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Drought Induced Impact on Growth and Yield of Wheat and Mustard: A Comparative Study

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ABSTRACT

Background: Drought stress poses a significant threat to global crop productivity and quality, with climate variability exacerbating its intensity in recent decades. This susceptibility underscores the urgent need to address the impact of water scarcity on agricultural systems.

Methods: Study was carried out to investigate the effects of drought on mustard (TS 67) and wheat (HD 3086) cultivars popularly grown in north eastern part of India. Drought was imposed at three distinct stages of crop growth (vegetative, flowering and pod filing) for 15 days to study the variability in response mechanisms if any.

Result: Drought significantly ($p \leq 0.05$) reduced plant height and leaf number in both the crops. It had a significant ($p \leq 0.05$) inhibitory impact on leaf chlorophyll content in the tested wheat and mustard cultivars. Drought lowers the rate of photosynthesis and this decline was more distinct when stress was applied during flowering stage of both the crops. Plant height stress tolerance index (PHSI) and dry matter stress tolerance index (DMSI) values indicated mustard (TS 67) as more tolerant crop to the imposed drought compared to wheat (HD 3086).

Key words: Chlorophyll, DMSI, Photosynthetic rate, PHSI, Proline.

INTRODUCTION

Climate variability in the recent decades is increasing the intensity of drought stress (Masroor *et al*., 2020). It is reported that, crop yield is highly susceptible to water deficit stress compared to other abiotic factors (Sánchez-Rodríguez *et al*., 2010). Decline in food quality and productivity under water deficit condition poses a serious threat to agriculture (IPCC, 2014). About 16% of India's land area are drought prone due to arid, semi-arid and sub-humid climate (GoI, 2013). According to Cattivelli *et al*. (2008), approximately 68% of India's agricultural land (140 million hectare) is vulnerable to drought. Water is a critical factor for plant's various metabolic and photosynthesis activities (Tun Oo *et al*., 2020). Therefore, minimizing agricultural losses due to drought has become a major challenge under the present changing climate (Anjum *et al*., 2011a). Plants employed different tolerance mechanisms to resist water deficit (Dey *et al*., 2022). Crop plants with higher drought tolerance shorten their life cycle to complete reproduction phase before extreme drought occurs (Pamungkas *et al*., 2022). Drought avoidance is executed in crops by reducing water loss, leaf area, light absorption *etc*. While drought tolerance takes place through cooperation of biochemical and physiological alteration at cellular and molecular levels (Hossain *et al*., 2020, Khanna, 2022). In response to drought stress crop synthesises antioxidants, proline, secondary metabolites and hormones etc. and alters physiological processes such as stomatal conductance, transpiration, photosynthesis, osmotic regulation, water transmission and leaf water content (Bangar *et al.,* 2019; Saini, 2021). There are extensive effects of water stress on plant physiology, especially on photosynthetic capacity. Long-term stress severely diminishes plant growth and productivity. Impact of drought varies depending on crop species, developmental stage and the growth environment (Nezhadahmadi *et al*., 2013). Frequency and duration of drought determines the intensity of impacts on crop seed germination, seedling establishment, flowering and grain maturation (Anjum *et al*., 2017). Several studies have investigated the impact of drought stress on wheat, rice, soybean and mustard (Kulczycki *et al*., 2022). Growth period is considered as the most crucial for managing drought stress in plant (Çakir, 2004). Crop varieties with higher capacity to synthesize proline, soluble sugar, antioxidants and free radicle scavenging activities can combat drought stress and pose superior potential to

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maintain yield and food security in water deficit lands (Basu *et al*., 2016).

Wheat (*Triticum aestivum* L.) and mustard (*Brassica juncea* L.) are two most important cereal and oilseed crop of India having economic and social value. According to FAO (2019), drought affected about 65 million ha of wheat producing land worldwide in the year 2013. Similarly, Srivastava *et al*. (2021) reported heavy loss of Indian mustard yield (17-94%) under drought stress. Screening of drought tolerant crop variety is a promising strategy to improve crop yield under water deficit condition. Therefore, the objective of this work was to study the impact of water deficit stress on wheat (*Triticum aestivum* L.) and mustard (*Brassica juncea* L.) at their different growth stages and to examine their stress tolerant traits.

