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Research Article

Exploring the genetic variability for higher water productivity in wheat crop under moisture stress conditions

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Abstract

Wheat is the flagship and staple food crop in India. Cultivation of wheat taking place under assured irrigation facility in India. One of the biggest difficulties faced by wheat farmers in all regions is depletion of ground water resources at an alarming rate. This study was conducted to test the hypothesis that variability with respect to water use efficiency exists in wheat genotypes and the use of higher water use efficient genotypes reduced the amount of irrigation water for harvesting the desirable level of yield. The field experiment was carried out in split plot design during *rabi* season of 2020-21 under two different moisture levels. Genotype DBW 110 was top ranked for WUE (1.28 kg/M^3 & 1.71 kg/M^3) at IARI Gauria Karma. Whereas at Karnal centre, genotype 40 ESWYT 33 ranked first with WUE of 2.42 and 3.04 kg/M^3 under 80 and 60 % of ET respectively. Identification and deployment of wheat genotypes having higher water use efficiency could be the water saving technology in the water scarce scenario.

1. Introduction

For the survival of any civilization, water is the most critical natural resource and agriculture sector is the largest consumer of water resources. The water requirement has been increasing with time in all walks of life including agriculture. Agriculture activities make use of nearly 80% of water which is generally withdrawn from rivers, lakes and other aquifers. Over the years, the increase in population has resulted in increased demand of water for irrigation and other uses which cause excessive withdrawal of underground water. The per capita available water has declined from about 10018 M^3 in 1975 to about 6500 M^3 in 2000 and is declining continuously (Singh *et al.*, 2012). The per capita water availability has been projected to reduce sharply to 1341 M^3 by 2025 and further down to 1140 M^3 by 2050 (Government of India, 2009). Though water is a precious and scarce natural resource, its use efficiency is very low in the range of 30-40% (Singh *et al.*, 2012). About 60-70% of irrigation water is lost during conveyance and application. Since volumetric soil moisture content and potential evaporation are the two major factors directly affecting the water use, therefore proper irrigation scheduling with judicious quantity of water is critical for efficient water management in field crop production. Irrigation frequency and water use are particularly important in order to harvest higher yields (Meena *et al.*, 2018). The excessive water application can result in waterlogging and leaching of nutrients below the root zone. To improve water use efficiency and crop yield there must be an optimum level of irrigation water depth as water use efficiency has been reported to be decrease with increasing irrigation depth (Meena *et al.*, 2019; Qui *et al.*, 2008). The use of less volume of water but with more frequency is better over scheduling of few applications of large irrigation volumes in terms of water use efficiency

(Meena *et al.*, 2015; Meena *et al.*, 2018; Aujla *et al.*, 2007; Hogeboom and Hoekstra, 2017). Uncontrolled irrigation supported by subsidized/free electricity clubbed with low water productivity is leading to un-sustainability of the wheat cultivation (Humphreys *et al.*, 2010; Meena *et al.*, 2019). In the regions of water scarcity, food security can be ensured by enhancing the overall water use efficiency of crops, which helps to produce more crop per drop of water. Water use efficiency can be improved mainly by two approaches *viz*, agronomic intervention (adopting efficient irrigation systems and efficient irrigation scheduling) and selection of genotypes with climate resilience (Kumar *et al.,* 2019). The continuous worsening situation of depleting fresh water resources therefore calls for development of improved irrigation scheduling with less volume of water as well as identification of water use efficient genotypes with better yield. Looking at the prevailing scenario of depleting water resources, the present study has been undertaken in two different agro climatic regions aiming to find the optimum levels of irrigations.

2. Materials & Methods

The field experiments were conducted at two locations during 2020-21. At the research farm of ICAR-Indian Institute of Wheat and Barley Research, Karnal (29°43' N, 76° 58' E and 252 altitude), Haryana and ICAR-Indian Agricultural Research Institute, Gauria-Karma, Jharkhand (24°17'27.9"N, 85°20'11.3"E and 378 altitude). The agro-climatic conditions of the Karnal location are characterized by sub-tropical and semi-arid conditions. Average annual rainfall of this area is 744 mm, of which about 80% is received during the monsoon season, starting from the end of June to middle of September. The mean maximum temperature ranges between 34- 39°C in summer and mean minimum temperature ranges between 6 -7°C in winter. The diurnal variation in temperature and other climatic parameters were recorded during wheat growing season at both locations (Fig.1 & 2). These weather data were used for calculation of daily reference evapo-transpiration which was used to estimation of crop water requirement The soil texture of experimental field was sandy loam with pH 7.6 and electrical conductivity 0.25 dS/m in 1:2.5 soil water suspension. The soil was having 0.42% organic carbon, 193 kg/ha available N, 17.9 kg/ha available P, and 241 kg/ha available K. The agro-climatic conditions of the Gauria-Karma location are characterized by sub-tropical and semi-arid conditions. Average annual rainfall of this area is 1155 mm, of which about 80% is received during the monsoon season, starting from the end of June to middle of September. The mean maximum temperature ranges between 30 -36°C in summer and mean minimum temperature ranges between 8- 9°C in winter. The soil texture of experimental field was sandy loam with pH 7.2 and electrical conductivity 0.31 dS/m in 1:2.5 soil water suspension. The soil was having 0.65% organic carbon, 210 kg/ha available N, 18.2 kg/ha available P and 260 kg/ha available K.

