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Screening of drought tolerant finger millet [*Eleusine coracana* (L.) Gaertn] genotypes using combination of drought tolerance indices based on grain yield

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Abstract

The field experiments were conducted at College of Agriculture, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga during summer 2021 and 2022 on sandy loam soils. The experiment was laid out in a split plot design comprising of three replications and twenty four treatment combinations. Six finger millet genotypes of varying duration were evaluated for grain yield under drought stress imposed by withholding the irrigation for fifteen days at vegetative, reproductive and grain filling stage tested against well watered condition. The genotype ML-365 showed least significant marginal yield (7.73, 21.59 and 12.65%) reduction closely followed by GPU-28 (10.95, 28.58 and 12.65%) at vegetative, reproductive and grain filling stage, respectively. The grain yield obtained were used to determine different drought tolerance indices (DTI) *viz.* geometric mean productivity, mean productivity, harmonic mean, drought resistance index, yield index, yield stability index for each genotype. The genotype ML-365 was found highly drought tolerant across DTI whereas GPU-28, KMR-301 and L-5 were found moderate while KMR-204 and GPU-45 remained less tolerant.

Keywords: Drought indices, finger millet, grain yield, tolerant genotypes

Introduction

Drought is the most severe environmental stress responsible for poor agricultural productivity and yield decline (Zougmore, 2018) [31]. Due to global climate change, it is predicted that drought episodes will increase in frequency, be longer and more severe, exacerbating its negative effects on crops and compromise food security particularly in most arid and semi-arid region of the world. Over time, plants have evolved a range of drought tolerance andparative mechanisms to counteract the detrimental effects of drought. Finger millet [*Eleusine coracana* (L.) Gaertn.] Is a cereal crop cultivated in semi-arid and arid regions of the world under rain fed conditions (Thilakarathna and Raizada, 2015) [28] and plays a significant role in food security especially sub-Saharan Africa and South Asia region. The crop is considered to be drought tolerant compared with other cereal crops and it is reported that the reproductive and gain filling stages are the most sensitive to moisture stress reducing the yield significantly (Talwar *et al*., 2020). A recent study analysed the data published from 1980 to 2015 and reported that up to 21 and 40% yield reductions in wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.), respectively, due to drought on a global scale (Daryanto *et al*., 2016) [10]. Stress for 25 to 30 days invariably occurs during either stage of crop growth every year and decreases the grain yield significantly in finger millet (Maqsood and Ali, 2007) [19]. Achieving a yield increase and stability under drought environment has been recognized to be a difficult challenge, while progress in yield has been much higher in favourable environments (Richards *et al*., 2002) [24]. It is therefore an ideal crop for reshaping food propensity of people due to its nutritional richness, high photosynthetic efficiency and better tolerance to biotic and abiotic stressors than other crops (Kumar *et al*., 2016) [18]. The efficiency of breeding programs in diverse environments can be significantly improved by gaining an understanding of the associations between yield performance and different selection criteria, including estimates of stress tolerance in genetic materials (Collard and Mackill, 2008; Mau *et al*., 2019) [9, 20]. In most of the crops, yield performance is the main criterion considered for evaluating tolerance to its stability under different growth conditions. Therefore, screening for tolerance to a specific stress is based on high performance in non-stressed and stressed environments (Clarke *et al*., 1992) [8], such that genotypes with high yields in both environments are considered

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tolerant. During the process, several yield-based indices have been suggested for evaluating stress tolerance in crops. The commonly used drought tolerance indices are mean productivity (MP), yield stability index (YSI), geometric mean productivity (GMP), yield index (YI), harmonic mean (HM) and drought resistance index (DRI) to identify drought tolerant genotypes under stress conditions (Mau *et al*., 2019 and Ferede *et al*., 2020) [20, 12]. In the present study, an attempt has been made to identify finger millet genotypes tolerant to moisture stress given at three different stages using drought tolerance indices.

Material and Methods

Field experiments were conducted at College of Agriculture, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga (650 m above the mean sea level, 13° 58' North latitude and 75° 34' East longitude) during summer 2021 and 2022 on sandy clay loam soil. The experiment was laid out in split plot design with three replications and the treatment details is described in Table 1. Stress imposition was done by withholding the irrigation for fifteen days as per the plan mentioned in the Table 2 and Table 3. Whereas, irrigation was provided to the control plots (No stress plots) at regular intervals of once in three days to maintain the adequate field capacity as to maintain the crop without any stress. The data was analysed statistically for test of significance following the procedure described by Gomez and Gomez (1984) [16]. The results have been discussed at the probability level of five%. The level of significance used in “F” and “t” test was p=0.05. Critical difference (CD) values were calculated wherever the “F” test was found significant. Otherwise, against CD values abbreviation NS (Non-significant) was indicated. Duncan’s Multiple Range Test (DMRT) was also facilitated for non-significant interaction effects wherever essential.