MATERIALS AND METHODS

Site description and seed collection

The experimental station/polyhouse of Tezpur University, Assam, India is located at the north bank of the river Brahmaputra (Fig 1). The site experiences subtropical monsoons, which produce warm and humid summers and dry winters. Popular cultivars of wheat (HD 3086) and mustard (TS 67) of the region were screened through a survey conducted with the farmers of different agro-climatic zones of Assam with the help of Krishi Vigyan Kendra's of the state. Precipitations and temperature variabilities during the experimentation period were collected from National Aeronautics and Space Administration (NASA) website and presented in Fig 2. Observed soil physio-chemical characteristics of the experimental field is presented in Table 1.

Experimental design

Factorial randomized block designs (RBD) with three replications were used for the experiment. A total of 24 plots (1.5 m × 1.5 m) were prepared keeping a gap of 0.5 m between the plots. Wheat (*Triticum aestivum* L.) seeds were shown on 8th December, 2021 maintaining a spacing of 30 cm. Mustards (*Brassica juncea* L.) seeds (20g) were sown on the plots on 20th November 2021. After sprouting, thinning was performed to maintain a spacing of 12 cm between the seedlings. The crops were grown till maturity. In our experimental field, high water use efficiency is achieved through drip irrigation. The crops need average around 370 mm of water to complete its life cycle. Irrigation was withdrawn for 15 consecutive days at vegetative (T_1), flowering (T_2) and seed filling (T_3) phase of the crops life cycle to create drought condition. One set of plots were kept with normal irrigation throughout the growing period to represent control (T_0). Morphological, physiological and biochemical parameters of both the crops were recorded after each treatment (T_1, T_2, T_3).

Morphological parameters

Plant height stress tolerance index (PHSI) and leaf area index (LAI) were calculated using the formulas given by Nawaz *et al*. (2013) and Moosavi (2012), respectively.

Plant height stress tolerance index (PHSI) =

$$\frac{\text{Height of stressed plant}}{\text{Height of control plant}} \times 100$$

$$\text{Leaf area index (LAI)} = \frac{\text{Total leaf area/plant}}{\text{Ground surface area/plant}}$$

Dry matter stress tolerance index (DMSI) was calculated according to the formula described by Nawaz *et al*. (2013) as follows:

Dry matter stress tolerance index (DMSI) =

$$\frac{\text{Dry biomass of stressed plant}}{\text{Dry biomass of control plant}} \times 100$$

Physiological parameters

Photosynthesis rate (P_N) was recorded using an infrared gas analyser (LI-6400 portable photosynthesis system, Li-Cor, Lincoln, USA) under ambient environmental condition. Relative leaf water content (RLWC) was measured by the method described by Lin and Ehleringer (1982). The formula for calculating RLWC is:

Relative leaf water content (RLWC) =

$$\frac{\text{Leaf fresh weight - Leaf dry weight}}{\text{Leaf turgid weight - Leaf dry weight}} \times 100$$

Biochemical parameters

Leaf total chlorophyll was extracted with 80% acetone following the method of Anderson and Boardman (1964). The total chlorophyll content was calculated following the equation:

Total chlorophyll (mg g^{-1} FW) =

$$20.2\,(A_{645}) + 8.02\,(A_{663}) \times \frac{V}{1000 \times W}$$

Where,

FW= Fresh weight.

A_{645} and A_{663}= Absorbance of extract at 645 and 663, respectively.

Chlorophyll stability index (CSI) was calculated to measure the integrity of chlorophyll pigments under drought condition with the formula given by Sairam *et al*. (1997).

Chlorophyll stability index (CSI) =

$$\frac{\text{Total chlorophyll in stressed treatment}}{\text{Total chlorophyll in control}} \times 100$$

Proline content in the leaves were determined according to the method of Bates *et al*. (1973). The following equation was used for calculating the leaves proline content.