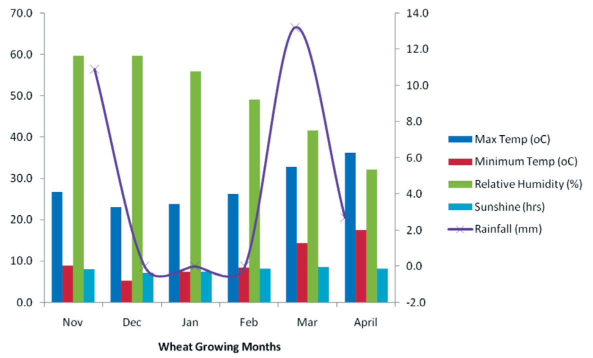

Fig.1 Monthly mean maximum and minimum temperature (°C), Relative Humidity (%), Rainfall (mm) and Sunshine hours at IARI, Goria Karma, Jharkhand

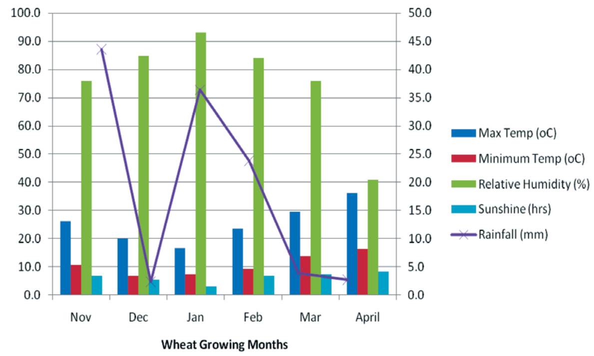

Fig.2 Monthly mean maximum and minimum temperature (°C), Relative Humidity (%), Rainfall (mm) and Sunshine hours at IIWBR, Karnal, Haryana

The experiment was laid out in split plot design with three replications. The main treatment consists of two levels of irrigation (80 ETc and 60 ETc) and sub plot consists ten number of wheat genotypes (Table 1). The crop was irrigated by micro irrigation (drip irrigation). The genotypes were sown in 8 x 2 m^2 plots with rows 20 cm apart. All recommended agronomic practices for the region except irrigation application were carried out at the proper time. Seeding density of approximately 250 plants m^{-2} was maintained using a calibrated precision seed drill machine for sowing. Two soil moisture treatments were imposed by drip system to compensate 80% and 60% of ET. The water requirement of the crop was calculated using a computer based programme CROPWAT 8.0, a decision support tool developed by the Land and Water Development Division of FAO. The amount of applied water was measured by the inbuilt water meter in the pipe line of the drip system. A filter was installed in the main line to prevent sediment from blocking the emitters. Plots in each replication were separated by a buffer zone of one-meter-wide strip.

Water use efficiency analysis combined for physical accounting of water with yield to assess how much value is being obtained from the use of water. For this analysis, physical water productivity was calculated as: WUE= Output/Q

Where WUE, water use efficiency (productivity of water) in kg/m3); output, yield of wheat in kg/ha; Q, water used by the crop in m^3/ha.