Computation of stress indices based on yield

Pooled data on yield of six finger millet genotypes were obtained from the control and stressed treatments at harvest to screen superior genotype based on the different drought indices as indicated in Table 4

Table 1: Treatment details followed in the experiment

<table>
<tr><th>Sl. No.</th><th>Treatment details followed</th><th colspan="2">Description</th></tr>
<tr><td colspan="4">I. Main-plot treatments: Degree of stress (S)
Degree of stress relates to withdrawal of irrigation for fifteen days at different growth stages of finger millet genotypes</td></tr>
<tr><td>S_0</td><td>No stress</td><td colspan="2">Irrigation applied at all the growth stages</td></tr>
<tr><td>S_1</td><td>Stress @ vegetative stage (Phase I)</td><td colspan="2">Irrigation withheld @ vegetative stage for 15 days <i>i.e.</i>, from 10 to 25 DAT for all duration genotypes</td></tr>
<tr><td>S_2</td><td>Stress @ reproductive stage (Phase II)</td><td colspan="2">Irrigation withheld @ reproductive stage for 15 days <i>i.e.</i>, from 27-41 DAT for short duration genotypes and 33-47 DAT for medium and long duration genotypes</td></tr>
<tr><td>S_3</td><td>Stress @ grain filling stage (Phase III)</td><td colspan="2">Irrigation withheld @ grain filling stage for 15 days <i>i.e.</i>, from 44-58 DAT for short duration genotypes and 50-64 DAT for medium and long duration genotypes</td></tr>
<tr><td colspan="4">II. Sub-plot treatments: Genotypes (G)</td></tr>
<tr><td>G_1</td><td>KMR-204</td><td colspan="2" rowspan="2">Short duration genotypes</td></tr>
<tr><td>G_2</td><td>GPU-45</td></tr>
<tr><td>G_3</td><td>ML-365</td><td colspan="2" rowspan="2">Medium duration genotypes</td></tr>
<tr><td>G_4</td><td>GPU-28</td></tr>
<tr><td>G_5</td><td>KMR-301</td><td colspan="2" rowspan="2">Long duration genotypes</td></tr>
<tr><td>G_6</td><td>L-5</td></tr>
<tr><td colspan="4">III. Interaction (Degree of stress × Genotypes)</td></tr>
<tr><td>T_1: S_0G_1</td><td>T_7: S_1G_1</td><td>T_{13}: S_2G_1</td><td>T_{19}: S_3G_1</td></tr>
<tr><td>T_2: S_0G_2</td><td>T_8: S_1G_2</td><td>T_{14}: S_2G_2</td><td>T_{20}: S_3G_2</td></tr>
<tr><td>T_3: S_0G_3</td><td>T_9: S_1G_3</td><td>T_{15}: S_2G_3</td><td>T_{21}: S_3G_3</td></tr>
<tr><td>T_4: S_0G_4</td><td>T_{10}: S_1G_4</td><td>T_{16}: S_2G_4</td><td>T_{22}: S_3G_4</td></tr>
<tr><td>T_5: S_0G_5</td><td>T_{11}: S_1G_5</td><td>T_{17}: S_2G_5</td><td>T_{23}: S_3G_5</td></tr>
<tr><td>T_6: S_0G_6</td><td>T_{12}: S_1G_6</td><td>T_{18}: S_2G_6</td><td>T_{24}: S_3G_6</td></tr>
</table>

Table 2: Schedule of stress imposition during 2021

	Months	Dates																														
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Imposition of stress @ vegetative stage	January																				🟥											
Number of days under vegetative stress	January																				🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
	February	🟨	🟨	🟨																												
Alleviation of stress @ vegetative stage	February				🟩																											
Imposition of stress @ reproductive stage of short duration genotypes	February					🟥																										
Number of days under reproductive stress						🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨												
Alleviation of stress @ reproductive stage of short duration genotypes																					🟩											
Imposition of stress @ reproductive stage of medium and long duration genotypes									🟥																							
Number of days under reproductive stress									🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨									
Alleviation of stress @ reproductive stage of medium and long duration genotypes																								🟩								
Imposition of stress @ grain filling stage of short duration genotypes																							🟥									
Number of days under grain filling stress	February																						🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
	March	🟨	🟨	🟨	🟨	🟨																										
Alleviation of stress @ grain filling stage of short duration genotypes	March						🟩																									
Imposition of stress @ grain filling stage of medium and long duration genotypes	February																								🟥							
Number of days under grain filling stress	February																								🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
	March	🟨	🟨	🟨	🟨	🟨	🟨	🟨																								
Alleviation of stress @ grain filling stage of medium and long duration genotypes	March								🟩																							

🟥 **: Imposition of stress** 🟨 **: Number of days under respective stress** 🟩 **: Alleviation of stress**

Table 3: Schedule of stress imposition during 2022

	Months	Ates																														
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Imposition of stress @ vegetative stage	January												🟥																			
Number of days under vegetative stress													🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨					
Alleviation of stress @ vegetative stage																												🟩				
Imposition of stress @ reproductive stage of short duration genotypes																													🟥			
Number of days under reproductive stress	January																												🟨	🟨	🟨	🟨
	February	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨																				
Alleviation of stress @ reproductive stage of short duration genotype es	February												🟩																			
Imposition of stress @ reproductive stage of medium and long duration genotypes		🟥																														
Number of days under reproductive stress		🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨																
Alleviation of stress @ reproductive stage of medium and long du ration genotypes																	🟩															
Imposition of stress @ grain filling stage of short duration genotypes															🟥																	
Number of days und er grain filling stress															🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨			
Alleviation of stress s @ grain filling stage of short duration genotypes																														🟩		
Imposition of stress @ grain filling stage of medium and long duration genotype																		🟥														
Number of days under grain filling stress	February																	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Alleviation of s tress @ grain filling stage of medium and long duration genotypes	March	🟩																														

