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EVALUATION OF STRESS TOLERANCE INDICES IN HUW-234 X HUW-468 DERIVED WHEAT (*Triticum aestivum* L.) RIL MAPPING POPULATION FOR IDENTIFICATION OF HEAT TOLERANT GENOTYPES

Sadiah Shafi[1], Parvaze A. Sofi[1], Bikram Singh[2], J.P. Jaiswal[3], V.K. Mishra[4] and R.R. Mir[1]

[1]Division of Genetics & Plant Breeding, S.K. University of Agricultural Sciences & Technology (SKUAST) of Kashmir, Wadura, Sopore - 193 201, Jammu & Kashmir (India)
[2]Division of Genetics & Plant Breeding, SKUAST-Jammu, Chatta - 180 001, Jammu & Kashmir (India)
[3]Division of Genetics & Plant Breeding, GB Pant University of Agriculture & Technology, Pantnagar - 263 145, Uttarakhand (India)
[4]Division of Genetics & Plant Breeding, Banaras Hindu University, Varanasi, Uttar Pradesh (India)
*e-mail:*parvazesofi@gmail.com*

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ABSTRACT

A 'HUW-234 x HUW-468' RIL population of wheat was evaluated along with 2 parental checks under normal (NS) and heat stress (HS) environments. Five stress tolerance indices namely SSI, TOL, MP, GMP and STI were used to discriminate the genotypic response in terms of susceptibility and tolerance to heat stress using comparative yield data under stress and non-stress conditions. Among various indices used, the mean value and the minimum and maximum values recorded were 0.972 (0.270 and 1.386) for SSI, 2.469 (0.428 and 5.362) for TOL, 2.781 (1.635 and 4.124) for MP, 2.465 (1.449 and 3.667) for GMP and 0.401 (0.145 and 0.838) for STI, respectively. Yield (YHS) was found positively correlated with GMP (r = 0.752), followed by STI (r = 0.699) and MP (0.416) but negatively correlated with SSI (r = -0.699) and TOL (r = -0.361). Yield (YNS) was found positively correlated with MP (r = 0.923), followed by TOL (r = 0.919), GMP (r = 0.676) and SSI (r = 0.653). Based on this study it is recommended that the genotypes having higher value of GMP and STI should be selected while as the genotypes with higher SSI, TOL and STI should be rejected.

Keywords: GMP, RIL, stress tolerance indices, SSI, wheat, yield traits

Abbreviations: GMP - Geometric mean productivity; MP - Mean productivity, SSI - Stress susceptibility index, STI - Stress tolerance index**,** TOL - Tolerance index,

INTRODUCTION

Wheat (*Triticum* spp.) is one of the principal food grains of the world and contributes to the international food security. It is the most traded cereal grain, with 10% of total production sold in international markets (Enghiad *et al*., 2017). It is the most widely grown cereal, with production spanning from the equator to latitudes of more than 60º N and 50º S, and altitudes of up to 3,000 m masl. It is the most widely grown cereal in temperate and some tropical environments, where it is often cultivated as winter season crop in rotation with a number of other crops. As a cool season crop, wheat has as an optimal daytime growing temperature during reproductive development of 15°C and for every unit change above this optimum a reduction in yield of 3-4% has been observed. With global yearly production of more than 750 million tons, wheat (*Triticum aestivum* L.) has become the world's greatest and most significant food crop for direct consumption (FAO, 2017). In India, wheat production touched 100 million tonnes in 2018-19, with Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan, Bihar, Maharashtra, Gujarat, Karnataka, West Bengal, Uttarakhand, Himachal Pradesh and Jammu & Kashmir (J&K) as major wheat growing states, contributing about 99.5% of total wheat production in India (Anonymous, 2019). In J&K wheat is grown on an area of 2.85 million ha with the production of 5.40 million tones and productivity of 1.94 tonnes ha^{-1} (Anonymous, 2017).

