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RESEARCH PAPER

Association between drought tolerance traits, yield components and yield under moisture stress condition in maize

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Abstract: Maize is one of the important cereal crops with diverse uses. The production potential of the crop is affected by drought stress worldwide especially under changing climate scenario. The present investigation was carried out under simulated moisture stress condition to study association of drought tolerance traits, yield components with grain yield in maize hybrids. Significant genetic variability was observed among maize hybrids for phenological, physiological and yield attributing traits. Significant positive correlation was observed between drought tolerance traits (RWC at 75 DAS, SLW at 60 DAS), phenological (plant height, ear height, total number of leaves), yield components (cob length, cob girth, number of kernel rows per cob, number of kernels per row, cobs per plant and harvest index) and seed yield. Seed yield had significant negative correlation with proline content at 75 DAS both at phenotypic and genotypic level. Drought tolerance traits *viz.,* RWC (60 and 75 DAS), SLW (60 DAS), proline (60 DAS), pollen fertility, days to 50% silking and yield components *viz.,* number of kernels per row, cobs per plant, shelling percentage and harvest index exhibited high positive direct effect. Thus, these traits can be used as selection criteria since these traits were found to be the important direct contributors for grain yield under moisture stress condition.

Key words: Drought tolerance, Maize, Moisture stress, Yield

Introduction

Maize (*Zea mays* L.), the world's leading cereal crop is known for its highest genetic yield potential (ICAR-IIMR, 2021). Maize has multiple uses *viz.,*food for human beings, fodder for livestock, feed for poultry and raw material for food, medicine and textile industries. A plant may experience biotic and abiotic stresses in the field like disease attack, water scarcity, water logging, salinity, high and low temperature extremes etc. either continuously or with some breaks at different times during the growing season (Trester and Bacic, 2005). Among the abiotic stresses, drought is one of the major constraints, as nearly 80% of the maize crop is grown under rainfed condition (Rijsberman *et al.,* 2004). Depending on the duration and intensity of moisture stress and crop stage, yield losses may vary from 30 to 90% (Sah *et al.,* 2020). Under the climate change scenario due to global warming, breeding for drought tolerance has become an important objective in all maize growing areas.

The best option for good production, crop yield improvement and yield stability under drought stress conditions is to develop drought tolerant crop varieties. One of the major goals of drought breeding programs is selection of the lines/ cultivars/genotypes which are performing best under stress conditions. However, low heritability of drought tolerance and complex nature along with lack of effective selection procedures limit development of drought tolerant crop cultivars . Therefore, the traits influencing yield are understood through correlation studies to determine the nature and extent of relationships between yield and other yield attributing traits. Yield improvement and stability is the primary objective of a plant breeder. Therefore, correlation analysis of a particular trait with other traits attributing to yield is of great importance for selecting lines for higher yield. Further, path analysis helps to partition the correlation coefficient into its direct and indirect effects (Gazal *et al.,* 2017).

Drought tolerance is conditioned by various mechanisms *viz*., maintaining chlorophyll content, relative water content, specific leaf area, accumulation of proline and wax content to combat drought situation. Drought being complex trait, selection based on secondary traits *viz.,* leaf senescence, anthesis silking interval, relative water content, leaf rolling, ears per plant occupies importance (Obeng-Bio *et al.* 2011, Chen *et al.,* 2016, Raouf *et al*., 2016). Proline accumulation showed positive correlation with drought stress (Efeoglu, 2009, Witt *et al.,* 2012, Yin *et al.,* 2012, Rahul *et al.,* 2018). Therefore, the drought tolerant cultivars in maize can be developed by the introgression of these mechanisms in the elite inbreds and combining them in hybrid cultivars through genetic approaches. Significant negative association of yield with days to 50% silking, anthesis to silking interval, RWC at 90 DAS was reported (Kuchanur *et al*., 2013).

Drought in maize ultimately results in yield reduction. Therefore, there is necessity to study the yield attributing traits and their association with yield under moisture stress in addition to studying the drought tolerance traits. Significant positive association of seed yield with cob length, cob girth, number of grains per row, number of ears per plant and 100 grain weight were noted both at genotypic and/or phenotypic levels under moisture stress condition (Kuchanur *et al*., 2013, Barutcular *et al.* 2016)

Though correlation gives the relationship between any two traits, it will not give cause and effect relationship. Path analysis helps in identification of those components with significant

Table 1. Weather data over the years (1950 -2021) and during the crop period (December 2021 to April 2022)

Month	Rain fall (mm)		Rainy days		Temperature (°C)				Relative humidity (%)			
					Maximum		Minimum		Maximum		Minimum	
	1950-2021	2021-2022	1950-2021	2021-2022	1950-2021	2021 -2022	1950-2021	2021 -2022	1950-2021	2021-2022	1950-2021	2021-2022
December 2021	0.4	27.4	1.0	2.0	28.5	28.1	14.2	14.5	60.9	87.1	56.5	75.4
January 2022	2.0	0.0	0.0	0.0	29.8	28.2	14.2	13.2	76.0	78.2	52.0	51.9
February 2022	2.6	0.0	0.0	0.0	32.4	32.0	16.0	15.1	71.0	61.8	43.0	32.9
March 2022	15.3	48.8	1.0	6.0	35.3	34.2	19.1	18.9	73.0	66.1	35.0	36.7
April 2022	39.2	114.4	3.0	8.0	36.5	34.8	20.8	21.1	79.0	75.7	37.0	52.5
Mean/Total	59.5	190.6	5.0	16.0	32.5	31.5	16.9	16.6	72.0	73.9	44.7	49.9

