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IDENTIFICATION OF WATERLOGGING STRESS TOLERANT MAIZE (*Zea mays* L.) HYBRIDS USING DIFFERENT SELECTION INDICES

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About 15% of the maize-cultivating areas are affected by severe waterlogging stress or flooding in South and Southeast Asia, causing yearly production losses approximately by 25~30% (Chen *et al*., 2014). In general, maize is highly sensitive to excess soil moisture mostly at early vegetative stages. Waterlogging at early vegetative stages results in severe reduction in traits such as plant height, days to flowering and maturity, dry matter accumulation along with grain yield potential (Liu *et al*., 2010). In India, only 15% of the maize growing area is under proper irrigation (Sah *et al*., 2020). India projected 0.9 mha as waterlogging affected area (MoA&FW, GOI, 2018). It was reported that 12% of global cultivated land was severely affected by waterlogging stress that resulting in a nearly 20% decline in crop production through limiting plant growth and development by altering morphological, physiological, and anatomical mechanisms (Abiko *et al.*, 2012 and Luan, 2018). The contingent flooding by continuous rainfall coupled with inadequate drainage and elevated groundwater table are the key constraints in maize production in Asian tropics and other parts of the world (Singh *et al.*, 2017). Over the years the total maize cultivating area in South and Southeast Asia alone are frequently affected by waterlogging problems. Therefore, it is necessary to focus on identification of tolerance in maize against excessive soil moisture and waterlogging in India to meet the increasing demand of grain yield production.

Several studies reported effect of waterlogging stress in genetic variability in maize for tolerance to excess moisture (Campbell *et al*., 2015; Zaidi *et al*., 2003, 2004). Screening of maize genotypes tolerant to excess moisture in field conditions through available abiotic stress tolerance indices could be an ideal approach to provide promising cultivars for maize-growing farmers in the Asian tropics. Mean productivity (MP), stress susceptibility index (SSI) (Fischer and Maurer, 1978), stress tolerance index (STI) (Fernandez, 1992), yield stability index (YSI) (Bouslama and Schapaugh, 1984), relative drought index (RDI) (Fischer and Wood, 1979) and yield index (YI) (Gavuzzi *et al*., 1997) are useful measures to evaluate the stable performance of cultivars in both the stress and non-stress conditions. Although, several screening techniques and selection indices were available but identification of suitable and precise index for selection of ideal cultivars for target stress conditions at field level is a major bottleneck. However, a vast literature is available on abiotic stress selection indices and their association with grain yields under drought conditions (Jafari *et al*., 2009; Khodarahmpour and Hamidi, 2011; Kiani, 2013; Naghavi *et al*., 2013; Barutcular *et al.,* 2016; Arisandy *et al*., 2017), but very limited literature is available on application of selection indices for screening waterlogging stress tolerant maize hybrids. Hence, the present study was attempted to determine the excess moisture stress tolerance in maize hybrids under field conditions.

Fifty medium duration maize hybrids including five commercial checks which include two internal checks (CAH 153 and CAH 1511) and three commercial hybrids (900 MG, P 3502 and Hytech 5106) were procured from the International Maize and Wheat Improvement Center (CIMMYT)-Asia office, Hyderabad, India. The material was obtained from an elite pool of 600 diverse maize lines (from the CIMMYT's maize germplasm sourced from Asian tropics) crossed with two testers *viz*, CML451 and CL02450 through biparental pattern. The testers used were globally released CIMMYT's leading testers belonging to separate heterotic groups with high grain yield potential, high general and specific combining abilities and tolerant to many abiotic stresses. The hybrids were at multi-location trial (MLT) screening under optimal soil moisture, drought and waterlogging conditions.

All the hybrids were evaluated along with five checks in two sets *viz*., set I under optimum or well-irrigated and set II under managed waterlogging stress during *kharif* -2018 at Banaras Hindu University, Varanasi (India). Manual sowing was done with 4 m in length and number of rows was two. Both sets of test hybrids were planted in alpha lattice design (0, 1) (Patterson and Williams, 1976) with two replications. All the trials were planted with 60 cm row-to-row and 20 cm within-row spacing. Meteorological data including

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Table 1. List of 50 maize hybrids evaluated under well-water and managed waterlogging stress during *Kharif* 2018