Climatic change has negatively impacted the yield, especially through drought and terminal heat stress. In case of wheat, drought and terminal heat stress are more pronounced as it encounters rising temperatures towards grain formation phase. In wheat, terminal heat stress, invariably occurs when mean temperature during grain filling stage goes above 31°C. Modeling studies have predicted wheat yield losses upto 10-40% by 2050 (Dubey *et al*., 2020). The current climate model predicts that temperature will increase by 1.8-5.8°C at the end of this century (IPCC, 2007) and terminal heat stress will increase in wheat production environments (Semenov, 2009). High temperature is more damaging when it comes at reproductive and grain filling stages (Farooq *et al.*, 2011), by implicating photosynthesis, pollen tube development, resource remobilization, grain abortion, as well as causing oxidative damage (Wahid *et al.*, 2007; Wang *et al.*, 2011). In Kashmir, the situation is quite challenging as the existing cultivars are long duration types which mature in the 2nd week of June, when temperature and water stress often come together. Hence, there is a need to develop early maturing cum terminal heat stress resilient varieties that could fit in rotation with rice to augment food production.

Breeding for water stress tolerance is very difficult as the stress conditions created in experimental set up and actual field conditions invariably have poor correspondence. In fact, the translation of greenhouse and laboratory observations to myriad of diverse patterns and processes observed in the field is a huge challenge, even in case of experiments where seemingly fair amount of control is expected (Poorter *et al*., 2016). Even in the experiments where similar traits are studied under different screening systems, the correspondence is not fairly straightforward. Yield has been the primary breeding objective in production breeding and has been improved by targeting yield *per se* as well as yield components based on correlated response. A major problem encountered by researchers while dealing with yield data is that yield under stress *per se* and yield differences under non-stress and stress conditions (Yp-Yd) cannot effectively discriminate the genotypes into tolerant and susceptible. Historically the plant breeding programmes have mainly focused on selecting genotypes that exhibit higher yield under yield non-stress conditions followed by testing under stress conditions of various severities (mild/severe) and applying stress at various stages (early season, intermittent and terminal stress) on the assumption is that a genotype with high yield potential will perform comparably well under most environments (Blum, 2005). There are evidences that higher yield potential under non-stress conditions may correspondingly comp arable under mild stress but a lower yield and higher resilience under severe stress may be desirable (Panthuwan *et al*., 2002).

Stress tolerance indices (STI) are quantitative measures that characterize water stress response by yield data from one or several environments based on timing, duration and intensity of stress. Such indices are more readily useable than raw yield data. Breeders often found it useful to interpret differential yielding abilities in terms of various indices calculated from seed yield. Since STI are yield based parameters, selection could vary depending on the index chosen. The strategy of using differential yield reduction (Yp-Yd) due to stress as a basis for selecting cultivars with tolerance to stress can be counterproductive because of the likelihood of selecting low yielding cultivars with a small yield differential. No significant correlation between yield reduction and yield under stress has been reported which suggest that differential yield reduction cannot be a useful predictor of stress tolerance (Samper, 1984).

A large number of such indices have been proposed and used by wheat breeders to discriminate the plant response such as stress susceptibility index (SSI), tolerance index (TOL), mean productivity (MP), geometric mean productivity (GMP), STI and many more (Fernandez, 1992; Moosavi *et al*., 2008; Thiry *et al*., 2016). A predominantly held premise by many workers is that selection based on yield under both non-stress and stress conditions is more efficient especially under stress conditions (Moosavi *et al.,* 2008; Mohammadi *et al.,* 2010). In light of this premise, many STI have been proposed for screening stress tolerant genotypes based on mathematical relationship between yield under stress and non-stress conditions aimed at identifying stable, high yielding, drought tolerant genotypes. Rosielle and Hamblin (1981) introduced TOL and MP: mean productivity, while Fisher and Maurer (1978) offered SSI and Fernandez (1992) defined a new advanced index namely STI. In wheat, a number of early studies (Fard and Sedaghat, 2013, Ali and Al Sadek, 2016) have reported the usefulness of STI in delineating genotypic differences under stress. These and other studies have reinforced the utility of using yield-based indices instead of yield *per se* for genotypic classification into tolerant and susceptible lines. The present study was undertaken to assess a RIL mapping population of wheat derived from a heat tolerant (HUW-234) and susceptible (HUW-468) variety.