effects on yield for potential use as selection criteria (Board *et al.,* 1997; Moghaddam *et al.,* 1998). Breeders have utilized path-coefficient analysis for assessing the direct and indirect effects of different morphological and yield components on grain yield in maize (Kumar *et al*., 2017 and Kandel *et al.,* 2018). These studies have shown that, days to 50% tasseling, days to 50% silking, plant height, cob length, cob girth and 100 grain weight as most important yield contributing traits having direct effect on yield in maize. But less effort has been done on the study of direct and indirect contribution of different yield components on yield under heat stress (Jodage *et al.,* 2017) and morphological traits on yield (Dao *et al.,* 2017) under drought. In the present study, effort was made to assess the association of various morphological, phenological, physiological, biochemical and yield components with the grain yield under moisture stress condition in maize hybrids. Further, direct and indirect contribution of different drought tolerance traits and yield components on grain yield was studied.

Material and methods

The study was carried out during post-rainy season of 2021-22 at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad. Post-rainy season was chosen for the study to ensure rain free period during drought simulation period. The details of the different weather parameters during the crop growth period are provided in Table 1.

Seven maize inbreds were crossed during *kharif* 2021 in a half diallel fashion to generate 21 hybrids. Among the seven maize inbreds, six (IMIC 2024, GPM 114, PDM 4641, CAL 1426-2, CML 451 and CML 582) were tolerant/moderately tolerant to drought while one maize inbred, IMIC 2030 was drought susceptible (Hugar, 2021). The hybrids were sown on 14th December 2021 by following randomized block design with two replications under simulated moisture stress condition (Table 2). In each replication, individual maize hybrids were hand dibbled in two rows of 3 m row length with a spacing of 60 cm between rows and 20 cm between plants so as to have at least 28 plants in each plot.

Irrigation was provided at an interval of 10-12 days until 55 DAS. Thereafter, artificial moisture stress condition was created by withholding irrigation until 85 DAS. This period was coinciding with the pre-tasselling to initiation of seed formation and it corresponded to 637^{o}C growing degree day units (GDDU) to 1021.5 ^{o}C GDDU (Zaman *et al*., 2016). The irrigation schedule was restored on 86 DAS. GDDU indicates the stage of crop suited to induce stress in a particular location. All other recommended agronomic and plant protection practices were followed to raise a good crop. Soil moisture was measured randomly from five spots at 15 days interval.

Randomly selected five plants from each maize hybrid were tagged from both the rows (2 or 3 plants in each row) to account for row effect at 30 days after sowing (DAS) for recording morpho-physiological observations. Relative water content (Barrs and Weatherly, 1962), specific leaf weight, SPAD chlorophyll meter reading, proline content (Bates *et al.,* 1973) and wax content (Ebercon *et al.,* 1977) were recorded twice at 60 and 75 DAS following standard procedures. Besides, pollen fertility at 50% tasseling, days to 50% tasseling and days to 50% silking were also recorded. Anthesis-silking interval was calculated as the difference between the days to 50% tasselling and days to 50% silking. Plant height, ear height, number of dry leaves and total number of leaves were recorded at the time of harvest by counting the leaves. Post-harvest observations *viz.,* cob length, cob girth, number of kernel rows per cob, number of kernels per row were measured from randomly selected five cobs. Shelling percentage and 100 seed weight were recorded

Table 2. List of maize hybrids and drought reaction status of their parental inbreds

Hybrids	Drought reaction status
IMIC 2024 × GPM 114	T X T
IMIC 2024 × CML 451	T X T
IMIC 2024 × PDM 4641	T X T
IMIC 2024 × CML 582	T X T
IMIC 2024 × CAL 1426-2	T X T
IMIC 2024 × IMIC 2030	T X S
GPM 114 × CML 451	T X T
GPM 114 × PDM 4641	T X T
GPM 114 × CML 582	T X T
GPM 114 × CAL 1426-2	T X T
GPM 114 × IMIC 2030	T X S
CML 451 × PDM 4641	T X T
CML 451 × CML 582	T X T
CML 451 × CAL 1426-2	T X T
CML 451 × IMIC 2030	T X S
PDM 4641 × CML 582	T X T
PDM 4641 × CAL1 426-2	T X T
PDM 4641 × IMIC 2030	T X S
CML 582 × CAL 14262	T X T
CML 582 × IMIC 2030	T X S
CAL 1426-2 × IMIC 2030	T X S

T- Drought tolerant, S- Drought susceptible from a sample of cobs. Shelling percentage was measured as the ratio of kernels to the cob weight and expressed in percentage. The grain yield was recorded from the total plot of each maize hybrid and expressed in kg/ha using appropriate conversion factor and considering the moisture content of maize hybrids at the time of harvest. Harvest index was calculated as ratio of grain yield to the total biomass in the entire plot of each hybrid.

Statistical analysis

The data recorded on various traits during field experimentation was analyzed using R Studio (version 4.2.1) statistical package. The analysis of variance for randomized block design was carried out as per the model proposed by Panse and Sukhatme (1967).