Proline (μ mol g^{-1} FW) =

$$\frac{\mu\text{g proline ml}^{-1} \times \text{ml toluene}}{115.13} \times \frac{5}{\text{Sample weight (g)}}$$

Here, FW is fresh weight, 115.13 is molecular weight of proline.

Yield indices

The harvest index (HI) of the crop was calculated following the formula given by Gholinezhad *et al*. (2009).

$$\text{Harvest index (HI)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

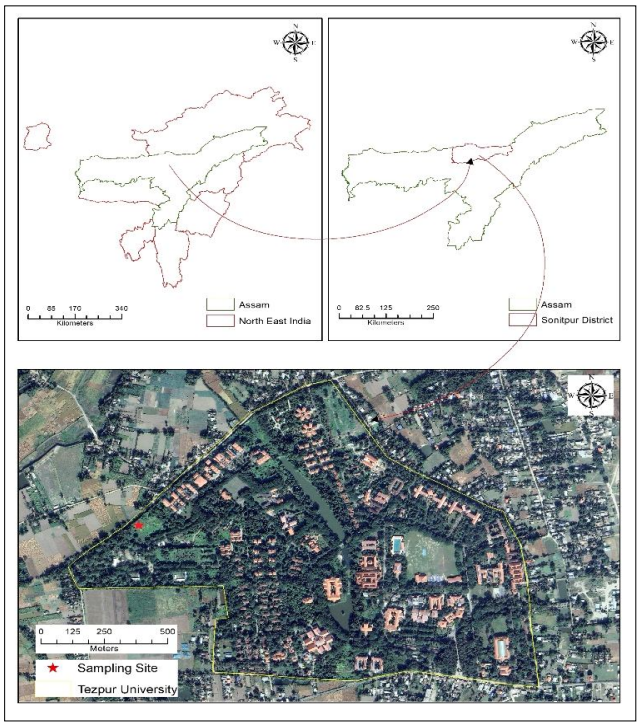

Fig 1: Location of experimental site at Tezpur University campus, Assam, India.

Statistical analysis

All the data obtained were subjected to one-way analysis of variance (ANOVA). SPSS 16.0 statistical package was used to perform the analysis of data. Mean comparison among the treatments were performed by least significant difference (LSD) test and Duncan's multiple range test (DMRT) at $p \leq 0.05$.

RESULTS AND DISCUSSION

Plant height declined significantly under drought at different growth stages of both the crops (Table 2). Reduction in plant height was maximum in vegetative growth phase (T_1) compared to flowering (T_2) and seed filling (T_3) of both the crops. Highest reduction was observed in wheat (27.3%) compared to mustard (23.39%) due to drought at vegetative stage (T_1). While least reduction of the same was recorded when drought appeared at seed filling stage (T_3 treatment) of mustard crop (1.8%) compared to wheat (5.1%). Likewise, lower plant height stress tolerance index (PHSI) was noted under drought at vegetative stage (T_1 treatment) with the least value in wheat crop (72.7%) followed by mustard (76.6%) (Fig 3). Whereas, highest PHSI (96.07%) in mustard was noted under the treatment T_3 (water withdrawal at seed filling stage) compared to wheat (94.9%) under the same treatment. Irrespective of the crops, the recorded PHSI was in the order: seed filling (T_3 treatment) > flowering (T_2 treatment) > vegetative (T_1 treatment).

