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Contents

Research Articles

Short Communication

Journal of Cereal Research
Volume 14 (Spl - 2): 1-7
Homepage: http://epubs.icar.org.in/ejournal/index.php/JWR

Research Article

Root characterization and Identification of drought tolerant dicoccum wheat germplasm lines using Stress tolerance Index (STI)

Sharada Halehundi Bellegowda[1]*, Uday Govidareddy[1], Priyanka Krishnareddy[2], Gopalareddy Krishnappa[3] and Shamarao Jagirdhar[2]

[1]*AICRP on wheat, Department of Genetics and Plant Breeding, University of Agricultural Sciences Dharwad 580005, Karnataka*
[2]*Department of Plant Pathology, University of Agricultural Sciences Dharwad 580005, Karnataka*
[3]*Sugarcane Breeding Institute, Coimbatore 641007, Tamil Nadu*

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****Corresponding author:***
E-mail: sharadabgowda234@gmail.com

ABSTRACT

Dicoccum wheat germplasm lines/local collections from different eco-geographical zones were evaluated for their response to terminal drought stress. Assessing the genetic diversity for dicoccum wheat germplasm lines under stress and non-stress conditions was prime objective of the study conducted in Rabi 2020-21. Results of multivariate analysis on root traits revealed that the root length and root volume were highly influencing grain yield under stress conditions. A clustering analysis based on agro-morphological and root traits indicated a good level of genetic diversity among germplasm. Most yield and yield-attributing characteristics showed a significant decrease in mean performance under stress conditions. Drought tolerant germplasm lines were classified based on Stress Susceptibility Index (SSI) and Stress Tolerance Index (STI). Among the seventy-dicoccum germplasm lines DDK-50378 showed good SSI with 0.21. Twenty germplasm lines performed better with STI (>0.9). The germplasm lines DDK-50341, DDK-50380, and DDK-50381 produced better yield with increased root length and root volume under moisture stress than the top yielding standard check DDK 1025. These genotypes proven to be promising and carry genes for drought tolerance and can be further utilized in breeding program for drought tolerance.

Key words: *Triticum dicoccum*, Terminal Drought, Root Phenotyping, Drought Tolerance

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most widely grown cereal species and an essential component of the global food security, providing 20% of the total calories consumed by the world's growing population (Shahinnia *et al.,* 2016). Emmer wheat (*Triticum dicoccum* Schrank) is one among the oldest cultivated plant that has been a staple crop over centuries (Nesbitt and Samuel, 1996). It is now a minor crop, cultivated mainly in isolated, marginal areas where no other crop can be grown economically, where its typical characteristics, such as the ability to adopt to poor and stony soils, resistance to low temperatures, considerable ability to control weeds, and resistance to diseases common to other cereals can be used as advantage. Emmer wheat consequently represents a valuable genetic resource to improve resistance to biotic and abiotic stress in bread wheat and durum wheat

(Dorofeev *et al.,* 1979; Castagna *et al.,* 1996; Marconi and Cubadda, 2005; Zaharieva *et al.,* 2010; Singh *et al.,* 2018).

Climate change is expected to have large effects on global wheat production: for every 1°C increase in temperature, global wheat yields are predicted to decline by 4.1–6.4% (Budak *et al.*, 2013). Changing crop phenology is considered an important bio-indicator of climate change, with the recent warming trend causing advancement in crop phenology (Morgounov *et al.,* 2018). Rising temperatures are the main driver of projected negative climate change impacts on wheat yields (Porter *et al.,* 2014). However, with global climate change, the stability and productivity of wheat are affected by various abiotic stresses. Among the abiotic stresses, that limit crop productivity, drought is the most damaging factor and drought tolerance is one of the most difficult traits to improve by breeding (Tuberosa and Salvi, 2006). Therefore, increasing crop yield, under drought conditions is one of the most important challenges faced by the breeders (Tuberosa, 2012). Owing to the climate change, intensity and frequency of drought periods are expected to increase, and act as a difficulty for sustainable crop production (Wassmann *et al.,* 2009; Ray *et al.,* 2013; Mohammadi, 2016; Mwadzingeni *et al.,* 2016). Dicoccum wheat is cultivated majorly in areas under assured irrigation conditions. Farmers are nowadays willing to grow dicoccum wheat under limited water conditions. To extend the area under the cultivation of emmer wheat by making it possible to cultivate even under limited water conditions, to fulfil the value based market demand of dicoccum products and to preserve the conventional quality characters of dicoccum, the selection of lines that can perform better even under limited water condition is necessary (Sharada *et al.,* 2021).