Genotype Code	Genotype Name	Genotype Code	Genotype Name
G1	VH12148	G26	VH12263
G2	ZH161032	G27	VH1253
G3	VH113014	G28	VH12132
G4	VH11130	G29	ZH161529
G5	ZH17191	G30	VH112563
G6	VH131167	G31	ZH16929-1
G7	ZH161531	G32	ZH161035
G8	ZH114233	G33	ZH16929-2
G9	VH12186	G34	ZH137998
G10	VH12148	G35	ZH161034
G11	ZH161532	G36	VH112986
G12	VH11129	G37	VH112744
G13	ZH17192	G38	VH121082
G14	VH112926	G39	ZH116105
G15	VH112733	G40	VH112888
G16	VH123021	G41	VH112732
G17	VH123045	G42	VH121043
G18	ZH161530	G43	VH12254
G19	VH112967	G44	ZH161529
G20	VH12316	G45	ZH161035
G21	ZH114250	G46	CAH153
G22	VH12264	G47	CAH1511
G23	VH1230	G48	900 MG
G24	ZH14435	G49	P 3502
G25	VH12229	G50	Hytech5106

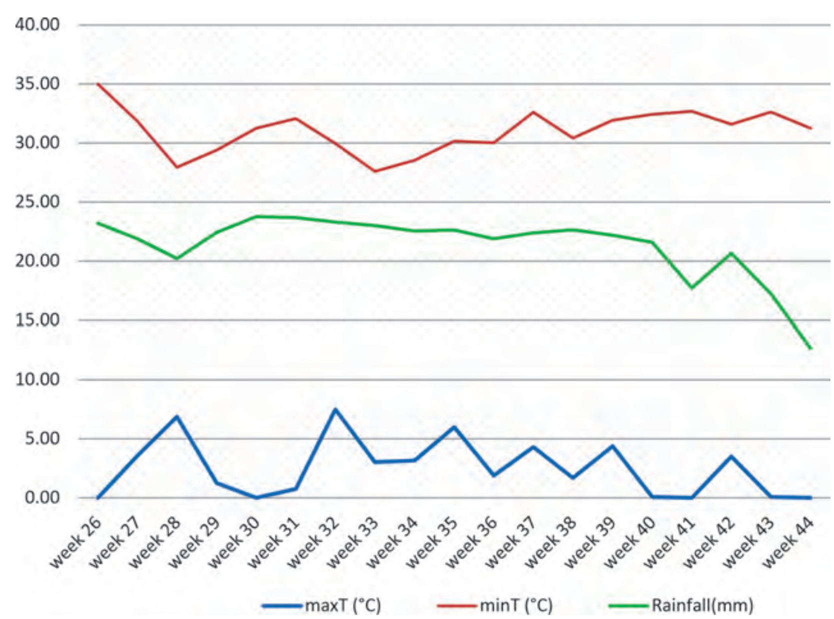


Fig. 1. Whether data including maximum (maxT), minimum (minT) temperatures and rainfall during *Kharif* 2018 at Varanasi.

maximum, minimum temperatures and rainfall received during crop growing period on standard week bases was shown in the Figure 1. Irrigation was scheduled at critical stages of growth stages of maize such as knee height stage, reproductive periods and followed by grain filling stages. The waterlogging stress treatment was imposed by giving flood irrigation to the experimental field at 'knee high' stage ('V_6-V_7' stage). The water level in the plots was retained stagnant at a depth of 10 ± 0.5 cm continuously for seven days by providing water through need-based supplemental irrigation at a rate that surpassed infiltration and evaporation. Draining of stagnant water in the field was carried out after seventh day and recommended irrigation at critical stages was resumed as per crop needs (Zaidi *et al*., 2016).

Fresh weight of all the plots under both the trials including non-stress and managed waterlogging trials was recorded using electronic weighing balance and converted in to grain yield per hectare under stress-free (Yp) and grain yield under stress (Ys), respectively by using shelling and moisture percent measured. Conversion of grain yield per hectare was standardized at 12.5 moisture percent using the following formula as suggested by ASTM, 2001. Grain yield data under non-stress and stress environments were subjected to the analysis of variance (ANOVA) for the alpha lattice design given by Patterson and Williams (1976). Grain yield reduction due to waterlogging stress compared to optimum-irrigated fields was calculated by the formula given by Oyekunle *et al*., 2019. Nine selection indices *viz*., tolerance index (TOL), mean productivity (MP), geometric mean productivity (GMP), harmonic mean (HM), stress susceptibility index (SSI), stress tolerance index (STI), yield index (YI), yield stability index (YSI) and relative stress index (RSI) were computed by the formulae given in the table 2. Estimates of above mentioned stress tolerance indices, genotype ranking and association of these indices with grain yield under non-stress and stress environments were carried out using an online software, *i*PASTIC: an online toolkit to calculate plant abiotic stress indices (Pour-Aboughadareh *et al.,* 2019).