Table 1. Pedigree details of the genotypes used for estimating at IARI Gauria Karma, Jharkhand and IIWBR, Karnal

SN	ICAR-IIWBR Karnal		ICAR-IARI Gauria Karma	
	Genotype	Pedigree	Genotype	Pedigree
1	DBW 243	BECARD/KACHU	HI 8627	HD4672/PDW233
2	DBW 313	REH/HARE/2*/BCN/3/CROC/AE.SQ(213)//PGO/4/HUITES/5/PBW585//PBW509/PBW581	PYT 62	DBW 90/DPW 621-50
3	40 ESWYT 21	BORL14/CHIPAK	PYT 30	DPW621-50/PBW 703
4	DBW 360	HD2967/WH1080	NIAW 3170	SKOLL/ROLF07
5	DBW 325	CHIPAK	DBW 110	KIRITATI/4/2*SERI1B*2/3/KAUZ*2/BOW//KAUZ
6	40 ESWYT 39	SUP152/BAJ #1//KFA/2*KACHU	NIDW 1149	NIDW295 /NIDW15
7	DBW223	PBW550/CBW38	DBW 187	NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR/5/KACHU/6/KACHU
8	40 ESWYT 33	MUTUS*2/MUU//2*MUCUY	NIAW 1415	GW 9506/PRL//PRL
9	40 ESWYT 37	NADI#2*2/6/BECARD #1/5/KIRITATI/4/2*SERI.1B*2/3/KAUZ*2/BOW//KAUZ	NIDW 15 D	DOM 50
10	40 ESWYT 17	NADI#1*2/3/MUTUS/AKURI #1//MUTUS	DBW 222	KACHU/SAUAL/8/ATTILA*2/PBW65/6/PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1/7/ATTILA/2*PASTOR

3. Results & discussion

Analysis of variance

Combined analysis of variance of the split plot design across locations for genotypes and evapo-transpiration (ET) for the studied 10 wheat genotypes under two levels of irrigation is presented in Table 2. The significant genotypic and ET difference indicates that there is variation in the water use efficiency among the genotypes at both the locations. Thus, some of these genotypes can be used for developing wheat varieties with higher water use efficiency.

Table 2. Analysis of Variance for yield and WUE under 80 and 60ET at IARI Gauria Karma, Jharkhand and IIWBR, Karnal locations

Main plots	MS							
	IARI, Jharkhand				IIWBR Karnal			
Variable	Yield		WUE		Yield		WUE	
	80ET	60ET	80ET	60ET	80ET	60ET	80ET	60ET
Blocks	151472.9	179207.4	0.01	0.03	13080.5	62228.5	0.00	0.03
Genotype	541548.2***	1049830.9***	0.04***	0.18***	142981.7	314179.8***	0.03	0.13***
Error	48698.8	125053.3	0.00	0.02	62569.3	43417.7	0.01	0.01

Ranking of genotypes

When means were ranked using Tukey's test of significance, under 60 and 80 % of ET, genotype DBW 110 was the top ranked for WUE (1.28 kg/M^3 & 1.71 kg/M^3 respectively) due to its highest grain yield (4593.75 Kg/ha & 4114.58 Kg/ha respectively) at IARI Gauria Karma, Jharkhand location. This is the genotype which ranked first under both moisture levels followed by genotype NIDW 1149 which maintained third rank under both soil moisture scenarios for grain yield and WUE and both genotypes remained statistically at par (Table 3). The lowest ranked genotype under was NIAW 3170 under both irrigation levels and it is having 1.0 and 1.06 Kg/M3 WUE under 80 & 60 ET, respectively.

Table 3. Wheat grain yield and WUE affected by different moisture levels at IARI, Gauria Karma, Jharkhand

Irrigation Levels	Yield, kg/ha	WUE, kg/m^3
80 ET	4084	1.134
60 ET	3172	1.322
CD=0.05	374.34	0.137

Genotypes	Yield, Kg/ha		WUE, Kg/M^3	
	80 ET	60 ET	80 ET	60 ET
HI 8627	4500.00^b	3489.58^d	1.25^b	1.45^d
PYT 62	4088.54^f	2614.58^h	1.14^f	1.09^h
PYT 30	3781.25^g	3208.33^e	1.05^g	1.34^e
NIAW 3170	3578.13^i	2541.67^j	1.00^i	1.06^j
DBW 110	4593.75^a	4114.58^a	1.28^a	1.71^a
NIDW 1149	4479.17^c	3750.00^c	1.24^c	1.56^c
PBW 187	3645.83^h	2552.08^i	1.01^h	1.06^i
NIAW 1415	4197.92^e	3848.96^b	1.17^e	1.60^b
NDW 15 D	4468.75^d	2817.71^f	1.24^{cd}	1.17^f
DBW 222	3505.21^j	2786.46^g	0.97^j	1.16^g
CD=0.05	378.55	606.61	0.105	0.25