Domestication and selective breeding has limited the genetic diversity of wheat, leading to cultivars adapted to artificial environments which has resulted in reduced resistance to drought stress (Kumar *et al.,* 2008; Budak *et al.,* 2013). One opportunity is presented by the exploitation of local germplasm of emmer wheat. The present study focuses on characterizing and screening dicoccum wheat germplasm lines for root characters and to identify the drought tolerant wheat germplasam with relatively high stress tolerance index (STI).

2. Materials and methods

2.1 Plant materials

Study materials consisted of seventy-dicoccum wheat germplasm lines were used which were collected from different parts of Tamilnadu, Karnataka and Maharashtra. DDK 1025, DDK 1029, HW 1098 and NP 200 were used as cultivated check variety. The germplasm lines were evaluated in two different sets under stress (drought stress for 20 days during flowering stage), and non-stress (timely sown irrigated) conditions, during *Rabi* 2020 and 2021. Conducting the test for homogeneity-pooled data was used for statistical analysis. The germplasm lines were planted in an augmented design each entry spaced in 20 cm line spacing and plot size containing six rows of 3 m length. Standard agronomic practices were followed for raising the crop.

2.2 Root characterization

Root characterization was done under root phenotyping structures. Seeds were sown in the PVC pipes of 1.5 m height (Fig 1). A well-sieved soil mix along with the vermicompost was used to grow the plants in the PVC pipes. The non-stress and the stress conditions were artificially maintained in the pipes. The observations were recorded by maintaining the moisture through irrigating the pipes at a regular interval and moisture stress was imposed for drought set from 15-30 days at reproductive stage.

Observation on morphological and root characters was recorded following the standard procedures. Selection of genotypes based on their performance under drought stress and non-stress situations, was based on Fisher and Maurer (1978) stress susceptibility index (SSI) as a method of determining yield stability by accounting for variations in both prospective and actual yields in diverse environments. Stress Tolerance Index (STI) was developed as a tool for assessing genotype's potential for high yield and stress tolerance (Fernandez, 1992). These were used in order to classify genotypes into different drought tolerance categories as reported by Sang *et al.* (2014).

Fig 1: Different stages of dicoccum germplasm lines under PVC pipes for root characters

3. Results and discussion

3.1 Variability studies

Analysis of variance for the morpho-yield traits showed significant difference among the genotypes, which revealed that for most of germplasm diverse and collected from different ecological conditions (Table 1). Under drought stress condition, decreasing mean performance of the genotypes was recorded in morpho yield contributing characters like spikelets per spike, and 1000 grain weight in drought stress conditions compared to non-stress similar to the observations made by by Kilic and Yaggbasanlar (2010). Genotypes exhibited significant differences for the root related traits under both conditions (stress and non-stress), checks varieties showed no variations for their mean performance for root volume under both the conditions explaining their adaptability to irrigated conditions. Percent reduction in performance was computed for various traits to understand their sensitivity under moisture stress condition (Table 2). Most yield-attributing characters, such as spikelets per spike, and grain yield per plot, were seriously impacted by drought and showed a significant decrease in mean performance. Under drought stress, germplasm exhibited a significant reduction in grain yield production (41.76 %) compared to non-stress conditions. Under moisture stress, it was observed that there was an increase in performance of root related traits such as root length (by 46.44 %), root volume (by 34.24 %), dry root weight (by 43.43 %) and fresh root weight (by 42.24 %). Research findings explain that due to a lack of moisture during crop growth and development, the genotype with tolerance capacity elongates their roots towards the availability of water.