MATERIALS AND METHODS

The present study was undertaken in *kharif* 2018 at experimental farm of Faculty of Agriculture at Wadura, Sopore, Kashmir (34°17’ N and 74°33’ E at an altitude of 1594 m masl) and Division Genetics and Plant Breeding, Faculty of Agriculture, SKUAST-J Chatta, Jammu (32°39' N and 74°58' E at an altitude of 332 m amsl). The minimum and maximum temperature during experimental period at Wadura experimental site was 14.87 and 28.97°C, respectively; while the minimum and maximum relative humidity was 55.68 and 80.14% and the total rainfall was 336.2 mm. The Chatta experimental site was used as a heat stress site while as Wadura site was used as ambient temperature site for the estimation of various stress tolerance indices based on yields at the two sites.

Plant material

The material used in present study comprised of 164 genotypes including 160 bi-parental RIL’s derived from a cross of ‘HUW-234 x HUW-468’ and four checks namely ‘Shalimar Wheat-1’, ‘Shalimar Wheat-2’, ‘HUW-234’ and ‘HUW-468’. ‘Shalimar Wheat-1’ and ‘Shalimar Wheat-2’ are the varieties released by SKUAST-Kashmir, while as, ‘HUW-234’ and ‘HUW-468’ are the parents of RIL population. ‘HUW-234’ (HU12*2/CPAN 1666) is a wheat variety released by BHU, Varanasi, Uttar Pradesh, (India) in 1986 as ‘Malvya-234’ for late sown irrigated conditions. ‘HUW-468’ (CPAN 1962/TONI// LIRA/PRL) is also released by BHU Varanasi in 1999 as ‘Malvya-468’ for timely sown irrigated conditions. ‘HUW-234’ has shown substantial heat tolerance while as ‘HUW-468’ is a heat susceptible genotype (Joshi *et al.*, 2007).

Field design

The field evaluation was done using augmented block design. Augmented designs consist of two kinds of treatments, the checks or the standard treatments and new or augmented treatments (Federer, 1956). The design presumes checks as fixed effects whereas the new entries as random effects. The new entries are usually not replicated especially when dealing with large germplasm sets. However, the checks are replicated to act as points of reference. Both the checks and new entries are randomly distributed among the blocks. Federer (2001) provided for statistical analysis of such designs wherein the random effects of new entries are used to account for various sources of variation.

Stress tolerance indices

Based on established experimental evidences, five stress tolerance indices were used. Seed yield was calculated as the mean of all plants across the replications. Various drought tolerance indices were calculated based on the values of seed yield plant^{-1} under irrigated and drought conditions to discriminate genotypes on the basis of drought response in terms of grain yield. The calculations were done as follows:

Stress susceptibility index (SSI) = {1- (Y_S / Y_{NS})}/ {1-(X_S / X_{NS}} (Fisher and Maurer, 1978**)**
Tolerance index (TOL) = Y_{NS} - Y_S (Rosielle and Hamblin, 1981)
Mean productivity (MP) = (Y_S + Y_{NS}) / 2 (Rosielle and Hamblin, 1981)
Geometric mean productivity (GMP) = √(Y_{NS} x Y_S) (Fernandez , 1992)
Stress Tolerance Index (STI) = Y_S x Y_{NS}) / X^2_{NS} (Fernandez, 1992)

Where Y_S and Y_{NS} are mean yields of genotypes under stress and non-stress conditions, respectively and X_S and X_{NS} are mean yield of all genotypes under stress and non-stress conditions, respectively.