🟥 **: Imposition of stress** 🟨 **: Number of days under respective stress** 🟩 **: Alleviation of stress**

Table 4: Pattern of selection and formula for computation of stress indices

Sl. No.	Index	Formula	Pattern of selection	Reference
1.	Tolerance index	$TOL = Y_P - Y_S$	Minimum value	Rosielle and Hamblin (1981) [25]
2.	Mean productivity	$MP = \frac{Y_P + Y_S}{2}$	Maximum value	Rosielle and Hamblin (1981) [25]
3.	Geometric Mean Productivity	$GMP = \sqrt{Y_S \times Y_P}$	Maximum value	Fernandez (1992) [13]
4.	Harmonic Mean	$HM = \frac{2(Y_S \times Y_P)}{(Y_S + Y_P)}$	Maximum value	Bidinger *et al.* (1987) [5]
5.	Stress Susceptibility Index	$SSI = \frac{1-(Y_S / Y_P)}{1-(\bar{Y}_S / \bar{Y}_P)}$	Minimum value	Fischer and Maurer (1978) [14]
6.	Stress Tolerance Index	$STI = \frac{Y_S \times Y_P}{(\bar{Y}_P)^2}$	Maximum value	Fernandez (1992) [13]
7.	Yield Index	$YI = \frac{Y_S}{\bar{Y}_s}$	Maximum value	Gavuzzi *et al.* (1997) [15]
8.	Yield Stability Index	$YSI = \frac{Y_S}{Y_P}$	Maximum value	Bouslama and Schapaugh (1984) [6]
9.	Relative Drought Index	$RSI = \frac{(Y_S / Y_P)}{(\bar{Y}_S / \bar{Y}_P)}$	Maximum value	Fischer and Maurer (1978) [14]

Where,
Y_s = yield in stress condition Yp= yield in control condition

Results and Discussion

Influence of degree of stress at different growth phases of finger millet genotypes on yield and yield components of finger millet under field condition

The results of pooled data on various yield and yield components *viz*., number of ear heads, number of fingers, spikelet fertility, test weight, grain yield, straw yield and harvest index of finger millet genotypes are presented in Table 5 & 6 and discussed below.

The pooled data indicated that, the mean number of ear heads across the stress treatments decreased significantly compared to that of their control plots. At phase-II and III, lowest number of ear heads (4.06 and 6.83 hill-1 *viz*., 26.84 and 20.71% lower over control) was noticed under plots receiving stress @ reproductive stage (S2) over control (5.55 and 8.61 hill-1, respectively). Comparison among the genotypes indicated ML-365 (6.70 and 9.52 hill-1, respectively) and GPU-45 (3.72 and 6.29 hill-1, respectively) recorded highest and lowest number of ear heads at phase-II and III, respectively. Further, interaction effect between degree of stress and genotypes found comparable in the study (Table 5).

The observation on spikelet fertility differed significantly for imposed stress. Stress @ reproductive stage (S2) recorded significantly lowest spikelet fertility (76.63%) by 17.19% as compared to S0 (92.54%). Among the genotypes, ML-365 recorded significantly highest spikelet fertility of 90.32% closely followed by KMR-301 (87.84%) and GPU-28 (87.64%) (Fig 1). Further, interaction between degree of stress and genotypes did not show statistical significance (Table 5). The perusal of data revealed that, at harvest, number of fingers in the test did not differ significantly for imposed stress. The values varied from 7.25 (S2) to 8.26 (S0) ear head-1, with the observation that in stressed plots it reduced slightly. Further, among the genotypes tested, ML-365 recorded significantly highest number of fingers (9.94 ear head-1) closely followed by KMR-301 (8.62 ear head-1) and GPU-28 (8.50 ear head-1). At harvest, significantly lowest test weight (2.93 g) was recorded under plots receiving stress @ reproductive stage (S2) with reduction percentage of 11.75% as compared to control (3.32 g) which was on par with S1 (3.14 g). Comparison between genotypes showed that ML-365 recorded significantly highest test weight (3.62 g) over rest of the genotypes. Further, interaction between degree of stress and genotypes did not show statistical significance (Table 6).

At harvest, significantly lowest grain and straw yield of 26.19

and 62.16 q ha-1 was recorded under plots receiving stress at reproductive stage (S2) with reduction percentage to an extent of 33.19 and 45.76%, respectively, as compared to control (39.21 and 90.60 q ha-1) which was closely followed by S1 (34.08 and 78.31 q ha-1). However, treatment stress @ grain filling recorded 31.32 and 71.80 q ha-1, respectively, grain and straw yields thereby achieved 20.13 and 26.19% lesser, respectively. Comparison between genotypes showed that ML-365 recorded significantly highest grain (47.98 q ha-1) and straw (102.98 q ha-1) yield while lowest grain and straw yield of 19.48 and 49.29 q ha-1 was documented in GPU-45 over rest of the genotypes. Further, interaction between degree of stress and genotypes was found comparable for grain and straw yield (Table 6). At harvest, plots experienced stress did not vary significantly for harvest index. However, values ranged from 29.13% for S2 to 30.73% for S1. Among the genotypes tried, ML-365 filed highest harvest index (31.92%) followed by KMR-301 (31.00%) and GPU-28 (30.03%). Further, interaction effects did not show significant relations for harvest index (Table 6).