3.2 Phenotypic diversity

Correlation studies between root traits and yield revealed that with increase in root length, there was increase in the grain yield both under stress and non-stress condition. Interestingly it was observed that under drought condition there was decrease in the grain yield with the increase in shoot length. Phenotypic diversity analysis done using D^2-statistics revealed different number of clusters under stress and non-stress conditions. Nine clusters under non-stress and 3 clusters under stress condition was observed indicating ample amount of diversity. Root length followed by root volume was a major contributor to diversity under stress condition (Table 2a and 2b). Cluster I has the most lines, including the ones with the longest roots (DDK-50381, DDK-50378, DDK-50323, and DDK-50341). It's crucial to remember that when computing cluster mean, the superiority of one genotype over another for a specific feature might be diluted by other genotypes in the same cluster that is inferior or intermediate for the same trait. As a result, in addition to choosing genotypes for hybridization from clusters with a greater intercluster distance, one may also consider selecting parents depending on the amount of divergence for a trait of interest within a cluster (Sharada *et al.,* 2021).

The clustering pattern shows that the distribution of different wheat genotypes into clusters happened at random, regardless of their geographical origin. Rahman *et al.* (2015), Mudra *et al.* (2015), Bhanupriya *et al.* (2014) and Kumar *et al.* (2019) found that genetic drift and selection in diverse environments can produce more genotypic diversity than geographical distances. As a result, choosing parental material for hybridization solely on the basis of geographical diversity may not be productive.

Table 1: ANOVA for augmented design for different morpho-physiological traits under both stress and non-stress condition

	Source	Block (eliminating Treatments)	Treatment (ignoring Blocks)	Checks	Varieties	Checks vs Varieties	Error
	df	**5**	**69**	**3**	**65**	**1**	**15**
Spikelets per spike	Non-stress	0.84	5.02**	21.37**	3.70	41.42**	2.37
	Stress	0.16	3.13**	1.09	2.79	31.29**	0.02
Spike length	Non-stress	1.56	4.38**	6.38**	4.36**	0.01	0.73
	Stress	0.07	2.43**	4.16**	2.07**	20.87**	0.02
Thousand grain weight	Non-stress	1.09	27.07**	31.96**	24.55**	175.98**	1.86
	Stress	0.40	29.45**	39.22**	23.03**	417.56**	1.00
Grain yield	Non-stress	15983.80	557037.9**	793838.7**	506017.5**	3162964.7**	58079.5
	Stress	11624.34	411258.9**	625119.9**	334834.5**	4737257.3**	3486.69
Root length	Non-stress	1.47	215.36**	685.38**	177.78**	1247.69**	0.51
	Stress	3.62	1186.14**	7939.7**	866.97**	1671.67**	4.79
Root volume	Non-stress	1.44	13.31**	0.63	11.15**	191.58**	2.1
	Stress	5.56	13.36**	2.65	13.83**	14.48**	2.42

* - P = < 0.05; ** P = < 0.01

Table 2a: Intra and inter-cluster D^2 values in dicoccum wheat germplasm lines under non-stress condition

	Cluster. 1	Cluster. 2	Cluster. 3	Cluster. 4	Cluster. 5	Cluster. 6	Cluster. 7	Cluster. 8	Cluster. 9
Cluster. 1	15.60	21.37	20.60	25.51	20.14	30.35	33.68	33.29	31.52
Cluster. 2		16.41	30.13	30.15	24.21	37.07	42.14	41.40	39.55
Cluster. 3			19.04	28.12	23.60	27.61	26.51	29.66	27.50
Cluster. 4				21.08	29.37	36.63	40.32	27.43	29.58
Cluster. 5					0.00	25.76	27.84	33.01	30.99
Cluster. 6						0.00	0.23	43.58	34.48
Cluster. 7							0.00	35.75	24.71
Cluster. 8								0.00	25.93
Cluster. 9									0.00

Table 2b: Intra and inter-cluster D^2 values in dicoccum wheat germplasm lines under stress condition

	Cluster. 1	Cluster. 2	Cluster. 3
Cluster. 1	21.63	32.47	46.38
Cluster. 2		0	43.47
Cluster. 3			0

Table 3: Mean performance of drought tolerant germplasm lines based on SSI for root related traits and STI