The statistical parameters namely, phenotypic correlation coefficient (rp), genotypic correlation coefficient (rg) and path coefficient analysis were computed for all the traits to assess character association using R software (4.2.1). Different statistical methods employed for the analysis are presented below.

Genotypic and phenotypic correlation coefficients were calculated using the method given by Johnson *et al.* (1955).

$$\text{Genotypic correlation } rg\,(X_iX_j) = \frac{COVg\,(X_iX_j)}{\sqrt{V_g\,(X_i)\,V_g\,(X_j)}}$$

Where,

$r_g\,(X_iX_j)$ = Genotypic correlation between i^{th} and j^{th} character
$V_g\,(X_i)$ = Genotypic variance of i^{th} character
$V_g(X_j)$ = Genotypic variance of j^{th} character
$COV_g\,(X_iX_j)$ = Genotypic covariance between i^{th} and j^{th} character

$$\text{Phenotypic correlation } rp\,(X_iX_j) = \frac{COVp\,(X_iX_j)}{\sqrt{V_p\,(X_i)\,V_p\,(X_j)}}$$

Where,

$r_p\,(X_iX_j)$ = Phenotypic correlation between i^{th} and j^{th} character
$V_p(X_i)$ = Phenotypic variance of 'i^{th}' character
$V_p(X_j)$ = Phenotypic variance of 'j^{th}' character
$COV_p(X_iX_j)$ = Phenotypic covariance between 'i^{th}' and 'j^{th}' character

The significance of correlation coefficients was tested by comparing the genotypic and phenotypic correlation coefficients with table 'r' value [Fisher and Yates (1963)] at (n-2) degrees of freedom at 5 and 1% probability level where, 'n' denotes the number of treatments tested.

Path coefficient analysis was carried out by the procedure originally proposed by Wright (1921, 1923) which was subsequently elaborated by Dewey and Lu (1959) to estimate the direct and indirect effects of the individual characters on yield.

Besides the direct and indirect effects, the residual effect which measures the contribution of the characters not considered in the causal scheme was obtained as:

$$\text{Residual effect } (P_{RY}) = \sqrt{1-[P_{1y}r_{1y}+p_{2y}r_{2y}+.........+P_{iy}r_{iy}]^2}$$

Where,

P_{RY} = Residual effect
P_{iy} = Direct effect of 'x_i' on 'y'
r_{iy} = Correlation coefficient of 'x_i' with 'y'

The scales for path coefficients as proposed by Lenka and Mishra (1973) are as follows:

Value for Direct or Indirect effect	Rate or Scale
0.00 - 0.09	Negligible
0.10 - 0.19	Low
0.20 - 0.29	Moderate
0.30 - 0.99	High
> 1.00	Very High

Results and discussion

Twenty-one maize hybrids were evaluated under moisture stress condition during *rabi* season to avoid obstruction to the experiment due to rains. Weather data of 70 years at the experimental location has indicated very less rainfall during December to March months (<16 mm) and hence the experiment was conducted during this period. The mid-season water stress was simulated by withholding irrigation from 55^{th} to 85^{th} day after sowing to coincide it with the pre-tasseling and silking periods. During *rabi* 2021, only 6 mm rainfall was received during moisture stress treatment period favouring the drought stress induction. The soil moisture got depleted from 36% at 45 DAS to 15.14% at 85 DAS (Fig 1). The temperature and relative humidity during the drought simulation period was around the optimum and hence, the experimental results were not much compounded by heat stress effects (Table 1).

Mean sum of squares attributed to genotypes for physiological (Table 3A), phenological (Table 3B) and yield and yield attributing traits except cob length (Table 3C) was significant indicating presence of significant variability among maize hybrids under moisture stress condition. Earlier, Khalily *et al.* (2010), Kuchanur *et al.* (2013) and Barutcular *et al.* (2016) reported significant differences among maize genotypes under moisture stress condition. Significant genotypic variability could be due to involvement of drought tolerant and susceptible inbreds in the pedigree of studied maize hybrids.

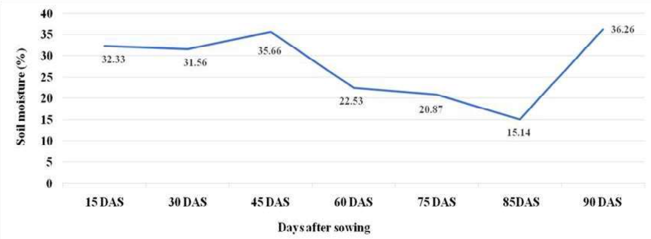

Fig 1. Soil moisture status of experimental plot

Genotypic correlations were slightly higher in magnitude than phenotypic correlations which indicate that though, there was a strong inherent association between characters studied; its expression was reduced due to the influence of moisture stress. There was a significant positive correlation of grain yield with relative water content at 75 DAS, specific leaf weight at 60 DAS, plant height, ear height, total number of leaves, cob length, cob girth, number of kernel rows per cob, number of kernels per row, number of cobs per plant and harvest index at both phenotypic and genotypic level under moisture stress condition (Table 4). These results suggested exploiting correlated response of drought tolerance traits like relative water content and specific leaf weight and yield components with grain yield during selection under moisture stress condition. Monneveux *et al.*, 2006; Kuchanur *et al.,* 2013; Rajwade *et al.*, 2018; Chaurasia *et al.*, 2020 and Hugar, 2021 also noted significant positive correlation between relative water content, specific leaf weight and grain yield under moistures stress indicating significant effect of moistures stress on these traits.