Prevalence of drought in different stages of crop growth affected growth and development hampered flower production and grain filling ability and thus results in smaller and fewer grains. Many yield determining physiological processes in plants respond to drought as it integrates many of these physiological processes in a complex way. Drought stress decrease the photosynthetic rate and disrupts the carbohydrate metabolism and level of sucrose in leaves that spills over to a decreased export rate presumably due to activity of acid invertase (Kim *et al*., 2000) [17]. Limited photosynthesis and sucrose accumulation in the leaves may hamper the rate of sucrose export to the sink organs and ultimately affect the reproductive development. Assimilate translocation to reproductive sinks is vital for seed development. Seed set and filling can be limited by availability or utilization, i.e., assimilate source or sink limitation, respectively (Asch *et al*., 2005) [4]. For drought stress, severity, duration and timing of stress, as well responses of plants after stress removal and interaction between stress and other factors are extremely important. Accordingly, water stress applied at pre anthesis reduced time to anthesis, while at post anthesis it shortened the grain filling period in triticale genotypes (Estrada-Campuzano *et al*., 2008) [11]. In barley (Hordeum vulgare), drought stress reduces grain yield by decreasing number of tillers, spikes, rains per plant and grain weight. Post anthesis drought stress was detrimental to grain yield regardless of the stress severity (Samarah, 2005) [26]. Drought induced yield reduction has been reported in many crop species, which depends upon the severity and duration of the stress period. In maize, drought reduced yield by delaying silking, thus increased the anthesis-to-silking interval. This trait was highly correlated with grain yield, specifically ear and kernel number per plant (Cattivelli *et al*., 2008) [7]. Following heading, drought had little effect on the rate of kernel filling in wheat, but its duration (time from fertilization to maturity) was shortened thereby dry weight reduced at maturity (Wardlaw and Willenbrink, 2000) [29]. In pearl millet (Pennisetum glaucum), co-mapping of the harvest index and panicle harvest index with grain yield revealed that greater drought tolerance was achieved by higher partitioning of dry matter from stover to grains (Yadav *et al*., 2004) [30]. Drought at flowering commonly results in barrenness. A major cause of this, though not the only one, was reduction in assimilate flux to the developing ear below some threshold level necessary to sustain optimal grain growth (Yadav *et al*., 2004) [30]. A reduced acid invertase activity can arrest the development of reproductive tissues due to improper phloem unloading (Reddy *et al*., 2020) [23]. In addition, drought stress may inhibit important functions of vascular invertase mediated sucrose hydrolysis and osmotic potential modulation. In drought-stressed maize, a low invertase activity in the young ovaries lowers the ratio of hexoses to sucrose. This may inhibit cell division in the developing embryo/endosperm, resulting in weak sink intensity and may ultimately lead to fruit abortion (Andersen *et al*., 2002) [3].

Evaluation of finger millet genotypes for drought tolerance using stress indices

In the present study, different indices were worked out to find the degree of stress effects based on the variation in yield (Pooled data of two years) obtained under stressed and control environments and are presented in the Table 7a, 7b and 7c, respectively. Stress susceptibility index indicates degree of stress to withhold the activities to a minimal extent that would impact yield to a maximum degree whereas, stress tolerance index indicates maximum tolerance level for the physiological activities by imposed stress to carry out normal activities reflecting higher performances. The data on these factors revealed minimum and maximum value for ML-365 followed by GPU-28 and KMR-301 at different stages of stress imposition (S1, S2 and S3).

Relative drought index invariably takes into account the intensity of stress and its impact on variation in the yield by taking respective means in to consideration. On the other hand, yield stability index calculated based on ratio of yield realised under stressed to that of control. In both of these situations, ML-365 achieved maximum values (1.07 & 0.93, 1.17 & 0.78, 1.10 & 0.88, respectively) closely followed by GPU-28 (1.02 & 0.89, 1.05 & 0.70 and 1.02 & 0.82, respectively) and KMR-301 (1.01 & 0.88, 1.03 & 0.69 and 1.01 & 0.81, respectively) at stress @ vegetative, reproductive and grain filling stage, respectively.

The other essential indices such as tolerance index, mean productivity, geometric mean productivity, harmonic mean and yield index also evidences superiority of ML-365 followed by GPU-28 at different stages of stress imposition.