Germplasm lines	**Stress susceptibility indices**						**Root traits**			
	YS (kg/ha)	**YP (kg/ha)**	**SSI**	**Category**	**STI**	**Category**	**RL (cm)**		**RV (cm^3)**	
							S	**NS**	**S**	**NS**
DDK-50341	3345.00	4025.00	0.95	Moderate	0.89	Moderate	87	35	14	12
DDK-50380	3240.00	3558.33	0.92	Moderate	0.84	Moderate	57	48	14	9
DDK-50381	3105.00	3416.67	0.63	Moderate	0.87	Moderate	150	28	14	13
DDK-50378	2591.67	2733.33	0.21	Tolerant	0.80	Moderate	125	48	19	13
DDK-50337	2233.33	2741.67	0.59	Moderate	0.81	Moderate	67	40	18	6
DDK-50323	2041.67	2458.33	0.58	Moderate	0.80	Moderate	138	52	15	11
DDK 1025	2751.44	3577.78	0.84	Moderate	0.55	Susceptible	60	45	14	12
DDK 1029	2474.17	2980.56	0.65	Moderate	0.65	Susceptible	55	35	13	12
NP 200	2211.39	2913.89	0.90	Moderate	0.67	Susceptible	70	60	15	12
HW 1098	2007.36	2741.67	0.92	Moderate	0.71	Susceptible	137	45	16	15

YS – Yield under stress; YP – Yield under non-stress; SSI – Stress susceptibility index STI – Stress tolerance index; RL – Root length; SL – Shoot length; RV – Root volume; S – Stress; NS – Non-stress

3.3 Identification of drought-tolerant germplasm lines

Measuring the root length revealed that the lines DDK-50381, DDK-50378, DDK-50323 and DDK-50341 exhibited better root length among all the lines. The absence of efficient, repeatable screening procedures and the inability to consistently establish defined and repeatable water stress circumstances where huge populations may be assessed efficiently make breeding for drought resistance difficult (Ramirez and Kelly, 1998). The relative yield performance of germplasm lines in stress and non-stress environments appears to be a typical starting point for finding stress-tolerant germplasm lines (Mohammadi *et al.,* 2012). Thus, drought indices have been used to screen drought-tolerant genotypes because they give a measure of drought based on the loss in yield under drought circumstances compared to normal environments (Mitra, 2001). Stress sensitivity and stress tolerance indices were investigated in the current study-utilizing yield under moisture stress and non-stress conditions to discover drought stress tolerance germplasm lines. Based on drought sensitivity, the 70 germplasm lines were categorized as tolerant, moderately tolerant, or sensitive. The yield ratio of each variety in stressed vs. non-stressed circumstances as compared to the proportions in total germplasm lines to determine the stress susceptibility index. So it was observed that one germplasm line (DDK-50378) was falling in the tolerant category. This line was having moderate production even under stressed condition. Three basic techniques for selecting tolerant genotypes were to select under favourable, stressed, and both circumstances simultaneously. Several indices have been developed to describe a genotype's behaviour in stress and non-stress conditions (Mohammadi *et al.,* 2012). Both the stress susceptibility index (SSI) and the stress tolerance index (STI) were utilised in our study to identify drought-tolerant germplasm lines without compromising yield under stress conditions. Thus, in our study, the selected tolerant line based on STI was found to be a promising drought tolerant line with modest production potential. Based on the stress tolerance index (STI), 20 germplasm lines were under the category of tolerance, 26 germplasm lines were moderately tolerant and 34 were susceptible lines. Germplasm lines viz., DDK-50378, DDK-50323 and DDK-50381 showed high STI values with more root length indicating they are suitable for terminal drought stress conditions. DDK 50341 showed high stress tolerance index with least difference in root length under stress and non-stress conditions, indicating the suitability of genotype to intermittent stress (restricted irrigation) with moderate tolerance to drought stress