At ICAR- IIWBR, Karnal, different set of genotypes were evaluated under same soil moisture scenario *i.e.* 80 and 60 % of ET. At Karnal only genotype 40 ESWYT 33 maintain same rank under both soil moisture levels which indicate that this genotype having resilience against soil moisture stress condition. Genotype 40 ESWYT 33 ranked first when means were ranked using Tukey's test of significance with WUE of 2.42 and 3.04 kg/M^3 under 80 and 60 % of ET respectively (Table 4). Under 60 % of ET the second ranked genotype was 40 ESWYT 37 having WUE of 3.0 Kg/ha seems to be promising under soil moisture stress conditions along with 40 ESWYT 33 genotype (Table 4). The water use efficient genotypes were also reported in few reports (Meena *et al.*, 2019; Ahmadi *et al.*, 2018; Fletcher *et al.*, 2018). The genotypes identified for higher water use efficiency are readily available for hybridization to incorporate useful variability for WUE into breeding programmes to develop high yielding genotypes having characters of high water use efficiency.

Table 4. Wheat grain yield and WUE affected by different moisture levels at ICAR- IIWBR, Karnal, Haryana

Irrigation Levels	Yield, kg/ha	WUE, kg/m^{3}
80 ET	4753	2.21
60 ET	4162	2.75
CD=0.05	158.64	0.15

Genotypes	Yield, Kg/ha		WUE, Kg/M^{3}	
	80 ET	60 ET	80 ET	60 ET
DBW 243	4662.22^{e}	4260.42^{d}	2.16^{e}	2.81^{d}
DBW 313	4825.97^{c}	3882.22^{h}	2.24^{c}	2.56^{h}
40 ESWYT 21	4577.50^{j}	3660.56^{j}	2.12^{j}	2.41^{j}
DBW 360	5062.78^{b}	4072.36^{g}	2.35^{b}	2.69^{g}
DBW 325	4638.19^{f}	3746.11^{i}	2.15^{f}	2.47^{i}
40 ESWYT 39	4592.36^{i}	4207.50^{f}	2.13^{i}	2.78^{f}
DBW223	4613.47^{h}	4398.33^{c}	2.14^{h}	2.90^{c}
40 ESWYT 33	5213.47^{a}	4610.57^{a}	2.42^{a}	3.04^{a}
40 ESWYT 37	4726.00^{d}	4562.07^{b}	2.19^{d}	3.00^{b}
40 ESWYT 17	4621.07^{g}	4216.27^{e}	2.14^{g}	2.78^{e}
CD=0.05	429.09	357.43	0.19	0.24

Yield and biomass of wheat genotypes along with trait reduction (%) and yield stability index

Wheat genotypes were evaluated under two different irrigation conditions *viz.,* 80EC and 60EC and their performance is presented in Table 5. The grain yield varied from 3505 kg/ha (DBW222) to 4594 kg/ha (DBW110) under 80EC whereas it varied from 2542kg/ha (NIAW3170) to 4115 kg/ha (DBW110) under 60EC at Gauria-Karma. Highest biomass was reported in genotype DBW222 (12.4tons/ha) and PYT30 (9.9 tons/ha) under 80Ec and 60EC respectively. Maximum reduction of 37% (NIDW15) and 30% (DBW222) was reported in yield and biomass. The yield stability index indicated DBW 110 (YSI=0.90) was the most stable genotype among tested genotypes. Similarly, at IIWBR, Karnal the highest yielding genotype was 40ESWYT33 under both 80 EC (5213kg/ha) and 60EC (4611), whereas the genotypes DBW223 (14.1tons/ha) and 40ESWYT33 (10.1 tons/ha) reported highest in biomass under 80and 60EC respectively. Highest yield reduction of 20% was reported in genotypes DBW313, 40ESWYT21 and DBW360 whereas the genotype DBW 325 (42%) exhibited highest reduction in biomass. The genotype 40 ESWYT 37 (0.97) was reported to be highly stable as compared to all the tested genotypes (Table 5). Similar results were also reported by Meena *et al.* (2015) for wheat crop.