Analysis variation (ANOVA) showed a significant variation (p<0.001) among experimental maize hybrids for grain yield under both well-water and managed waterlogging stress conditions (Table 3). Kachapur *et al*. (2015), Kiani (2013) and Jafari *et al*. (2009) reported statistically significant variation in grain yield of maize under stress and non-stress conditions. The results showed that the hybrids *viz*., G2 (ZH161032, 11.46 t/ha), G9 (VH12186, 10.46 t/ha), G6 (VH131167, 10.2 t/ha), G31 (ZH16929-1, 9.97 t/ha) and G14 (VH112926, 9.89 t/ha) had maximum yield under optimal soil moisture while hybrids G38 (VH121082, 5.92 t/ha), G5 (ZH17191, 5.64 t/ha), G6 (VH131167, 5.54 t/ha), G35 (ZH161034, 5.36 t/ha) and G7 (ZH161531, 5.06 t/ha) showed highest yield under waterlogged conditions (Table 4). Decline in grain yield showed an approximate range of 20-85% under waterlogging condition. Lowest yield reduction was observed for the hybrids G12 (VH11129, 20.3%), G3 (VH121082, 27.3%), G40 (VH112888, 29.2%), G32 (ZH161035, 30.8%) and G42 (VH121043, 31.1%). This drastic declination in grain yield was due to the impact of waterlogging stress at early growth stages. Leaf rolling and senescence is a most common symptom of maize plant subjected to waterlogging stress (Yan *et al*., 1996). Consequently, chlorophyll content and related photosynthetic enzymes that reduced the photochemical efficiency of PSII resulted in a significant yield reduction (Ren *et al*., 2016).

All the nine estimated selection indices and genotype ranking are given in the Table 4. According to selection index TOL, the hybrids *viz*., G12 (VH11129), G42 (VH121043), G32 (ZH161035), G40 (VH112888) and G1 (VH12148) had maximum tolerance to waterlogging stress whereas MP was highest for the hybrids G6 (VH131167), G2 (ZH161032), G5 (ZH17191), G31 (ZH16929-1) and G49 (P 3502). Based on selection indices GMP, HM, STI and YI, the hybrids *viz*., G6 (VH131167), G5 (ZH17191), G31 (ZH16929-1), G49 (P 3502) and G38 (VH121082) showed maximum tolerance to waterlogging stress. Similarly, hybrids G12 (VH11129), G38 (VH121082), G40 (VH112888), G30 (ZH161035) and G42 (VH121043) were identified as most tolerant to excess soil moisture stress based on SSI, YSI and RSI. Integration of all the nine selection indices was carried out by the rank-sum (RS) method *i.e.* the sum of mean rank () of nine selection indices and standard deviation (R_{sd}) of ranks of each hybrid (Farshadfar *et al.,* 2012). Accordingly, the hybrids G38 (VH121082; R_S=10.77, R_{SD}=5.31), G5 (ZH17191; R_S=11.47, R_{SD}=5.65), G35 (ZH161034; R_S=12.84, R_{SD}=4.02), G33 (ZH16929-2; R_S=13.74, R_{SD}=2.92) and G7 (ZH161531; R_S=14.97, R_{SD}=4.55) were found to be the most waterlogging stress tolerant with least R_S values among 50 hybrids. In contrast, hybrids G26 (VH12263; R_S=53.81, R_{SD}=10.62), G23 (VH1230; R_S=52.43, R_{SD}=5.15), G43 (VH12254; R_S=51.17, R_{SD}=11.98), G46 (CAH153-2; R_S=50.08, R_{SD}=11.9) and G12 (VH11129; R_S=49.23, R_{SD}=21.14) were identified as least tolerant to excess moisture stress (Table 4). The same set of experimental hybrids was evaluated for stress selection indices to estimate drought tolerance during *Rabi* 2017 at Varanasi location (Singamsetti *et al*., 2019) and the study revealed that the hybrids *viz*., VH123021, 900MG, ZH161529, VH131167 and VH12264 were most drought stress tolerant while hybrids VH11129, VH12132, VH12263, ZH16105 and ZH14435 were most sensitive to drought stress.