Significant negative correlation was noted between proline content at 75 DAS and grain yield at genotypic and phenotypic level under moisture stress condition (Table 4) which could be due to diversion of energy towards proline production thus affecting grain yield under moisture stress condition. Contrary to the present results, Hugar (2021) reported significant positive correlation between grain yield and proline under moisture stress condition while studying maize inbreds. This could be because of differential response of maize inbreds and hybrids under moisture stress.

Non-significant correlation of grain yield with days to 50% tasseling, days to 50% silking and anthesis-silking interval at genotypic and phenotypic level under moisture stress condition suggested independent nature of these traits in the studied maize hybrids. This could be related to the drought tolerant inbreds in the pedigree of majority of these hybrids (Table 2). This indicated that the moisture stress induced in the present experiment during pre-tasselling, pre-silking and initiation of tasselling has not affected much on these traits. Monneveux *et al.* (2006), Obeng Bio *et al.,* 2011, Pavan *et al*., 2011, Khalily *et al*., 2010, Asima *et al.,* 2018, Ahmed *et al.,* 2020 also reported non-significant correlation for days to 50% silking and anthesis-silking interval under moisture stress condition. Contrary to the present results, Kuchanur *et al.* (2013), Al-Naggar *et al.* (2016), Kandel *et al.* (2018) and Chaurasia *et al.*(2020) reported significant negative correlation between grain yield and anthesis-silking interval, days to 50% anthesis, barren stalks and leaf rolling under moisture stress condition.

Significant correlation coefficients may not always show the true picture of association or could mislead the decision on selection of traits because the correlation between two variables may be due to a third factor. Therefore, it is necessary to analyse the cause and effect relationship between the variables. Path coefficient analysis helps in partitioning the correlation coefficient into direct and indirect effects and provides the information on actual contribution of a trait on the yield (Dewey and Lu, 1959).

The residual value for genotypic path coefficient with grain yield as dependent character was 0.11. This indicates that the study covered 89% of the characters under moisture stress which influence grain yield at genotypic level. The path coefficient analysis revealed that relative water content (60 and 75 DAS), specific leaf weight at 60 DAS, proline content

Table 3. Mean sum of squares due to different sources of variation for various traits in maize hybrids under moisture stress condition

A) Physiological parameters

Source of	df	RWC		SLW		SCMR		Proline		Wax		Pollen
Variation		60 DAS	75 DAS	60 DAS	75 DAS	60 DAS	75 DAS	60 DAS	75 DAS	60 DAS	75 DAS	fertility
Replication	1	1.56	10.16	0.01	0.24	1.73	1.18	0.04	0.02	0.01	0.01	0.86
Genotypes	20	116.50***	323.02***	0.08***	0.17***	10.57***	77.19***	33.50***	80.50**	3.15***	.41***	3.35***
Error	20	5.59	2.15	0.01	0.02	0.65	0.63	0.02	0.06	0.01	0.01	0.17
Total	41	123.65	335.33	0.10	0.43	12.95	79.00	33.56	80.58	3.17	4.43	4.38

B) Phenological parameters

Source of Variation	df	DFT	DFS	ASI	PH	EH	TL	DL
Replication	1	0.03	0.59	0.38	14.88	4.67	0.16	0.01
Genotypes	20	8.93***	36.83***	22.45***	736.13***	184.38***	1.36***	1.15***
Error	20	1.17	0.39	1.18	3.70	0.42	0.01	0.03
Total	41	10.13	37.81	24.01	754.71	189.47	1.53	1.19

C) Yield and yield components

Source of variation	df	Cob length	Cob girth	KRN	NKR	NCP	S %	100 GW	HI	GY
Replication	1	0.09	0.01	0.38	1.23	0.05	0.30	2.33	0.03	0.32
Genotypes	20	1.91	0.20***	1.21**	26.28***	0.04**	16.19***	29.46**	41.84***	5.75***
Error	20	1.21	0.01	0.34	1.73	0.01	1.25	0.97	1.08	0.06
Total	41	3.21	0.22	1.93	29.24	0.1	17.74	32.76	42.95	6.13

*, ** and *** - Significant at 0.05, 0.01 and 0.001 level of probability, respectively.

df - degrees of freedom
RWC - Relative water content
SLW - Specific leaf weight
SCMR - SPAD chlorophyll meter reading
DFT - Days to 50% tasseling
DFS - Days to 50% silking
ASI- Anthesis-silking interval
PH- Plant height
EH- Ear height
TL- Total number of leaves
DL- Total number of dry leaves
NCP- Number of cobs per plant
KRN- Number of kernel rows per cob
NKR- Number of kernels per row
S %- Shelling percentage
100 GW- 100 Grain weight
GY- Grain yield
DAS- Days after sowing

Table 4. Phenotypic (above diagonal) and genotypic (below diagonal) correlation among various traits under moisture stress condition in maize hybrids

