed to conduct the research and write the paper.

Conflict of Interest

The authors of the paper declare that there is no conflict of interest for the publication of this manuscript. This paper is the extended form of abstract published in 3rd International Online Conference on Agriculture by MDPI.

Ethics Approval Statement

This field-based study did not involve humans or animals. Experimental activities were carried out with prior approval from relevant authorities and in accordance with environmental and biosafety guidelines.

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