Table 2. Formulae for estimation of stress tolerance indices along with selection pattern of maize genotypes evaluated under stress-free and managed waterlogging stress conditions

Selection index	Formula	Selection criterion	Reference
Tolerance index (TOL)	$TOL = Y_p - Y_s$	Lower value	Rosielle and Hamblin (1981)
Mean productivity (MP)	$MP = \frac{Y_p + Y_s}{2}$	Higher value	Rosielle and Hamblin (1981)
Geometric mean productivity (GMP)	$GMP = \sqrt{Y_s \times Y_p}$	Higher value	Fernandez (1992)
Harmonic mean productivity (HM)	$HM = \frac{2(Y_s \times Y_p)}{Y_s + Y_p}$	Higher value	Bidinger *et al*. (1987)
Stress susceptibility index (SSI)	$SSI = \frac{1-(Y_s/Y_p)}{1-(\bar{Y}_s/\bar{Y}_p)}$	Lower value	Fischer and Maurer (1978)
Stress tolerance index (STI)	$STI = \frac{Y_s \times Y_p}{(\bar{Y}_p)^2}$	Higher value	Fernandez (1992)
Yield index (YI)	$YI = \frac{Y_s}{\bar{Y}_s}$	Higher value	Gavuzzi *et al*. (1997)
Yield stability index (YSI)	$YSI = \frac{Y_s}{Y_p}$	Higher value	Bouslama and Schapaugh (1984)
Relative stress index (RSI)	$RSI = \frac{Y_s/Y_p)}{\bar{Y}_s/\bar{Y}_p}$	Higher value	Fischer and Wood (1979)

Ys , *Yp* represent yield under stress and non-stress for each hybrid, respectively whereas $\bar{Ys}$ and $\bar{Yp}$ denoted mean grain yield under stress and non-stress conditions for all the genotypes under the trial, respectively.

Spearman's rank correlation was performed to study the relationship between stress selection indices and grain yield under both conditions. The association among selection indices assists plant breeders to determine the most desirable waterlogging stress tolerant criterion. The results revealed that the grain yield under non-stress condition had significant positive correlation with MP (r=0.93), GMP (r=0.83), HM (r=0.69), STI (r=0.83) and YI (r=0.83) whereas under waterlogging stress condition, it had strong positive association with MP (r=0.80), GMP (r=0.91), HM (r=0.98), SSI (r=0.71) STI (r=0.91), YI (r=0.91), YSI (r=0.71) and RSI (r=0.71). The indices *viz*, MP, GMP, HM, STI and YI showed strong positive correlation with yield under stress and optimum soil moisture field conditions. This suggested that these selection indices would be recommended for screening the maize hybrids with maximum grain yield under both conditions. Previous works by Anwar *et al*. (2011); Richard, (1996); Ramirez and Kelly, (1998) and Saba *et al*. (2001) reported almost identical genotype ranking pattern for MP, GMP and STI due to perfect correlation. The study involving association between grain yield and selection indices under both stress and optimal moisture conditions revealed that MP, GMP, HM showed similarity with those reported by Singh *et al*. (2017); Farshadfar and Sutka (2002) and Khodarampour *et al.* (2011) in maize. In the present study, significant negative (r=-0.74) correlation was found between TOL

Table 3. Analysis of variance for grain yield of 50 maize hybrids under well-water (non-stress) and waterlogging stress condition during *Kharif* 2018

Source	DF	Mean sum of squares	
		Well-irrigated	Waterlogging
Genotype	49	6.615***	2.728***
Replication	1	4.359**	0.304
Block(Replication)	8	0.937	0.399
Error	41	0.512	0.291

DF, degree of freedom
***, significant at 0.001 percent (p<0.001); **, significant at 0.01 percent (p<0.01)

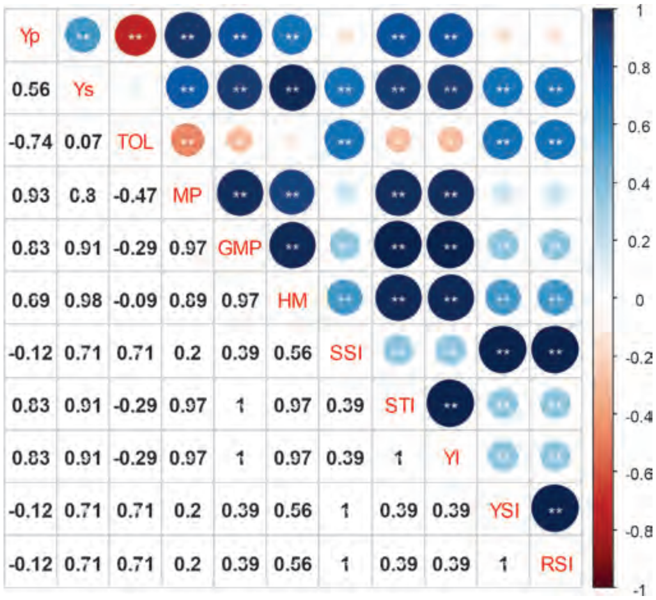
Table 4. Waterlogging stress tolerance index estimates and respective genotype ranks for 50 maize hybrids evaluated during *Kharif* 2018