Character	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18	X19	X20	X21	X22	X23	X24	X25	X26	X27
X1	1.00	0.16	-0.22	-0.01	-0.19	-0.42	0.31	0.23	-0.08	-0.29	-0.05	0.02	0.13	0.15	0.09	0.17	0.01	0.03	-0.08	0.09	0.05	-0.10	-0.17	-0.27	-0.01	-0.09	-0.29
X2	0.17	1.00	0.33	0.18	0.23	-0.23	-0.03	-0.07	0.01	-0.28	0.30	-0.02	-0.29	-0.35	0.25	0.39*	0.49**	0.21	0.29	0.30	0.13	0.31	0.35	0.18	0.03	0.41*	0.49**
X3	-0.19	0.36	1.00	0.19	0.21	-0.11	-0.13	-0.11	-0.07	-0.04	0.31	-0.04	-0.19	-0.21	0.32	0.41*	0.09	0.04	0.34	0.10	-0.10	0.38*	0.33	0.13	0.12	0.23	0.46*
X4	-0.09	0.23	0.33	1.00	-0.03	0.19	0.02	0.20	-0.37	-0.23	0.34	0.04	-0.23	-0.31	0.12	0.17	0.08	-0.15	-0.03	-0.10	-0.21	0.27	0.14	0.15	-0.18	0.22	0.14
X5	-0.18	0.24	0.27	0.05	1.00	0.22	-0.32	-0.13	0.03	-0.03	-0.13	-0.31	-0.62**	-0.57**	0.10	0.24	-0.26	-0.23	0.12	-0.12	0.14	0.14	0.37	-0.06	-0.40*	0.55**	0.26
X6	-0.44*	-0.24	-0.15	0.22	0.22	1.00	-0.01	-0.07	-0.30	-0.27	-0.20	-0.07	-0.35	-0.43*	-0.30	-0.22	-0.31	-0.45*	0.12	-0.15	0.04	0.09	-0.07	-0.23	-0.34	0.20	0.08
X7	0.33	-0.03	-0.15	0.03	-0.34	-0.01	1.00	0.83**	-0.18	-0.34	-0.37	0.12	0.03	-0.04	-0.14	-0.20	-0.08	-0.47*	0.18	0.07	-0.03	0.35	-0.21	0.12	-0.13	-0.24	-0.31
X8	0.25	-0.07	-0.13	0.22	-0.14	0.07	0.83**	1.00	-0.18	-0.26	-0.23	0.01	-0.18	-0.23	-0.33	-0.37	-0.21	-0.5**	0.07	-0.31	-0.32	0.33	-0.10	0.32	-0.48**	-0.16	-0.43*
X9	-0.09	0.01	-0.08	-0.41*	0.03	-0.30	-0.18	-0.18	1.00	0.78**	-0.02	-0.06	0.07	0.13	0.15	0.05	-0.19	0.10	-0.03	0.07	-0.16	-0.27	0.17	0.04	0.17	-0.23	0.04
X10	-0.31	-0.27	-0.05	-0.25	-0.04	-0.27	-0.34	-0.26	0.78**	1.00	0.03	-0.05	0.12	0.18	0.17	-0.01	-0.21	0.04	-0.16	-0.21	-0.24	-0.27	0.15	0.14	0.21	-0.31	0.07
X11	-0.08	0.31	0.41*	0.44*	-0.15	-0.20	-0.38*	-0.24	-0.02	0.03	1.00	0.07	0.03	-0.01	0.22	0.11	0.22	0.29	-0.20	-0.01	-0.04	-0.03	0.07	0.45*	0.01	0.12	0.25
X12	0.08	-0.03	-0.08	0.19	-0.45*	-0.06	0.14	-0.01	-0.07	-0.06	0.03	1.00	0.61**	0.11	0.23	0.08	0.14	-0.3	0.13	0.21	0.02	0.03	-0.41*	-0.09	0.27	-0.14	-0.17
X13	0.12	-0.29	-0.20	-0.26	-0.65**	-0.36	0.03	-0.19	0.07	0.12	0.03	0.68**	1.00	0.86**	0.17	-0.06	0.21	0.40*	-0.05	0.23	0.09	-0.43*	-0.45*	-0.18	0.66**	-0.57**	-0.30
X14	0.12	-0.37	-0.21	-0.46*	-0.58**	-0.43*	-0.04	-0.24	0.14	0.19	0.02	0.29	0.90**	1.00	0.01	-0.13	0.17	0.52**	-0.15	0.16	0.10	-0.55**	-0.25	-0.17	0.65**	-0.63**	-0.27
X15	0.10	0.26	0.38*	0.15	0.10	-0.30	-0.14	-0.34	0.16	0.17	0.24	0.26	0.18	0.07	1.00	0.90**	0.32	0.26	0.43*	0.68**	0.48**	0.30	0.27	0.02	0.54**	0.26	0.53**
X16	0.17	0.40*	0.49**	0.17	0.26	-0.22	-0.20	-0.37	0.05	-0.01	0.12	0.11	-0.06	-0.15	0.91**	1.00	0.34	0.26	0.44*	0.66**	0.45*	0.38*	0.32	-0.08	0.39*	0.39*	0.56**
X17	0.02	0.50**	0.10	0.08	-0.28	-0.33	0.08	-0.21	-0.19	-0.21	0.24	0.17	0.22	0.18	0.32	0.34	1.00	0.72**	0.14	0.55**	0.22	0.33	0.27	0.10	0.41*	0.25	0.49**
X18	0.02	0.22	0.05	-0.20	-0.22	-0.47*	-0.48**	-0.51**	0.10	0.04	0.30	0.04	0.41*	0.51**	0.27	0.27	0.72**	1.00	-0.13	0.43*	0.13	-0.10	0.20	0.06	0.53**	0.02	0.28
X19	-0.09	0.56**	0.58**	0.03	0.34	0.21	0.37	-0.13	-0.06	-0.32	-0.14	0.65**	-0.06	-0.48**	0.50**	0.52**	0.27	-0.30	1.00	0.45*	0.31	0.51**	0.30	-0.22	0.24	0.38*	0.46*
X20	0.12	0.32	0.15	-0.11	-0.14	-0.16	0.07	-0.33	-0.07	-0.22	0.03	0.27	0.26	0.17	0.72**	0.70**	0.59**	0.44*	0.69**	1.00	0.69**	0.40*	0.17	-0.07	0.68**	0.28	0.49*
X21	0.02	0.19	-0.12	-0.43*	0.24	0.05	-0.04	-0.42*	-0.21	-0.31	-0.05	0.13	0.14	0.11	0.64**	0.53**	0.31	0.19	0.65**	0.82**	1.00	0.17	0.11	-0.13	0.34	0.31	0.38*
X22	-0.07	0.33	0.41*	0.38*	0.19	0.09	0.37	0.35	-0.29	-0.29	0.01	0.07	-0.44*	-0.62**	0.33	0.41*	0.34	-0.13	0.68**	0.41*	0.17	1.00	0.44*	0.29	-0.11	0.60**	0.52**
X23	-0.36	0.49**	0.71**	0.15	0.58**	-0.12	-0.29	-0.13	0.23	0.21	0.15	-0.39	-0.58**	-0.52**	0.36	0.41*	0.37	0.21	0.49*	0.18	-0.16	0.53**	1.00	0.05	0.05	0.59**	0.71**
X24	-0.25	0.20	0.16	0.24	-0.10	-0.27	0.13	0.35	0.04	0.15	0.50**	-0.16	-0.21	-0.18	0.03	-0.09	0.12	0.08	-0.42*	-0.07	-0.18	0.34	0.07	1.00	-0.16	-0.08	0.01
X25	0.02	0.02	0.11	-0.20	-0.44*	-0.36	-0.14	-0.50**	0.17	0.22	0.05	0.32	0.68**	0.70**	0.55**	0.41*	0.43*	0.56**	0.38*	0.71**	0.39*	-0.14	0.04	-0.17	1.00	-0.22	0.29
X26	-0.10	0.43*	0.33	0.29	0.57**	0.21	-0.25	-0.16	-0.24	-0.32	0.14	-0.15	-0.60**	-0.69**	0.27	0.41*	0.26	0.02	0.70**	0.29	0.45*	0.63**	0.75**	-0.10	-0.26	1.00	0.66**
X27	-0.30	0.50**	0.53**	0.17	0.29	0.08	-0.31	-0.43*	0.04	0.07	0.27	-0.19	-0.31	-0.29	0.53**	0.56**	0.50**	0.29	0.88*	0.52**	0.42*	0.54**	0.93**	0.01	0.29	0.69**	1.00