Pearson's correlation coefficients (r) between Yp, Ys and the indices were determined to select the best indices for the screening of drought tolerant genotypes (Fig. 2). A positive significant correlation between Yp and Ys was recorded at all the stages of imposed stress. This may imply that high yielding potential under normal irrigation is necessarily accompanied by reasonable yield under stress condition. Similar results of the wheat and sorghum response to drought were previously recorded by Abede *et al*. (2020) [1] and Nazari *et al*. (2021) [22], respectively. In the present investigation, the data evidenced a negative relationship for SSI (- 0.90 & -0.93, -0.90 & -0.95 and -0.91 & -0.94, respectively) to that of yield obtained both under control as well as stress imposition @ vegetative, reproductive and grain filling stage, respectively (Fig. 1). Further, it is noted that stressed yield had a negative relationship with tolerance index. While, relationship of yield and indices calculated remained positive. A similar finding was also recorded by Mickky *et al*. (2019) [21] who evaluated ten wheat cultivars based on drought tolerance indices under normal irrigation

(Yp) and deficit irrigation (Ys). Based on the results, genotypes showing low fluctuation of yield under various levels of drought stress can be considered as drought tolerant along with drought tolerance indices for the stability of tolerance in the genotype (Ali and El-Sadek, 2016) [2]. Thus, performance of genotype ML-365 as best drought tolerant whereas GPU-28, KMR-301 and L-5 were moderate while KMR-204 and GPU-45 were less tolerant.

Table 5: Influence of degree of stress on number of ear heads (hill-1) and spikelet fertility of finger millet genotypes

Treatments	Number of ear heads				Spikelet fertility	
	Phase-II		Phase-III		Phase-III	
	Values	% Red over S$_0$	Values	% Red over S$_0$	Values	% Red over S$_0$
S$_0$	5.55	-	8.61	-	92.54	-
S$_1$	5.51	0.73	8.36	2.94	88.25	4.63
S$_2$	4.06	26.84	6.83	20.71	76.63	17.19
S$_3$	5.30	-	7.66	11.04	81.08	12.39
S. Em ±	0.14	-	0.16	-	1.17	-
CD @ 5%	0.48	-	0.54	-	4.05	-
	Values	% Red. over G$_3$	Values	% Red. over G$_3$	Values	% Red. over G$_3$
G$_1$	4.60	31.36	6.75	29.09	81.39	9.89
G$_2$	3.72	44.55	6.29	33.96	77.45	14.25
G$_3$	6.70	-	9.52	-	90.32	-
G$_4$	5.34	20.31	8.04	15.59	87.64	2.97
G$_5$	5.64	15.86	8.98	5.64	87.84	2.75
G$_6$	4.64	30.82	7.61	20.11	83.13	7.96
S. Em ±	0.15	-	0.17	-	1.71	-
CD @ 5%	0.43	-	0.48	-	4.89	-
	Values	% Red over S$_0$	Values	% Red over S$_0$	Values	% Red over S$_0$
S$_0$G$_1$	5.03^{efghi}	-	7.6^{efgh}	-	91.45^{abc}	-
S$_0$G$_2$	4.15^{hijk}	-	7.18^{fghi}	-	89.78^{abcd}	-
S$_0$G$_3$	7.17^{a}	-	9.95^{a}	-	95.02^{a}	-
S$_0$G$_4$	5.78^{cdef}	-	8.62^{bcde}	-	93.34^{ab}	-
S$_0$G$_5$	6.21^{abcd}	-	9.89^{a}	-	93.75^{a}	-
S$_0$G$_6$	5.1^{defgh}	-	8.45^{cde}	-	91.92^{abc}	-
S$_1$G$_1$	4.52^{ghijk}	2.25	7.33^{fghi}	3.47	84.9^{abcdef}	7.16
S$_1$G$_2$	3.65^{kl}	2.41	6.83^{ghij}	4.87	81.82^{bcdefg}	8.87
S$_1$G$_3$	6.82^{abc}	-0.56	9.88^{a}	0.67	94.37^{a}	0.68
S$_1$G$_4$	5.42^{defg}	-0.72	8.5^{bcde}	1.41	90.92^{abc}	2.59
S$_1$G$_5$	5.75^{cdef}	0.70	9.49^{abc}	4.03	90.88^{abc}	3.06
S$_1$G$_6$	4.66^{fghijk}	0.82	8.1^{def}	4.08	86.63^{abcde}	5.75
S$_2$G$_1$	3.78^{jkl}	29.09	5.65^{kl}	25.67	72.83^{gh}	20.36
S$_2$G$_2$	2.93^{l}	34.26	5.18^{l}	27.89	66.04^{h}	26.44
S$_2$G$_3$	5.97^{bcde}	20.37	8.68^{bcde}	12.71	84.15^{abcdef}	11.44
S$_2$G$_4$	4.67^{fghijk}	23.88	7.12^{fghi}	17.42	80.92^{cdefg}	13.31
S$_2$G$_5$	4.8^{efghijk}	27.71	7.8^{defg}	21.12	80.83^{cdefg}	13.78
S$_2$G$_6$	3.87^{ijkl}	29.21	6.53^{hijk}	22.67	75.03^{fgh}	18.37
S$_3$G$_1$	4.88^{efghij}	-	6.43^{ijk}	15.42	76.36^{efgh}	16.50
S$_3$G$_2$	3.93^{hijkl}	-	5.95^{jkl}	17.13	72.15^{gh}	19.64
S$_3$G$_3$	7^{ab}	-	9.58^{ab}	3.66	87.75^{abcde}	7.65
S$_3$G$_4$	5.42^{defg}	-	7.9^{defg}	8.37	85.38^{abcdef}	8.52
S$_3$G$_5$	5.85^{cdef}	-	8.75^{bcd}	11.48	85.88^{abcdef}	8.39
S$_3$G$_6$	4.83^{efghij}	-	7.34^{fghi}	13.08	78.95^{defg}	14.11