Genotype Code	Mean grain yield			Tolerance index		Mean productivity		Geometric mean productivity		Harmonic mean		Stress susceptibility index		Stress tolerance index		Yield index		Yield stability index		Relative stress index		$\bar{R}$	R_{SD}	R_S
	Yp	Ys	YR%	TOL	R	MP	R	GMP	R	HM	R	SSI	R	STI	R	YI	R	YSI	R	RSI	R			
G1	5.18	3.03	41.51	2.15	5	4.11	37	3.96	35	3.82	29	0.73	8	0.29	35	0.95	35	0.58	8	1.36	8	24.18	13.4	37.58
G2	11.46	4.1	64.22	7.36	48	7.78	2	6.85	6	6.04	10	1.13	35	0.86	6	1.29	6	0.36	35	0.83	35	17.91	16.05	33.96
G3	7.27	2.4	66.99	4.87	34	4.84	29	4.18	31	3.61	32	1.18	41	0.32	31	0.75	31	0.33	41	0.77	41	34	4.82	38.82
G4	7.14	2.63	63.17	4.51	27	4.89	27	4.33	28	3.84	28	1.11	32	0.34	28	0.83	28	0.37	32	0.86	32	29.18	1.99	31.17
G5	9.61	5.64	41.31	3.97	22	7.63	3	7.36	2	7.11	2	0.73	7	0.99	2	1.77	2	0.59	7	1.36	7	5.82	5.65	11.47
G6	10.2	5.54	45.69	4.66	30	7.87	1	7.52	1	7.18	1	0.8	12	1.03	1	1.74	1	0.54	12	1.26	12	7	8.61	15.61
G7	9.11	5.06	44.46	4.05	23	7.09	7	6.79	8	6.51	7	0.78	10	0.84	8	1.59	8	0.56	10	1.29	10	9.82	4.55	14.37
G8	4.66	2.35	49.57	2.31	7	3.51	46	3.31	43	3.12	39	0.87	15	0.2	43	0.74	43	0.5	15	1.17	15	31.82	14.56	46.38
G9	10.46	2.04	80.5	8.42	50	6.25	14	4.62	25	3.41	36	1.41	48	0.39	25	0.64	25	0.2	48	0.45	48	32.91	15.23	48.14
G10	6.85	2.44	64.38	4.41	25	4.65	31	4.09	32	3.6	33	1.13	36	0.31	32	0.77	32	0.36	36	0.83	36	32.55	3.14	35.69
G11	5.59	2.03	63.69	3.56	16	3.81	42	3.37	42	2.98	42	1.12	33	0.21	42	0.64	42	0.36	33	0.84	33	37	7.68	44.68
G12	3.5	2.79	20.29	0.71	1	3.15	48	3.12	46	3.1	40	0.36	1	0.18	46	0.88	46	0.8	1	1.85	1	28.09	21.14	49.23
G13	7.87	3.46	56.04	4.41	25	5.67	21	5.22	19	4.81	15	0.98	23	0.5	19	1.09	19	0.44	23	1.02	23	20.64	3.14	23.78
G14	9.89	3.15	68.15	6.74	47	6.52	13	5.58	14	4.78	17	1.2	43	0.57	14	0.99	14	0.32	43	0.74	43	25	14.88	39.88
G15	7.58	3.35	55.8	4.23	24	5.47	24	5.04	22	4.65	21	0.98	21	0.46	22	1.05	22	0.44	21	1.03	21	21.91	1.83	23.74
G16	9.77	4.72	51.69	5.05	37	7.25	6	6.79	7	6.36	8	0.91	18	0.84	7	1.48	7	0.48	18	1.12	18	12.82	9.03	21.85
G17	6.73	2.97	55.87	3.76	18	4.85	28	4.47	26	4.12	24	0.98	22	0.37	26	0.93	26	0.44	22	1.03	22	24.64	3.36	28
G18	6.17	2.22	64.02	3.95	21	4.2	36	3.7	37	3.27	37	1.12	34	0.25	37	0.7	37	0.36	34	0.84	34	34.82	4.63	39.45
G19	6.49	1.5	76.89	4.99	35	4	38	3.12	47	2.44	48	1.35	46	0.18	47	0.47	47	0.23	46	0.54	46	43.64	5.48	49.12
G20	6.16	3.07	50.16	3.09	14	4.62	32	4.35	27	4.1	25	0.88	17	0.35	27	0.96	27	0.5	17	1.16	17	24.09	6.97	31.06
G21	6.39	2.5	60.88	3.89	19	4.45	34	4	33	3.59	34	1.07	28	0.29	33	0.79	33	0.39	28	0.91	28	30.73	4.45	35.18
G22	6.25	1.59	74.56	4.66	31	3.92	41	3.15	45	2.54	46	1.31	45	0.18	45	0.5	45	0.25	45	0.59	45	42.73	4.86	47.59
G23	6.42	0.86	86.6	5.56	43	3.64	44	2.35	50	1.52	50	1.52	50	0.1	50	0.27	50	0.13	50	0.31	50	47.27	5.15	52.43
G24	8.15	2.67	67.24	5.48	42	5.41	25	4.66	24	4.02	26	1.18	42	0.4	24	0.84	24	0.33	42	0.76	42	31	8.6	39.6
G25	8.56	3.31	61.33	5.25	40	5.94	17	5.32	16	4.77	18	1.08	29	0.52	16	1.04	16	0.39	29	0.9	29	22.18	7.91	30.09
G26	4.24	1.42	66.51	2.82	12	2.83	50	2.45	49	2.13	49	1.17	40	0.11	49	0.45	49	0.33	40	0.78	40	43.18	10.62	53.81
G27	8.48	2.59	69.46	5.89	46	5.54	22	4.69	23	3.97	27	1.22	44	0.4	23	0.81	23	0.31	44	0.71	44	31.27	10.64	41.92
G28	7.39	1.63	77.94	5.76	45	4.51	33	3.47	40	2.67	45	1.37	47	0.22	40	0.51	40	0.22	47	0.51	47	41.45	6.43	47.88
G29	8.04	4.33	46.14	3.71	17	6.19	15	5.9	13	5.63	13	0.81	13	0.64	13	1.36	13	0.54	13	1.25	13	14.36	3.02	17.39
G30	8.07	3.37	58.24	4.7	32	5.72	20	5.21	20	4.75	19	1.02	26	0.5	20	1.06	20	0.42	26	0.97	26	22.55	4.21	26.75