Table 5. Yield and biomass of wheat genotypes along with trait reduction (%) and yield stability index under 80EC and 60EC

Genotype	Irrigation 80EC		Irrigation 60EC		Reduction (%)		Yield Stability Index (YSI)
	Yield (Kg/ha)	Biomass (tons/ha)	Yield (Kg/ha)	Biomass (tons/ha)	Yield	Biomass	
			IARI, Jharkhand				
HI 8627	4500	10.3	3490	8.5	22	17	0.78
PYT 62	4089	11.1	2615	9.6	36	14	0.64
PYT 30	3781	10.3	3208	9.9	15	4	0.85
NIAW 3170	3578	11.9	2542	9.4	29	21	0.71
DBW 110	4594	12.1	4115	9.6	10	21	0.90
NIDW 1149	4479	11.1	3750	9.2	16	18	0.84
PBW 187	3646	12.3	2552	9.3	30	24	0.70

NIAW 1415	4198	11.5	3849	9.6	8	16	0.92
NIDW 15	4469	10.9	2818	9.4	37	14	0.63
DBW 222	3505	12.4	2786	8.6	21	30	0.79
IIWBR, Karnal							
DBW 243	4662	12.5	4260	8.7	9	31	0.91
DBW 313	4826	12.3	3882	9.3	20	25	0.80
40 ESWYT 21	4578	13.0	3661	8.3	20	36	0.80
DBW 360	5063	13.4	4072	8.4	20	37	0.80
DBW 325	4638	12.9	3746	7.6	19	42	0.81
40 ESWYT 39	4592	13.3	4208	8.3	8	38	0.92
DBW223	4613	14.1	4398	9.3	5	34	0.95
40 ESWYT 33	5213	13.0	4611	10.1	12	23	0.88
40 ESWYT 37	4726	13.1	4562	9.4	3	28	0.97
40 ESWYT 17	4621	13.4	4216	8.9	9	34	0.91

Quantification of water savings

The top ranked genotypes viz. DBW 110 (4114.58 kg/ha), NIAW 1415 (3848.96 kg/ha) under 60 % ET soil moisture scenario and DBW 110 (4593.75 kg/ha), HI 8627 (4500.00 kg/ha) and NIDW 1149 (4479.17 kg/ha) under 80 % ET soil moisture scenario produced higher yield compared to bottom ranked genotypes viz. NIAW 3170 considered as check with a maximum WUE of 1.24 to 1.28 Kg/M^3 under irrigations at 80 ET and 1.60 to 1.71 kg/M^3 under 60% ET soil moisture scenario which is proved that by there is a saving of irrigation water *viz.* 24.21 to 38.01% by adopting the water use efficient genotypes in Gauria Karma, conditions (Table 2). Similarly, genotypes 40 ESWYT 33 (5213.47 kg/ha), DBW 360 (5062.78 kg/ha), DBW 313 (4825.97 kg/ha) with a maximum WUE (2.42 to 2.24 Kg/M^3) under irrigations at 80% of ET and 40 ESWYT 33 (4610.57 kg/M^3) and 40 ESWYT 37 (4562.07 kg/M^3) with WUE of 3.00 to 3.04 kg/M^3 indicated that irrigation water could be saved (12.39 to 20.72 %) by using higher water use efficient genotypes.

Wheat genotypes had been evaluated under two conditions of water availability i.e. at the 60 and 80 ET at IIWBR, Karnal and IARI, Jhkarkhand (Table 6). Two ways ANOVA exploited to compare yield and water use efficiency of genotypes. Highly significant differences had been observed between two water stages. Genotypes also expressed performance difference among them for yield and water use efficiency. The cross over interactions of Genotypes x Water availability had been exhibited by genotypes and water availability. More over the performance of genotypes had pooled over locations at 60 and 80 ET to point out the suitability of genotypes for 60 and 80 ET respectively.

Table 6. Pooled analysis of variance (80 and 60ET) for yield and WUE at IARI Gauria Karma, Jharkhand and Karnal locations.

Main plots	**Mean Sum of squares**			
	IARI, Jharkhand		**IIWBR, Karnal**	
Variable	Yield	WUE	Yield	WUE
Blocks	217138.7	0.03	54916.9	0.02
ET	12461344.4**	0.53*	5250982.5**	4.36**
Main Plot Error	113541.7	0.02	20392.1	0.01
Genotype	1322996.2***	0.17***	304226.5***	0.11***
Gen x ET	268382.9**	0.05**	152935.0*	0.06**
Error	86876.1	0.01	52993.5	0.02

4. Conclusions

The results showed that wheat genotypes have significant variation regarding yield under different soil moisture levels across the wheat growing zones. There is a need to select and breed genotypes having higher water use efficiency. Also there is urgent need to optimize the irrigation water use per irrigation to avoid excess use of irrigation water in different agro climatic conditions.

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Availability of data and materials

The data set used and/or analyzed in the present study are available from the corresponding author on reasonable request.

Declaration

Conflict of Interest

The authors declare no conflict of interest.

Consent for publication

All author agreed and approved the manuscript for publication in Journal of Cereal Research.

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