Note: S: Degree of stress, S$_0$: No stress (Control), S$_1$: Stress @ vegetative stage, S$_2$: Stress @ reproductive stage, S$_3$: Stress @ grain filling stage, G: Genotypes, G$_1$- KMR-204, G$_2$- GPU-45, G$_3$- ML-365, G$_4$- GPU-28, G$_5$- KMR-301, and G6- L-5. **Phase**: Stress imposition period, **Phase-II**: Stress imposition from 27 DAT to 41 DAT (for short duration genotypes) and stress imposition from 33 DAT to 47 DAT (for medium and long duration genotypes), **Phase-III**: Stress imposition from 44 DAT to 58 DAT (for short duration genotypes) and stress imposition from 50 DAT to 64 DAT (for medium and long duration genotypes, **Red.**: Reduction

Fig 1: Variation in spikelet fertility (%) between control and stressed genotypes of finger millet at after alleviation of stress @ Reproductive stage (S3).

Table 6: Influence of degree of stress on number of fingers (ear head^{-1}), test weight (g), grain and straw yield (q ha^{-1}) of finger millet genotypes at harvest

Treatments	Number of fingers	Test weight	Grain yield		Straw yield	
			Values	% Red. over S_0	Values	% Red. over S_0
S_0	8.26	3.32	39.21	-	90.60	-
S_1	8.00	3.14	34.08	13.09	78.31	15.70
S_2	7.25	2.93	26.19	33.19	62.16	45.76
S_3	7.96	3.08	31.32	20.13	71.80	26.19
S. Em ±	0.21	0.04	0.82	-	1.51	-
CD @ 5%	0.73	0.15	2.83	-	5.23	-
			Values	% Red. over G_3	Values	% Red. over G_3
G_1	6.52	2.82	25.27	47.33	62.28	39.53
G_2	6.26	2.67	19.48	59.40	49.29	52.13
G_3	9.94	3.62	47.98	-	102.98	-
G_4	8.50	3.14	31.53	34.29	74.04	28.10
G_5	8.62	3.37	41.38	13.75	92.81	9.88
G_6	7.36	3.08	30.56	36.31	72.90	29.21
S. Em ±	0.20	0.07	0.93	-	1.61	-
CD @ 5%	0.57	0.20	2.67	-	4.59	-
			Values	% Red. over S_0	Values	% Red. over S_0
S_0G_1	6.92^{ghij}	$3.05^{defghij}$	32.25^{fgh}	-	78.13^{fg}	-
S_0G_2	6.83^{ghij}	2.92^{fghijk}	26.08^{ijk}	-	64^{hij}	-
S_0G_3	10.16^{a}	3.76^{a}	53.5^{a}	-	116.33^{a}	-
S_0G_4	8.85^{bcde}	$3.3^{abcdefg}$	37.02^{ef}	-	87.09^{ef}	-
S_0G_5	9.03^{abcd}	3.59^{abc}	49.08^{ab}	-	110.07^{ab}	-
S_0G_6	7.8^{defgh}	3.31^{abcdef}	37.33^{def}	-	88^{e}	-
S_1G_1	6.62^{hijk}	2.83^{ghijk}	26.5^{hijk}	17.83	64.6^{hij}	17.32
S_1G_2	6.43^{ijk}	2.67^{ijk}	20.67^{kl}	20.77	52^{klm}	18.75
S_1G_3	9.98^{ab}	3.65^{a}	49.7^{ab}	7.10	106.17^{bc}	8.74
S_1G_4	8.68^{cdef}	$3.17^{bcdefgh}$	32.82^{fg}	11.35	76.42^{g}	12.26
S_1G_5	8.72^{cde}	3.41^{abcde}	43.03^{cd}	12.34	95.17^{de}	13.54
S_1G_6	7.55^{efghi}	$3.1^{defghij}$	31.75^{fghi}	14.96	75.5^{g}	14.20
S_2G_1	5.93^{jk}	2.64^{jk}	18.58^{lm}	42.38	48.5^{lm}	37.93
S_2G_2	5.42^{k}	2.48^{k}	13^{m}	50.16	35.5^{n}	44.53
S_2G_3	9.62^{abc}	3.46^{abcd}	41.82^{cde}	21.84	89.77^{e}	22.83
S_2G_4	7.77^{defgh}	$2.95^{efghijk}$	25.98^{ijk}	29.81	62.17^{hij}	28.62
S_2G_5	8.07^{defg}	$3.17^{bcdefgh}$	33.75^{fg}	31.24	77.33^{g}	29.74
S_2G_6	6.69^{hijk}	2.88^{fghijk}	24.04^{jkl}	35.62	59.67^{ijk}	32.20
S_3G_1	6.62^{hijk}	2.76^{hijk}	23.75^{jkl}	26.36	57.87^{jkl}	25.94
S_3G_2	6.38^{ijk}	2.63^{jk}	18.17^{lm}	30.35	45.67^{mn}	28.65
S_3G_3	10^{ab}	3.61^{ab}	46.9^{bc}	12.34	99.67^{cd}	14.33
S_3G_4	8.69^{cdef}	$3.13^{cdefghi}$	30.3^{ghi}	18.14	70.5^{gh}	19.05
S_3G_5	8.66^{cdef}	3.32^{abcdef}	39.67^{de}	19.19	88.67^{e}	19.44
S_3G_6	7.39^{fghi}	$3.02^{defghij}$	29.12^{ghij}	22.01	68.42^{ghi}	22.25

Note: S: Degree of stress, S_0: No stress (Control), S_1: Stress @ vegetative stage, S_2: Stress @ reproductive stage, S_3: Stress @ grain filling stage, G: Genotypes, G_1- KMR-204, G_2- GPU-45, G_3- ML-365, G_4- GPU-28, G_5- KMR-301, and G6- L-5. **Phase**: Stress imposition period, **Red**: Reduction.