X1- Relative water content (60 DAS)
X2 - Relative water content (75 DAS)
X3 - Specific leaf weight (60 DAS)
X4 - Specific leaf weight (75 DAS)
X5 - SCMR (60 DAS)
X6 - SCMR (75 DAS)
X7- Proline (60 DAS)
X8- Proline (75 DAS)
X9- Wax (60DAS)
X10- Wax (75DAS)
X11- Pollen fertility
X12- Days to 50 % tasseling
X13- Days to 50 % silking
X14 - Anthesis-Silking interval
X15 - Plant height
X16- Ear height
X17- Total number of leaves
X18- Number of dry leaves
X19- Cob length
X20- Cob girth
X21- Number of kernel rows per cob
X22- Number of kernels per row
X23- Number of cobs per plant
X24- Shelling percentage
X25- 100 grain weight
X26- Harvest index
X27- Grain yield

Table 5. Direct (diagonal) and indirect effects of various characters on grain yield at genotypic level in maize hybrids under moisture stress condition

Characters	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18	X19	X20	X21	X22	X23	X24	X25	X26
X1	0.69	-0.15	-0.17	0.03	0.09	-0.08	0.28	-0.42	0.01	0.31	0.09	-0.18	0.68	-0.80	0.35	-0.54	0.01	0.01	-0.01	-0.01	-0.01	0.12	0.41	-0.23	-0.01	0.05
X2	0.12	0.88	0.32	-0.07	-0.12	-0.04	-0.03	0.12	-0.01	0.28	-0.34	0.06	-1.59	2.56	0.93	-1.27	0.36	0.16	0.06	-0.03	-0.04	-0.57	0.56	0.19	-0.01	-0.24
X3	-0.13	-0.31	0.91	-0.10	-0.13	-0.03	-0.12	0.22	0.01	0.05	-0.45	0.19	-0.19	1.48	1.37	-1.56	0.07	0.04	0.06	-0.01	0.23	-0.71	0.80	0.15	-0.02	-0.18
X4	-0.06	-0.20	0.30	-0.31	-0.03	0.04	0.03	-0.38	0.07	0.26	-0.48	-0.44	-1.42	3.19	0.53	-0.54	0.05	-0.15	0.01	0.01	0.10	-0.65	0.17	0.22	0.03	-0.16
X5	-0.12	-0.21	0.25	-0.02	-0.50	0.04	-0.29	0.24	-0.01	0.04	0.17	1.04	-3.56	4.05	0.36	-0.83	-0.20	-0.16	0.04	0.01	-0.06	-0.34	0.67	-0.09	0.08	-0.31
X6	-0.30	0.21	-0.14	-0.07	-0.11	0.19	-0.01	0.12	0.05	0.27	0.21	0.14	-1.94	2.99	-1.09	0.70	-0.24	-0.34	0.02	0.01	-0.01	-0.15	-0.14	-0.25	0.06	-0.12
X7	0.23	0.03	-0.13	-0.01	0.17	-0.01	0.84	-1.45	0.03	0.34	0.42	-0.31	0.16	0.31	-0.51	0.63	-0.06	-0.35	0.04	-0.01	0.01	-0.64	-0.32	0.12	0.03	0.14
X8	0.17	0.06	-0.11	-0.07	0.07	-0.01	0.70	-1.74	0.03	0.26	0.26	0.01	-1.02	1.70	-1.22	1.16	-0.15	-0.37	-0.01	0.03	0.10	-0.61	-0.15	0.33	0.02	0.09
X9	-0.06	-0.01	-0.07	0.13	-0.02	-0.06	-0.15	0.31	-0.17	-0.79	0.02	0.15	0.40	-0.95	0.56	-0.15	-0.14	0.07	-0.01	0.01	0.05	0.50	0.26	0.04	0.09	0.13
X10	-0.21	0.24	-0.04	0.08	0.12	-0.05	-0.28	0.45	-0.13	-1.01	-0.04	0.14	0.64	-1.34	0.63	0.02	-0.15	0.03	-0.03	0.02	0.07	0.51	0.24	0.14	-0.03	0.18