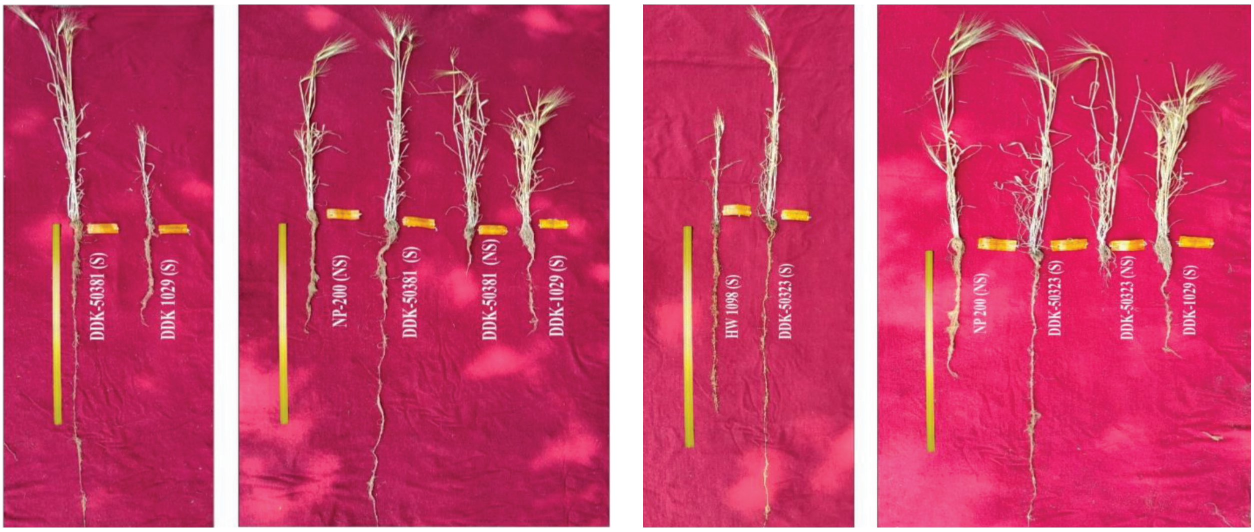

Figure 2: Differential root performance of dicoccum germplasm lines under stress and non-stress condition (S-stress and NS-non-stress conditions)

4. Conclusion

Our study revealed that the local germplasm collections act as reservoir of genes for abiotic stresses. This can be exploited in the breeding program for genetic improvement. The analysis of variance exhibited significant genetic variations among the genotypes for all quantitative characters studied under both the environmental conditions, which help us for selection and utilize them for breeding programme. The genetic diversity identified among the genotypes can be exploited in a breeding program aimed at developing drought-tolerant dicoccum wheat cultivars. DDK-50341 was found drought tolerant with minimal grain yield reduction. DDK-50378, DDK-50380, and DDK-50381 were moderately tolerant with higher yields based on SSI and STI.

Author contributions

All authors have contributed, read and agreed to the published version of the manuscript.

Compliance with ethical standards

No

Conflict of Interest

NA

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Research Article

Carbon footprints of rice-wheat cultivation across farm size categories: Evidence from Punjab in India

Sangeet Ranguwal[1*], BaljinderKaur Sidana[2] and Sunny Kumar[3]

[1] *Department of Economics and Sociology, Punjab Agricultural University, Ludhiana, Punjab*

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Corresponding author:
E-mail: sangeet@pau.edu

Abstract

Carbon footprint (CF) can be a powerful tool to guide sustainable food production systems. The present study quantified the CF and analyzed the variability in CF across farm categories along with share of different contributing inputs for rice and wheat production in the Punjab state. The carbon footprint of rice was found to be much higher (6.34 tons CO_2eqha^{-1} and 0.91 tons CO_2 eq ton^{-1}) than wheat (1.41 tons CO_2eqha^{-1} and 0.28 tons CO_2eqton^{-1}). For rice, among different sources of emission, methane formed major share (60.7 %) followed by free electricity for irrigation (17.9 %), N_2O (10.8 %), plant protection chemicals (7.5 %), diesel (6.1 %) and fertilizers (3 %) while for wheat the major share of emissions were from N_2O (41.3 %) followed by diesel fuel (28.1 %), fertilizers (11.8 %), electricity (10.6 %) and chemicals (5.1 %). Across farm categories, the share of fertilizers (in terms of on-farm (11.2 %) and off emissions (3.1)) remained the maximum for marginal farmers while large farmers contributed the most to the GHG emissions (18.5 %) by using free electricity. The share of on-farm emissions was higher for rice (95.5 %) than for wheat (80.1 %) because of cultivation of rice under flooded conditions leading to methane emissions. The major contributors to the higher off-farm wheat emissions were fertilizers especially P_2O_5, followed by the use of diesel fuel and chemicals. The study stresses the need for sustainable management of agro-inputs which will not only offset the associated GHG emissions but also will improve the soil health. In addition, awareness of climate-smart agricultural practices and access to technologies like DSR, laser leveling, and Happy seeder are key factors in determining the utilization of farm and land management practices that may simultaneously decrease these emissions and increase the adaptive capacity of farmers, and thus improve food security.