Table 7: Computed stress susceptible and tolerance indices for finger millet genotypes at different stages of stress imposition

Table 7a: Stress indices based on grain yield under control and stress @ vegetative stage (S1)

Genotypes	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
KMR-204	5.75	29.38	29.23	29.09	1.36	0.56	0.78	0.82	0.95
GPU-45	5.41	23.38	23.22	23.06	1.58	0.35	0.61	0.79	0.91
ML-365	3.8	51.6	51.57	51.53	0.54	1.73	1.46	0.93	1.07
GPU-28	4.2	34.92	34.86	34.79	0.87	0.79	0.96	0.89	1.02
KMR-301	6.05	46.05	45.96	45.86	0.94	1.37	1.26	0.88	1.01
L-5	5.58	34.54	34.43	34.31	1.14	0.77	0.93	0.85	0.98

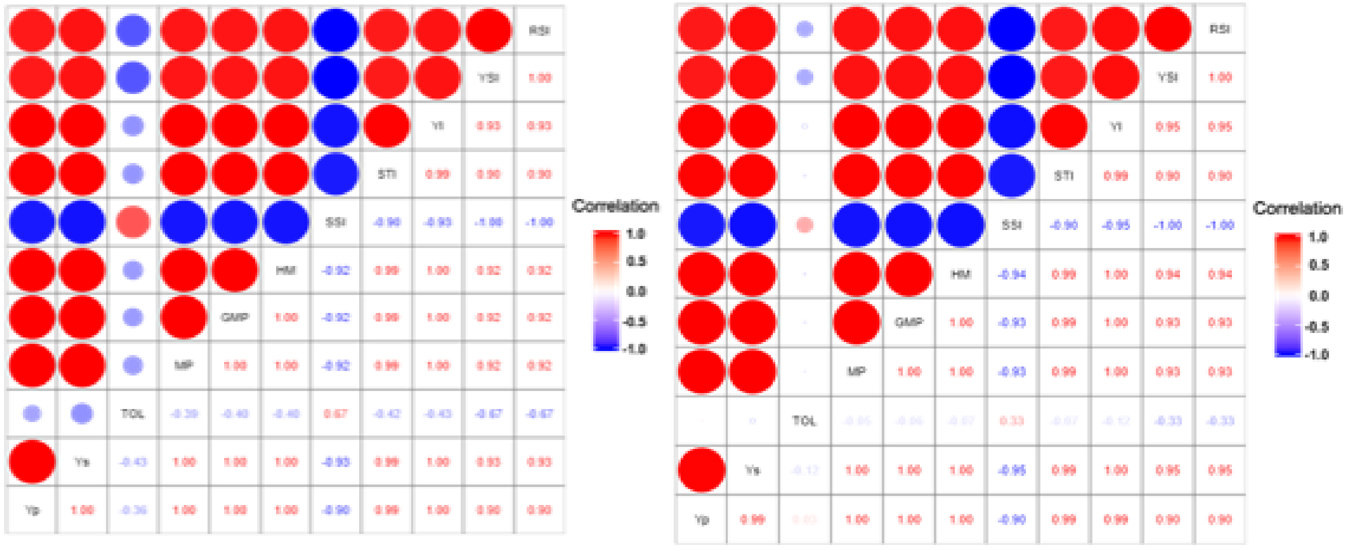
Table 7b: Stress indices based on grain yield under control and stress @ reproductive stage (S_2)

Genotypes	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
KMR-204	13.67	25.42	24.48	23.58	1.28	0.39	0.71	0.58	0.86
GPU-45	13.08	19.54	18.41	17.35	1.51	0.22	0.50	0.50	0.75
ML-365	11.68	47.66	47.30	46.94	0.66	1.46	1.60	0.78	1.17
GPU-28	11.04	31.50	31.01	30.53	0.90	0.63	0.99	0.70	1.05
KMR-301	15.33	41.42	40.70	40.00	0.94	1.08	1.29	0.69	1.03
L-5	13.29	30.69	29.96	29.25	1.07	0.58	0.92	0.64	0.96

Table 7c: Stress indices based on grain yield under control and stress @ grain filling stage (S_3)

Genotypes	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
KMR-204	8.50	28.00	27.68	27.35	1.31	0.50	0.76	0.74	0.92
GPU-45	7.91	22.13	21.77	21.42	1.51	0.31	0.58	0.70	0.87
ML-365	6.60	50.20	50.09	49.98	0.61	1.63	1.50	0.88	1.10
GPU-28	6.72	33.66	33.49	33.32	0.90	0.73	0.97	0.82	1.02
KMR-301	9.41	44.38	44.12	43.88	0.95	1.27	1.27	0.81	1.01
L-5	8.21	33.23	32.97	32.72	1.09	0.71	0.93	0.78	0.98