RESULTS AND DISCUSSION

Stress severity

In order to assess the severity of stress, the stress intensity index (SII) that measures the intensity of stress is a particular experiment was calculated. SII can take values between 0 and 1. The larger value of SII indicates more severe stress conditions (Dejan *et al.,* 2008). In present experiment, the overall stress intensity index was 0.614 reflecting that yield reduction was about more than one-half under high temperature stress conditions in comparison to yield under ambient conditions.

Stress tolerance indices

Five stress tolerance indices namely SSI**,** TOL**,** MP, GMP and STI were used in the present study to discriminate the genotypic response in terms of susceptibility and tolerance to heat stress using comparative yield data under ambient and heat stress conditions based on the survey of literature for established correlations of indices with yield under stress as well as their effectiveness in stress response discrimination. Among various indices used, SSI had a mean value of 0.972, with minimum and maximum values of 0.270 and 1.386, respectively (Table 1). The lowest value of SSI was recorded in ‘A-2608’, followed by ‘A-2612’ and ‘A-2537’; while the highest value was recorded in ‘A-192’. Chopra *et al.*(2013) used a ‘WL711’ and ‘C306’ RIL population comprising 206 RILs. Based on SSI of yield and yield components of medium to late flowering RILs, 8 RILs were identified for combining yield higher than the tolerant parent ‘C306’ with yield stability. They also observed that ‘C306’ had lower SSI value than ‘WL711’ which corresponded to their stress tolerance response. TOL had a mean value of 2.469, with minimum and maximum values of 0.428 and 5.362, respectively. The lowest value of TOL was recorded in ‘A-2608’, followed by ‘A-2612’ and ‘A-2537’; while the highest value was recorded in ‘A-2596’.MP had a mean value of 2.781, with minimum and maximum values of 1.635 and 4.124, respectively. The highest value of MP was noted in ‘A-2648’, followed by ‘A-186’ and ‘HUW-234’; while the lowest value was recorded in ‘A-2593’. GMP had a mean value of 2.465, with minimum and maximum values of 1.449 and 3.667, respectively (Table 1). The highest GMP value was found in ‘HUW-468’, followed by ‘A-2648’ and ‘A-186’; while the lowest value was recorded in ‘A-2593’. STI had a mean value of 0.401 with minimum and maximum values of 0.145 and 0.834, respectively. The highest STI value was noted in ‘A-2608’, followed by ‘A-2612’ and ‘A-2537’; while the lowest value was found in ‘A-192’. Higher values of SSI and TOL invariably indicate the susceptibility**,** while higher values of MP, GM and STI invariably indicate the tolerance. Similar results have been reported in wheat RIL population by Fard and Sedaghat (2013), Khan and Kabir (2014) and Kamrani *et al*. (2017).

Table 1: Descriptive statistics for stress indices

Statistic	SSI	TOL	MP	GMP	STI
Minimum	0.270	0.428	1.635	1.449	0.145
Maximum	1.386	5.362	4.124	3.667	0.834
Mean	0.972	2.469	2.781	2.465	0.401
Standard deviation	0.193	0.866	0.432	0.378	0.119

Table 2: Correlation coefficient matrix between seed yield and stress tolerance indices of RIL mapping population in wheat

Indices	YHS	YNS	SSI	TOL	MP	GMP	STI
YHS	1	0.035	-0.699*	-0.361*	0.416*	0.752**	0.699**
YNS		1	0.654**	0.919**	0.923**	0.677**	-0.653**
SSI			1	0.885**	0.326**	-0.066	-0.999**
TOL				1	0.698**	0.335*	-0.885**
MP					1	0.904*	0.328*
GMP						1	0.066
STI							1

*, ** Significant at 5 and 1% level, respectively.
Where, YHS = Yield under heat stress, YNS = Yield under non-heat stress, SSI = Susceptibly stress index, TOL = Tolerance index, MP = Mean productivity, GMP = Geometric mean productivity, STI = Stress tolerance index