Keywords: Carbon footprint, Methane, Fertilizers, Farm category

1. Introduction

Agriculture is both a victim of and a contributor to climate change. On the one hand, agricultural activities contribute to greenhouse gas (GHGs) emissions, mainly due to chemical fertilizers, pesticides, and animal waste. This rate is bound to rise further because of the increasing demand for food by the growing global population, a more robust market for dairy and meat products, and the intensification of agricultural practices. On the other hand, these GHGs include nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4) which contribute to climate change and global warming and thereby have a profound impact on the sustainability of agricultural production systems. Globally, agriculture and its related sectors contributed 24 percent of the world's GHGs emissions in 2010 (Smith *et al.,* 2014). These GHG emissions from agricultural production systems have increased more than two–folds in the last 55 years (FAOSTATS, 2019). During the last four decades, the emission of GHGs from agriculture and its related sector increased by 35 percent from 4.2 Gt CO_2eq per year to 5.7 Gt CO_2eq per year and the highest increase was observed during the most recent decade (Tubiello *et al.*, 2013). Asian countries contributed about 44 percent of the total agriculture-related GHG emissions in 2011. As per FAO reports, India ranks second (contributing about 21 %) for paddy based CO_2 (equivalent) emission, followed by China at world level (FAO STAT, 2019). The situation will become more stressed as the world population is increasing rapidly, and food demand is anticipated to double by the year 2050 (Khan and Hanjra, 2009; Imran *et al.,* 2020). At the same time, increasing GHG emissions with more requirements for food production is another key challenge. This scenario requires production systems to maintain high yields without compromising environmental integrity.

Rice-wheat as a dominant cropping system in major agricultural states of India including Punjab has depleted soil health and water resources despite its many benefits (Bhatt *et al.*, 2021; Singh *et al.*, 2021). The estimated annual global warming potential is about ~89 Teragram (Tg) CO_2–C for rice and 45 Tg CO_2–C for wheat (Sapkota *et al.*, 2017), and it showed an increasing trend (Smith et al., 2014). In Punjab, where more than 80 percent of gross cropped area is under rice and wheat crops (PAU, 2022), there has been a 173 percent increase in GHG emissions due to crop burning (mainly rice) between 1980 and 2013, primarily due to farm mechanization, (combined harvesters) that generates enormous amounts of unused stubble, which is burnt to save cost and time (Benbi, 2018). The carbon footprint analysis is beneficial for policymakers, administrators and researchers and is imperative for production planning (Basavalingaiah *et al.,* 2020; Kashyap and Agarwal, 2021). The present study quantifies carbon footprints for rice and wheat across different farm size categories while assessing the contribution of different inputs to it and suggests policy options for precise and effective efforts for mitigation of GHG emissions in the Punjab state.

2. Materials and Methods

Data for the study has been taken from the 'Cost of Cultivation Scheme' run by the Directorate of Economics and Statistics, Ministry of Agriculture, India. Under this scheme, data is collected from 300 farm households in 30 tehsils spread across the three agro-climatic zones of the Punjab state. From each zone, farmers are selected using a three-stage stratified sampling technique, with tehsil as stage one, a village/cluster of villages as stage two, and operational holdings within the clusters as stage three. From each cluster, ten operational holdings with two farmers from the five farm size groups were randomly chosen. Thus, the sample included 60 farmers from each of the five farm categories. Data related to different inputs such as seed, fuel (diesel consumed in diverse farm operations like preparatory tillage, inter-culture operations, harvesting, transport on farm, supervision, etc.), fertilizers (N, P_2O5, and K_2O), chemicals (insecticides/pesticides, fungicides, weedicides), crop yield (economic yield), total working hours of men and women labour as well as draught power used, agri-machinery/implement use for different farm operations, etc. were recorded for rice and wheat during 2018-19. In addition, estimation of by-products has been done from grain yield data for crops by using the crop-to-residue ratio method (Chauhan, 2012).