Drought reduced leaf number in both the crops (Table 2). Highest reduction in leaf number was recorded at seed filling stage (T_3 treatment) of wheat (17.3%) and mustard (18.4%) respectively. However, the lowest reduction was observed at vegetative stage (T_1 treatment) in mustard (28.1%) and wheat (22.7%). Drought induced reduction in leaf number was higher in mustard crop compared to wheat (Fig 4). We observed a decrease in leaf area index (LAI)

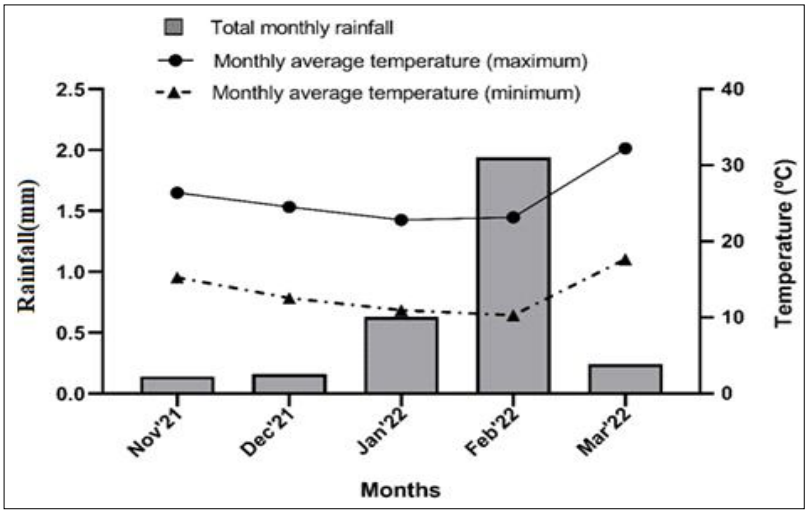

Fig 2: Meteorological parameters during the experimental period.

Table 1: Soil physiochemical characteristics of experimental field.

Parameters	Soil depth (cm)	Primary soil
pH	0-15	6.10±0.06
	15-30	5.53±0.04
EC (μS cm^{-1})	0-15	5.1±0.08
	15-30	4.9±0.08
WHC (%)	0-15	44.3±1.32
	15-30	42.7±1.64
SOC (%)	0-15	0.50±0.01
	15-30	0.48±0.02
Available N (mg kg^{-1})	0-15	39.17±0.82
	15-30	33.54±1.23
Available P (mg kg^{-1})	0-15	28.31±1.51
	15-30	42.62±1.26
Available K (mg kg^{-1})	0-15	201.3±3.28
	15-30	184.7±4.13

Data are mean ± S.D. (n=3). EC: Electrical conductivity; WHC: Water holding capacity; SOC: Soil organic carbon; N: Nitrogen; P: Phosphorus; K: Potassium.

when plants were grown under water deficit conditions. Maximum reduction in LAI was noted under drought at vegetative stage (T_1) of both mustard (55.8%) and wheat plants (39.1%). Least decline in LAI was found due to drought at flowering stage (T_3) (17.1%) in wheat and seed filling stage of mustard crop (50.1%). Total dry biomass of the plants reduced under water deficit condition (Table 2). In wheat, the dry biomass decreased by 2.94%, 14.91% and 4.30% at the vegetative, flowering and grain-filling stages. In mustard, this was 15.91%, 22.81% and 21.88%, respectively, for vegetative, flowering and grain filling. The most sensitive stage was the flowering stage in our study.

Total dry biomass of the plants reduced under water deficit condition (Table 2). Maximum inhibition in total biomass production was observed in wheat due to drought at flowering stage (22.8%) followed by seed filling (21.9%) and vegetative phase (15.9%). In case of mustard, the total biomass reduction was in the order: flowering phase (14.9%)> seed filling phase (4.3%)> vegetative phase (3.4%). Contrast to shoot biomass of the plants root

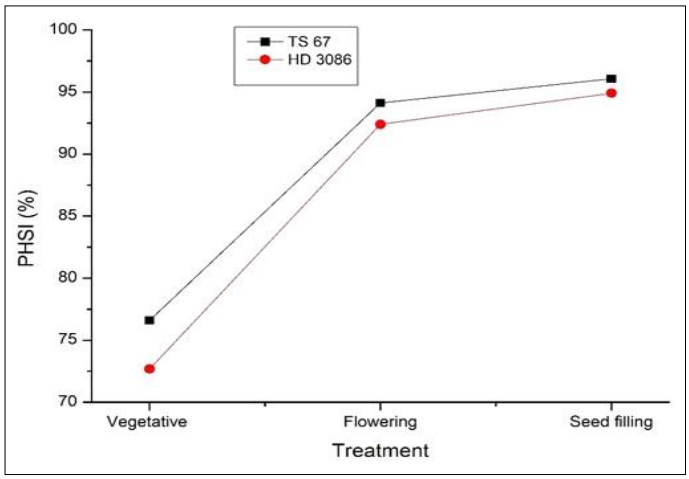

Fig 3: Plant height stress tolerance index (PHSI) under both stress and control conditions.