TOL- Tolerance index
MP- Mean productivity
GMP- Geometric mean productivity
HM- Harmonic mean
RSI- Relative drought index
SSI- Stress susceptibility index
STI- Stress tolerance index
YI- Yield index
YSI- Yield stability index



(a) (b)

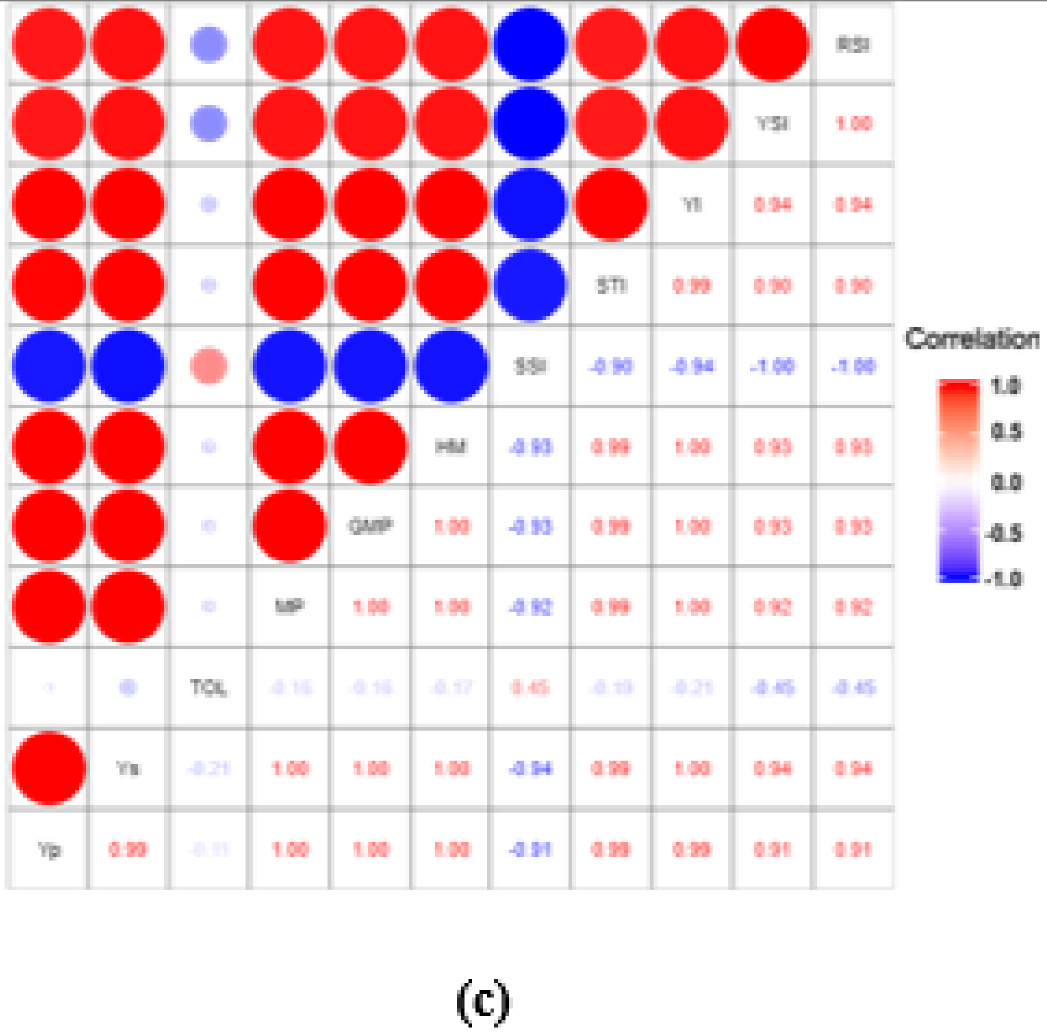


Fig 2: Heat map based on the actual values of indices (Pearson's correlation analysis) across six finger millet genotypes. Yp, yield under control; Ys, yield under stress @ vegetative stage (a), stress @ reproductive stage (b) and stress @ grain filling stage (c); TOL, tolerance index; MP, mean productivity, GMP, geometric mean probability; HM, Harmonic mean; SSI, stress susceptibility index; STI, stress tolerance index; YI, yield index; YSI, yield stability index; RSI, relative stress index

Conclusion

- Imposition of stress for fifteen days @ vegetative, reproductive and grain filling stage recorded significantly lowest grain (34.08, 26.19 and 31.32 kg ha-1, respectively) and straw yield (78.31, 62.16 and 71.80 kg ha-1, respectively) as compared to control.
- Among the genotypes tested, ML-365 followed by GPU-28 and KMR-301 recorded significantly highest percent increment in yield and yield components.
- In the interaction treatments, ML-365 with imposition of stress @ vegetative, reproductive and grain filling stage achieved significantly highest yield and yield components.
- Performance of genotypes based on stress indices indicates, ML-365 as best drought tolerant whereas GPU-28, KMR-301 and L-5 were moderate while KMR-204 and GPU-45 were less tolerant.

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