G31	9.97	4.97	50.15	5	36	7.47	4	7.04	3	6.63	4	0.88	16	0.91	3	1.56	3	0.5	16	1.16	16	10.18	9.76	19.94
G32	5.09	3.52	30.84	1.57	3	4.31	35	4.23	30	4.16	23	0.54	4	0.33	30	1.11	30	0.69	4	1.61	4	20.09	13.96	34.05
G33	8.44	4.92	41.71	3.52	15	6.68	12	6.44	10	6.22	9	0.73	9	0.76	10	1.55	10	0.58	9	1.35	9	10.82	2.92	13.74
G34	5.04	2.4	52.38	2.64	9	3.72	43	3.48	39	3.25	38	0.92	20	0.22	39	0.75	39	0.48	20	1.11	20	31.55	11.37	42.92
G35	8.33	5.36	35.65	2.97	13	6.85	10	6.68	9	6.52	6	0.63	6	0.82	9	1.68	9	0.64	6	1.5	6	8.82	4.02	12.84
G36	5.92	2.01	66.05	3.91	20	3.97	39	3.45	41	3	41	1.16	39	0.22	41	0.63	41	0.34	39	0.79	39	38.36	5.94	44.31
G37	7.11	2.52	64.56	4.59	28	4.82	30	4.23	29	3.72	30	1.13	37	0.33	29	0.79	29	0.35	37	0.82	37	31.64	3.5	35.13
G38	8.14	5.92	27.27	2.22	6	7.03	8	6.94	5	6.85	3	0.48	2	0.88	5	1.86	5	0.73	2	1.69	2	5.45	5.31	10.77
G39	4.91	2.1	57.23	2.81	11	3.51	46	3.21	44	2.94	43	1	25	0.19	44	0.66	44	0.43	25	0.99	25	35.64	11.38	47.02
G40	6.19	4.38	29.24	1.81	4	5.29	26	5.21	21	5.13	14	0.51	3	0.5	21	1.38	21	0.71	3	1.64	3	14.82	10.62	25.43
G41	8.48	3.35	60.5	5.13	38	5.92	18	5.33	15	4.8	16	1.06	27	0.52	15	1.05	15	0.4	27	0.92	27	21.09	7.22	28.31
G42	4.21	2.9	31.12	1.31	2	3.56	45	3.49	38	3.43	35	0.55	5	0.22	38	0.91	38	0.69	5	1.6	5	26.09	17.33	43.42
G43	4.44	1.71	61.49	2.73	10	3.08	49	2.76	48	2.47	47	1.08	30	0.14	48	0.54	48	0.39	30	0.89	30	39.18	11.98	51.17
G44	8.49	3.26	61.6	5.23	39	5.88	19	5.26	17	4.71	20	1.08	31	0.51	17	1.02	17	0.38	31	0.89	31	23.45	7.67	31.12
G45	5.12	2.8	45.31	2.32	8	3.96	40	3.79	36	3.62	31	0.8	11	0.26	36	0.88	36	0.55	11	1.27	11	26.36	12.72	39.08
G46	9.26	1.71	81.53	7.55	49	5.49	23	3.98	34	2.89	44	1.43	49	0.29	34	0.54	34	0.18	49	0.43	49	38.18	11.9	50.08
G47	9.29	4.45	52.1	4.84	33	6.87	9	6.43	11	6.02	11	0.91	19	0.76	11	1.4	11	0.48	19	1.11	19	14.82	6.89	21.7
G48	9.4	4.06	56.81	5.34	41	6.73	11	6.18	12	5.67	12	1	24	0.7	12	1.28	12	0.43	24	1	24	17.73	9.18	26.9
G49	9.65	5.01	48.08	4.64	29	7.33	5	6.95	4	6.6	5	0.84	14	0.88	4	1.57	4	0.52	14	1.21	14	9.64	7.33	16.96
G50	8.8	3.1	64.77	5.7	44	5.95	16	5.22	18	4.58	22	1.14	38	0.5	18	0.97	18	0.35	38	0.82	38	26	10.63	36.63