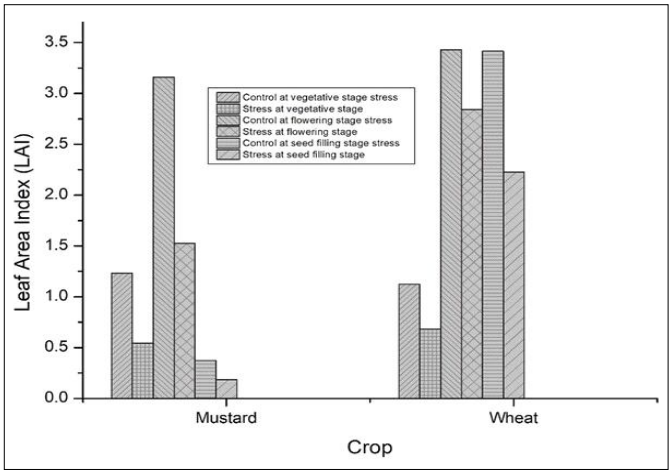

Fig 4: Leaf area index (LAI) under both stress and control condition.

biomass showed an increasing trend under water deficit environment (Table 2). Irrespective of the treatments, higher increment of root biomass was observed in wheat crop than mustard.

This improvement in root biomass was more due to drought at vegetative phase (57.1% and 33.3%) followed by flowering (38.5% and 27.8%) and seed filling phase (19.5% and 14.3%) in mustard and wheat respectively. Dry matter stress tolerance index (DMSI) was significantly higher in mustard crop (85.9-96.5%) compared to wheat (77.2 - 84.1%) (Fig 5).

Application of drought for fifteen consecutive days at three different growth stages significantly declined photosynthesis rate (P_N) of both the crops (Fig 6). This reduction was more distinct when stress was applied during flowering stage. At this stage, 22.12 % and 25.4% reduction were found for both wheat and mustard crop respectively. Grain filling stage was least affected with regard to photosynthesis ability where 13% and 15.4% reduction were observed for wheat and mustard respectively.

In both wheat and mustard, drought applied for fifteen consecutive days significantly reduced leaf water content. The reduction was more pronounced during the vegetative stages of both the crops specially in wheat. Maximum inhibition in total biomass production was observed at vegetative (29.6%) followed by flowering (26.24%) and seed filling phase (21.36%) in mustard crop (Fig 7).

From our experiment we found that drought had a significant inhibitory impact on leaf chlorophyll content of both the crops (mustard and wheat). Maximum reduction of total chlorophyll content was observed in plants experiencing drought during flowering stage (Table 3). The maximum CSI value observed during pod filling stage (60%)

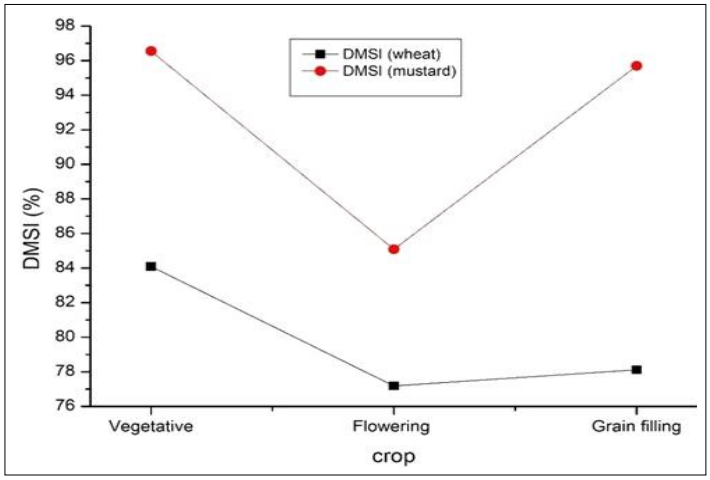

Fig 5: Dry matter stress tolerance index (DMSI) under both stress and control condition.