Association of yield (stress) and yield (non-stress) with stress indices

Associations were computed among stress indices and seed yield to identify desirable traits for indirect selection (Table 2). Among 21 possible combinations 18 were found to be significant. Yield under heat stress (YHS) was found positively correlated with GMP (r = 0.752), followed by STI (r = 0.699) and MP (R = 0.416); but negatively correlated with SSI (R = -0.699) and TOL (r = -0.361). Yield under non-stress (YNS) was found positively correlated with mean productivity (r = 0.923), followed by TOI (0.919), GMP (r = 0.676) and SSI (r = 0.653), but negatively correlated with STI (-0.653). Nouraein *et al*. (2013) evaluated a “Yecora Rojo x NO. 49” RIL population using different stress tolerance indices including STI, MP, GMP, TOL, and SSI. Significant and positive correlation was found between grain yield under stress condition (Ys) and STI, MP and GMP indicating the efficiency of these indices for screening drought tolerant genotypes. Among the drought tolerance indices, GMP showed higher correlation with grain yield under stress condition. The biplot based on components showed that the most appropriate indices to identify genotypes were GMP, MP, and STI.

Table 3: Identification of resilient genotypes using stress tolerance indices (values in parentheses are mean values of RILs)

Stress	Index	Best genotypes identified
Susceptibility based index	SSI	A-2608 (0.269), A-2612 (0.389), A-2537 (0.410), A-2566 (0.525), A-2625 (0.541), A-205 (0.543), A-187 (0.567), A-180 (0.635), A-2584 (0.675), A-2554 (0.675)
	TOL	A-2608 (0.428), A-2537 (0.696), A-2612 (0.750), A-205 (0.799), A-2566 (0.956), A-2625 (1.018), A-2506 (1.039), A-187 (1.043), A-180 (1.172), A-2584 (1.173)
Tolerance based index	STI	A-2608 (0.834), A-2612 (0.760), A-2537 (0.747), A-2566 (0.675), A-2625 (0.666), A-205 (0.666), A-187 (0.650), A-180 (0.608), A-2584 (0.584), A-2554 (0.583)
	MP	A-2596 (4.124), A-186 (3.923), HUW-234 (3.816), A-2596 (3.607), A-190 (3.566), A-2614 (3.556), A-2607 (3.516), A-2645 (3.437), A-2548 (3.436), A-2582 (3.408), A-2512 (3.398)
	GMP	HUW-234 (3.667), A-2648 (3.648), A-186 (3.297), A-2607 (3.248), A-2554 (3.184), A-2614 (3.166), A-2645 (3.138), A-190 (3.114), A-2509 (3.048), A-2512 (3.039)

Where, SSI = Susceptibly stress index, TOL = Tolerance index, MP = Mean productivity, GMP = Geometric mean productivity, STI = Stress tolerance index

Similarly, Ali and Al Sadek (2016) used several drought indices to identify drought-tolerant lines among 49 wheat lines grown under rainfed and irrigated conditions. Grain yield under both stress and non-stress environments were highly correlated with MP, GMP, STI, yield index (YI), harmonic mean (HM), drought resistance index (DRI), and modified stress tolerance index (STI). The indices namely MP, GMP and STI were identified as the best indices for the selection of the relatively tolerant lines. Srivastava *et al*. (2016) and Kamrani *et al.* (2017) also reported similar higher correlation of STI, GMP and MP with yield under stress. Among the stress indices the largest positive correlation was recorded between MP and GMP (r = 0.904), followed by TOL and SSI (r = 0.885); while as the largest negative correlation was recorded for STI and SSI (r = -0.999). Based on the results of present study, it is recommended that genotypes having higher value of GMP, STI and MP should be selected while as genotypes with higher SSI and TOL should be rejected.

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