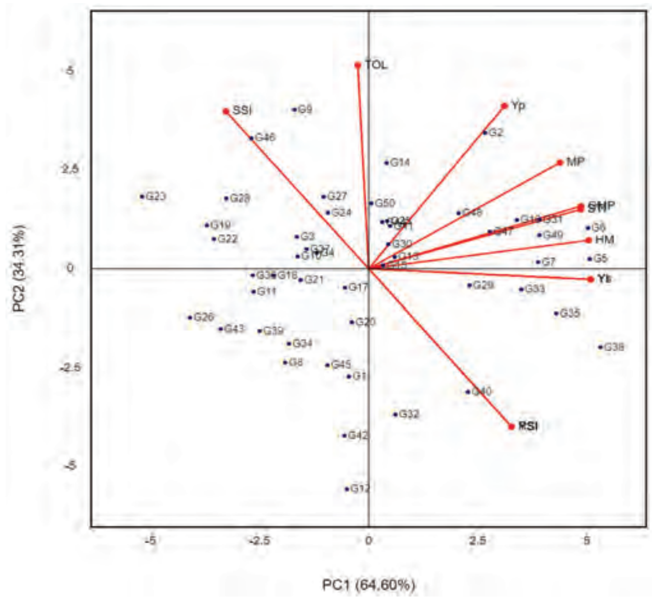
Yp, grain yield under well-water condition; Ys, grain yield under managed waterlogged condition; YR%, percent yield reduction; R, Ranks of genotype respective to the stress tolerance index; $\bar{R}$, Mean of all the ranks obtained from stress tolerance indices of a genotype; R_{SD} standard deviation of all the ranks obtained from stress tolerance indices of a genotype; R_S, sum of the mean rank and standard deviation of all the ranks

Bold values indicated the top best five hybrids



Yp, Grain yield under optimal; Ys, Grain yield under waterlogging; TOL, Tolerance index; MP, Mean productivity; GMP, Geometric mean productivity; HM, Harmonic mean productivity; SSI, Stress susceptibility index; STI, Stress tolerance index; YI, Yield index; YSI, Yield stability index; RSI, Relative stress index; **, significant at 0.01 percent (p<0.01); *, significant at 0.05 percent (p<0.05)