Table 2: Effect of water deficit stress (drought) on plant height, total leaves and dry biomass (mean ± S.D., n = 3).

Crop species	Treatments	Plant height (cm)	Total leaves/ plant	Shoot dry biomass (g plant^{-1})	Root dry biomass (g plant^{-1})	Total dry biomass (g plant^{-1})
Brassica juncea L.	Control $_{T0}$	34.5±0.59f	8.0±0.82f	0.51±0.03i	0.07±0.001f	0.68±0.03h
	Stressed $_{T1}$	26.43±0.54g	5.8±0.50g	0.45±0.03ij	0.11±0.001e	0.66±0.03h
	Control $_{T0}$	54±0.69d	13.8±0.96e	1.01±0.05f	0.13±0.003e	1.14±0.05f
	Stressed $_{T2}$	50.83±0.67e	10.3±0.96d	0.79±0.06h	0.18±0.002d	0.97±0.06g
	Control $_{T0}$	102±0.88c	25.8±0.96a	2.61±0.08c	0.41±0.022b	3.02±0.10c
	Stressed $_{T3}$	98±0.79c	23.8±0.50b	2.40±0.06d	0.49±0.016a	2.89±0.08d
Triticum aestivum L.	Control $_{T0}$	19.4±0.50f	5.5±0.58g	0.38±0.03j	0.06±0.003f	0.44±0.03i
	Stressed $_{T1}$	14.1±0.56h	4.3±0.50h	0.29±0.02k	0.08±0.002f	0.37±0.02i
	Control $_{T0}$	38.2±0.78d	10.5±0.58e	1.31±0.05e	0.18±0.009d	1.49±0.06e
	Stressed $_{T2}$	35.3±0.77e	8.5±0.58f	0.92±0.05g	0.23±0.012c	1.15±0.06f
	Control $_{T0}$	84.5±0.99a	18.8±0.96b	4.15±0.07a	0.42±0.031b	4.57±0.10a
	Stressed $_{T3}$	80.2±0.91b	15.5±0.58c	3.09±0.04b	0.48±0.025a	3.57±0.07b
LSD ($p \leq 0.05$)		0.60	0.52	0.04	0.012	0.05

*Mean values followed by same lowercase letters in a column don't differ significantly ($p \leq 0.05$) according to DMRT.

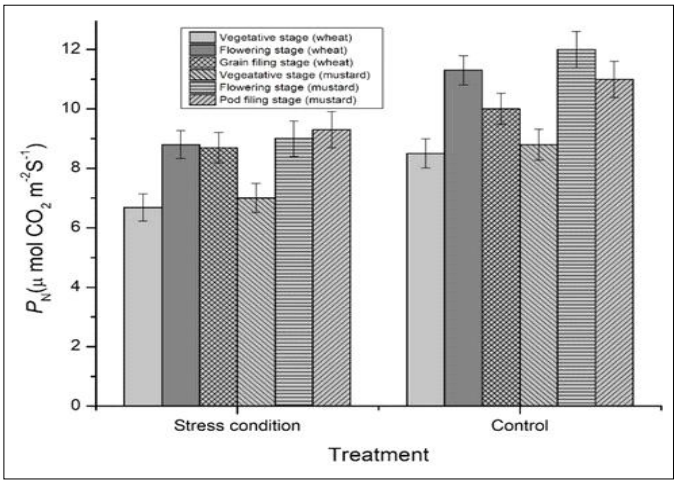

Fig 6: Photosynthetic rate (P_N) under both stress and control condition.