X11	-0.05	-0.27	0.37	-0.14	0.08	-0.04	-0.33	0.42	0.01	-0.03	1.09	-0.07	0.14	-0.11	0.86	-0.38	0.17	0.22	-0.01	-0.01	0.01	-0.01	0.17	0.46	-0.04	-0.08
X12	0.05	0.02	-0.07	-0.06	0.23	-0.01	0.11	0.01	0.01	0.06	-0.03	-2.30	3.70	-2.01	0.94	-0.33	0.13	0.03	0.06	-0.02	-0.03	-0.13	-0.44	-0.14	-0.01	0.09
X13	0.09	0.26	-0.18	0.08	0.33	-0.07	0.03	0.33	-0.01	-0.12	-0.03	-1.57	5.43	-6.23	0.65	0.20	0.16	0.30	-0.01	-0.02	-0.03	0.77	0.66	-0.19	-0.06	0.33
X14	0.08	0.32	-0.19	0.14	0.29	-0.08	-0.04	0.42	-0.02	-0.20	-0.02	-0.66	4.87	-6.95	0.28	0.46	0.13	0.37	-0.05	-0.01	-0.02	1.08	-0.59	-0.17	-0.12	0.38
X15	0.07	-0.23	0.34	-0.05	-0.05	-0.06	-0.12	0.59	-0.03	-0.18	-0.26	-0.60	0.97	-0.53	3.62	-2.86	0.23	0.19	0.05	-0.06	-0.15	-0.57	0.41	0.03	-0.12	-0.15
X16	0.12	-0.35	0.45	-0.05	-0.13	-0.04	-0.17	0.64	-0.01	0.01	-0.13	-0.24	-0.34	1.01	3.27	-3.16	0.25	0.19	0.05	-0.06	-0.12	-0.71	0.46	-0.08	-0.10	-0.22
X17	0.01	-0.44	0.09	-0.02	0.14	-0.06	-0.07	0.37	0.03	0.21	-0.26	-0.40	1.19	-1.26	1.16	-1.08	0.72	0.52	0.03	-0.05	-0.07	-0.59	0.42	0.11	-0.07	-0.15
X18	0.01	-0.19	0.04	0.06	0.11	-0.09	-0.41	0.88	-0.02	-0.04	-0.33	-0.10	2.22	-3.54	0.96	-0.85	0.52	0.72	-0.03	-0.04	-0.04	0.22	0.23	0.08	-0.10	-0.01
X19	-0.06	-0.52	0.53	-0.01	-0.18	0.04	0.31	0.23	0.01	0.33	0.16	-1.49	-0.35	3.31	1.81	-1.63	0.20	-0.22	0.10	-0.06	-0.15	-1.18	0.56	-0.39	-0.07	-0.39
X20	0.08	-0.28	0.14	0.04	0.07	-0.03	0.06	0.58	0.01	0.23	-0.04	-0.61	1.39	-1.20	2.61	-2.20	0.43	0.32	0.07	-0.08	-0.19	-0.71	0.20	-0.07	-0.12	-0.16
X21	0.02	-0.16	-0.11	0.14	-0.12	0.01	-0.03	0.74	0.04	0.31	0.05	-0.30	0.77	-0.74	2.32	-1.68	0.22	0.14	0.06	-0.07	-0.23	-0.31	-0.18	-0.17	-0.07	-0.25
X22	-0.05	-0.29	0.37	-0.12	-0.10	0.02	0.31	-0.61	0.05	0.30	-0.01	-0.17	-2.41	4.33	1.19	-1.29	0.25	-0.09	0.07	-0.03	-0.04	1.74	0.60	0.32	0.02	-0.35
X23	-0.25	-0.43	0.65	-0.05	-0.29	-0.02	-0.24	0.23	-0.04	-0.22	-0.16	0.90	-3.15	3.63	1.32	-1.29	0.27	0.15	0.05	-0.01	0.04	-0.92	1.13	0.06	-0.01	-0.41
X24	-0.17	-0.18	0.15	0.07	0.05	-0.05	0.11	-0.62	-0.01	-0.15	-0.54	0.36	-1.14	1.25	0.10	0.28	0.09	0.06	-0.04	0.01	0.04	-0.60	0.07	0.92	0.03	0.06
X25	0.01	-0.02	0.10	0.06	0.22	-0.07	-0.12	0.87	-0.03	-0.22	-0.05	-0.75	3.71	-4.85	2.01	-1.28	0.31	0.41	0.04	-0.06	-0.09	0.25	0.04	-0.15	0.17	0.14
X26	-0.07	-0.38	0.30	-0.09	-0.28	0.04	-0.21	0.28	0.04	0.32	-0.15	0.35	-3.26	4.80	0.98	-1.28	0.19	0.01	0.07	-0.02	-0.10	-1.10	0.84	-0.10	0.04	0.55
GY	-0.30	0.50*	0.53**	0.17	0.29	0.8	-0.31	-0.43*	0.04	0.07	0.27	-0.19	-0.31	-0.29	0.53*	0.56**	0.50*	0.29	0.88*	0.52**	0.42	0.54**	0.93**	0.01	0.29	0.69**