Fig. 2. Spearman's rank correlation coefficients among yield and nine stress tolerance indices estimated for waterlogging stress for 50 maize hybrids during *Kharif* 2018



PC1, First principal component 1; PC2, Second principal component; Yp, Grain yield under optimal; Ys, Grain yield under waterlogging; TOL, Tolerance index; MP, Mean productivity; GMP, Geometric mean productivity; HM, Harmonic mean productivity; SSI, Stress susceptibility index; STI, Stress tolerance index; YI, Yield index; YSI, Yield stability index; RSI, Relative stress index

Fig. 3. Biplot of principle component analysis (PCA) of 50 maize hybrids for grain yield under waterlogging stress (Ys), non-stress (Yp) and nine selection indices

and Yp suggesting that the selection for decreased TOL should give increased yield under non-stress conditions whereas almost no correlation (r=0.07) was observed between TOL and grain yield under waterlogging stress.

Grain yield under both the conditions showed highly positive and significant correlation with GMP, MP, HM, STI and YI especially under waterlogging stress conditions. Hence, selection for high GMP, MP, HM, STI and YI would give positive response in terms of grain yield at both conditions. Similarly, Singh *et al*. (2017) and Jafari *et al*. (2009) found that STI and GMP indices showed strong positive association with grain yield under both stress and stress-free conditions, and these could be used as the best selection indices for maize breeding programs. Selection indices *viz*., SSI, YSI and RSI had negative correlation with grain yield under well-irrigated condition while these had positive correlation with grain yield under managed waterlogging condition. This suggested that these selection indices would be worthwhile where the target condition is waterlogging or flood prone. Similar results were reported by Khalili *et al.* (2004), Khodarampour *et al.* (2011) and Singh *et al*. (2017). Farshadfar *et al*. (2001), Majid and Roza (2010), Naghavi *et al*.(2013), Mani and Deshpande *et al.* (2016) and Arisandy *et al*. (2017) reported that the stress indices showed relatively significant correlation with grain yield.

The relationships among different indices and with grain yield under both the moisture conditions are graphically depicted in a biplot of PCA1 and PCA2 (Fig. 3). The first principal component (PC1) contributed around 64.6% and second principal component explained about 34.3% of total variation. Both the components explained around 98.91% of total variation contributed by all the selection indices and grain yields under both conditions. This suggested the goodness of fit of the biplot constructed. The PCA1 and PCA2 mainly discriminate the selection indices in different groups based on association among them. One of the noteworthy interpretations of biplot is that the cosine of the angle between the vectors of any two indices represents the correlation coefficient between them. The cosine of the angles would be translated precisely into correlation coefficients, since the biplot explained almost all of the variation in the data set. The "waterlogging resistance" should be based on yield stability under excess soil moisture stress. Thus the hybrids with low variation under different field conditions could be reflected as "waterlogging resistant" hybrids. In our study, MP, GMP, HM, YI and RSI can be considered as the potential surrogates to screen "waterlogging resistant" hybrids as they are strongly associated (acute angle, <90°) with YSI (yield stability index). In contrast to this, "waterlogging stress tolerance" should not be based on stability in yield but it refers to hybrids with acceptable yield potential under excess moisture stress and maximum yield potential under well-irrigated conditions. Thus, the indices *viz*., TOL and SSI would be more beneficial for screening "waterlogging tolerant" hybrids as they are not positively associated with YSI (right angle, >90°). Kachapur *et al*. (2015) conducted principal component analysis and concluded STI and GMP were able to identify maize cultivars producing high yield in both water deficit and well-watered field conditions while TOL and SSI were found to be more beneficial indices in discriminating resistant cultivars under severe stress conditions. Khodarahmpour and Hamidi (2011) also reported similar results by performing PCA for the five stress tolerance indices estimated at different vegetative growth stages of maize inbred lines.

Based on the rank-sum approach of all selection indices, the hybrids VH121082, ZH17191, ZH161034, ZH16929-2, and ZH161531 were found as waterlogging stress tolerant. The selection indices MP, GMP, HM, STI, and YI demonstrated a substantial positive connection with yield under waterlogging and optimal moisture conditions, indicating that these indices would be suggested for screening maize hybrids under water logging stressed conditions.

Authors' contribution

Conceptualization and designing of the research work (AS, JPS, PHZ); Execution of field/lab experiments and data collection (AS, MK); Analysis of data and interpretation (KS, AS); Preparation of manuscript (AS).

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