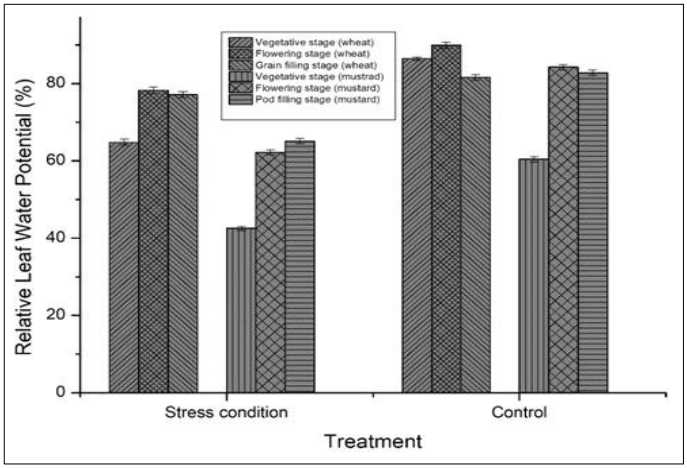

Fig 7: Leaf water potential (LWP) under both stress and control condition.

Table 3: Effect of water drought on leaf total chlorophyll, chlorophyll stability index (CSI) and proline content (mean ± S.D., n = 3).

Crop species	Treatments	Total chlorophyll (mg g^{-1} FW)	CSI (%)	Proline (μ mol g^{-1} FW)
Brassica juncea L.	Control $_{T0}$	0.75±0.04c		7.09±0.06i
	Stressed $_{T1}$	0.43±0.02d	57.3±1.21d	15.17±0.12b
	Control $_{T0}$	0.76±0.3c		7.64±0.04h
	Stressed $_{T2}$	0.45±0.02d	59.2±2.13d	15.64±0.29a
	Control $_{T0}$	0.75±0.05c		6.58±0.03j
	Stressed $_{T3}$	0.45±0.04d	60±1.35d	15 .21±0.17b
Triticum aestivum L.	Control $_{T0}$	0.98±0.05a		10.44±0.23e
	Stressed $_{T1}$	0.86±0.03b	87.8±2.46a	11.88±0.11d
	Control $_{T0}$	1.02±0.76a		8.07±0.09g
	Stressed $_{T2}$	0.82±0.06b	80.4±1.34c	12.27±0.14c
	Control $_{T0}$	1.01±0.05a		7.90±0.05g
	Stressed $_{T3}$	0.85±0.06b	84.2±2.26b	8.75±0.08f
LSD (p≤0.05)		0.03	1.52	0.11

*CSI is chlorophyll stability index; Mean values followed by same lowercase letters in a column don't differ significantly (p≤0.05) according to DMRT.

and vegetative phase (87.8%) in mustard and wheat respectively. Imposed drought significantly increased ($p \leq 0.01$) leaf proline content of all the studied cultivars. This increased accumulation of proline due to drought was more pronounced at flowering stage than vegetative and pod filling stages (Table 3).

Regardless of the plant's growth stage, water stress significantly reduced grain weight and harvest index (Fig 8). Plants suffering drought during the flowering stage produced fewer grain than those suffering drought during the vegetative and grain-filling stages. Both wheat and mustard showed minimum HI values under the treatment (T_3), *i.e.*, 18.55% and 18.64%, respectively.