X1- Relative water content (60 DAS)
X2 - Relative water content (75 DAS)
X3 - Specific leaf weight (60 DAS)
X4 - Specific leaf weight (75 DAS)
X5-SCMR (60 DAS)
X6- SCMR (75 DAS)
X7- Proline (60 DAS)
X8- Proline (75 DAS)
X9- Wax (60DAS)
X10-Wax (75DAS)
X11- Pollen fertility
X12- Days to 50% tasseling
X13 - Days to 50 % silking
X14 - Anthesis-Silking interval
X15 - Plant height
X16- Ear height
X17- Total number of leaves
X18- Number of dry leaves
X19- Cob length
X20- Cob girth
X21- Number of kernel rows per cob
X22- Number of kernels per row
X23- Number of cobs per plant
X24- Shelling percentage
X25- 100 grain weight
X26- Harvest index

Residual value = 0.11

(60 DAS), pollen fertility, days to 50 % silking, plant height, total number of leaves, number of dry leaves, number of kernels per row, number of cobs per plant, shelling percentage and harvest index exhibited high positive direct effect on grain yield under moisture stress condition (Table 5). Relative water content (60 and 75 DAS) has significant direct effect which helps in maintaining water balance in the cells besides helping in the efficient photosynthesis in the source. Leaf relative water content (RWC) is an important indicator of water status in plants which reflects the balance between water supply to the leaf tissue and transpiration rate (Lugojan and Ciulca, 2011). Earlier, high direct effect of days to 50% silking (Rishav *et al.,* 2016, Bello *et al.,* 2009, Beulah *et al.* 2018), relative water content (Li-Ping *et al*., 2015, Kandel *et al.,* 2018, Gazal *et al.,* 2017), proline content (Yin *et al.,* 2012, Sinay and Tanrobak, 2015, Mazloom *et al.,* 2020), wax content (Li *et al.,* 2019) on grain yield in maize was reported. High direct effect of these traits appeared to be the main reason for their strong association with grain yield. Hence, direct selection for these traits would be effective for identification of drought tolerant genotypes under moisture stress condition.

SCMR (60 DAS), proline content (75 DAS), wax content (75 DAS) days to 50% tasseling, anthesis-silking interval and ear height exhibited higher negative direct effect on grain yield (Table 5). This suggested that, indirect selection for these traits would be effective for grain yield under moisture stress condition which was substantiated by the earlier results on higher negative direct effect of anthesis-silking interval (Khalily *et al.,* 2010, Hassan *et al.,* 2008, Sah *et al.,* 2020), days to 50% tasseling (Pavan *et al.,* 2011, Kandel *et al.,* 2018, Chavan *et al.,* 2020) and days to 50% tasseling, anthesis-silking interval, wax content (75 DAS) and ear height (Hugar, 2021) while studying maize genotypes.

The results thus emphasized the strategy of selection based on relative water content, specific leaf weight, proline content, days to 50% silking, days to 50% tasseling, anthesis-silking interval, plant height, ear height, cob length, cob girth, number of cobs per plant and harvest index since these traits were found to be the important direct contributors for grain yield especially under moisture stress condition. Among these traits, relative water content and number of kernels per row may be given more importance during selection of high yielding maize hybrids suitable for moisture stress situation.

Conclusion

Significant genetic variability was observed among the maize hybrids for phenological, physiological and yield attributing traits under moistures stress condition. There was significant positive correlation between RWC, SLW, yield components and seed yield. Strategy of selection should concentrate on RWC and number of kernels per row in selecting high yielding maize hybrids specifically for moisture stress condition as these traits have exhibited highest direct effect on seed yield.

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