Significant reduction in height, biomass and leaf number due to low turgor pressure was documented by earlier researchers that resulted in lower plant growth (Semerci *et al*., 2017; Wato, 2020). The significant differences in terms of PHSI index justifies that the reduction is much higher in wheat compared to mustard (Fig 3). The results revealed that water restriction significantly inhibited shoot growth, resulting in lower plant biomass of the studied crops. For both the crops, maximum reduction of total biomass was recorded when stress was applied during flowering stage followed by seed filling and vegetative phase. But when we compare both the crops, it is observed that this reduction was higher in wheat than mustard. The two crops also showed noticeable difference in terms of DMSI (Fig 5). Both the PHSI and DMSI values indicate that the mustard (TS 67) is tolerant to stress as compared to wheat (HD 3086). Plants suffering from drought and heat stress showed decreased antioxidant enzyme activity, reduced nutrient uptake and shorter root and shoot length (Prasad *et al*., 2017). Water stress reduced leaf area by causing a decrease in mitotic activity of epidermal cells, resulting in fewer cells per leaf (Farooq *et al*., 2009). In case of physiological parameters, photosynthetic rate and relative leaf water were observed to be mostly affected at the flowering stage and vegetative stage respectively for both the crops. As a result of drought stress, plants shut down their stomata to limit water loss through transpiration which leads to reduction in photosynthesis rates because of lower CO_2 concentrations in leaves (Osakabe *et al*., 2014). Leaf water potential (LWP) represents an indicator of soil water stress, providing insights into plant water relations (Farooq *et al*., 2012). It was observed in previous experiment that the chlorophyll a, chlorophyll b and total chlorophyll content of all sunflower varieties decreased in response to drought stress (Manivannan *et al*., 2007). In our experiment also, both LWP and total chlorophyll content decreased in all the growth stages while we applied drought stress. In drought-stressed plants, chlorophyll decreases primarily as a result of active oxygen species damaging chloroplasts (Smirnoff, 1995). In our experiment, maximum reduction of total chlorophyll was observed in plants experiencing drought during flowering stage.

An increased accumulation of proline due to drought was more noticeable during drought at flowering stage than vegetative or pod filling phases. Proline acts as a defensive mechanism against plant stress (Verbruggen and Hermans 2008). Mafakheri *et al*. (2010) also observed a higher increase in proline content during drought at flowering stage compared to vegetative stage. We found a positive (r = 0.47208469) correlation between PHSI and proline content and both were higher in mustard than wheat when these two parameters were correlated. Irrespective of the plant growth stages, water stress significantly reduced the number of pods for both wheat and mustard respectively. Plants that were subjected to drought during

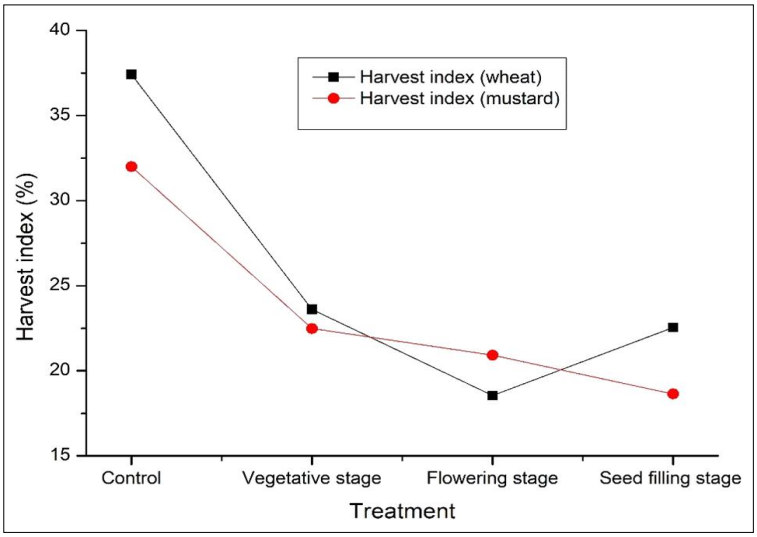

Fig 8: Harvest index (HI) of wheat and mustard.

the flowering stage resulted fewer pods in case of both wheat and mustard compared to the plants suffered drought during other stages.

CONCLUSION

Drought affected morphological, physiological and biochemical parameters of both crops, which decreased the yield significantly. When it comes to morphological characteristics, both crops are more sensitive in their vegetative stages. Increased proline concentrations during water stress treatment showed the crop's defensive mechanism to cope. Also, PHSI and DMSI values indicate that the mustard (TS 67) is more tolerant to stress as compared to wheat (HD 3086).

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Conflict of interest

All authors declare that they have no conflicts of interest.

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