The amount of GHG emissions from input use during crop cultivation was estimated by using the CO_2 emission coefficients of farm inputs (Table 1). Three key GHGs emissions under consideration were carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). The amount of produced CO_2 equivalent was calculated by multiplying the quantity of input (diesel fuel, chemical fertilizer, farm yard manure, and electricity) by their corresponding emission factor.

Off-farm operations i.e. production, formulation, storage and distribution of external inputs are carbon based operations and application with tractorized equipment lead to combustion of fossil fuel, and use of energy from alternate sources, which also emits CO2 and other greenhouse gases (GHGs) into the atmosphere. Accordingly, the GHG emissions were also classified as off-farm emissions (embodied in inputs like chemical fertilizers, Plant protection chemicals and diesel) and on farm emissions (emissions from use of diesel fuel, electricity, CH_4 emissions on the farm. N_2O is emitted directly from agricultural farms and from nitrogen (N) that leaves the field and enters other ecosystems via volatilization and leaching. It was assumed that this includes emissions directly from the field and indirect emissions from N leached or volatilized from the fields. The CH_4 emissions generated from rice fields were also computed according to Intergovernmental Panel on Climate Change's (IPCC, 2006). The carbon footprint was accounted for by individual inputs used in the seeding to harvesting stages of rice and wheat crop production.

Table 1: Emission factors for different inputs used in the cultivation of rice and wheat

	Inputs	Emission factor	Unit	Reference
A	**Off-farm emissions**			
1	**Chemical fertilizers**			
	Nitrogen (N)	1.3	Kg CO_2/ Kg N	Lal, 2004
	Phosphate (P_2O_5)	0.2	Kg CO_2/ Kg P_2O_5	
	Potassium (K_2O)	0.2	Kg CO_2/ Kg K_2O	
2	**Plant protection chemicals**			
	Herbicide	3.9	Kg CO_2/Kg	Soni *et al.*, 2013; Lal, 2004
	Insecticide	6.3	Kg CO_2/ Kg	
	Fungicide	5.1	Kg CO_2/ Kg	
3	Diesel	0.016 Kg CO_2 eq./MJ diesel X 36.4 MJ/ litre diesel	kg CO_2 eq/litre	Nguyen *et al.,* 2012
B	**On-farm emissions**			
1	Nitrogen (N) fertilizer	4.7	Kg CO_2/Kg N	Lal, 2004
2	Diesel	0.074 Kg CO_2 eq./MJ diesel X 36.4 MJ/litre diesel	Kg CO_2eq/litre	Nguyen *et al.*, 2012
3	Electricity	0.8	Kg CO_2 /KWh	Lohsomboon, 2003
4	Irrigation (CH_4 in case of rice)	1.1 Kg CH_4 /Ha/day X 25 Kg CO_2 eq.	Kg/ha/day	Khosa *et al.*, 2011

The GHG emissions associated with inputs, including agrochemicals, electricity, and farm machinery, were calculated using the following equation:

$$CF_A = \Sigma(A_i * EF_i)$$

Where CF_A is the sum of GHG emissions (per hectare) due to i^{th} input in t CO_2 eq

A_i is the amount of i^{th} agricultural input, and EF_i is the emission factor of the i^{th} input (in t CO_2 eq per unit volume or mass).

The energy requirement for electricity consumption in lifting groundwater for irrigation has been calculated using the capacity of the submersible pump-set/electric motor along with the duration of use as follows:

Electricity consumption (KWh) = Capacity of the submersible pump-set/electric motor (HP) * duration of use * 0.746

The carbon footprint per unit area (in Kg CO_2eq/Ha) was calculated as follows.

$$CF_{\text{per unit area}} = (CF_{\text{on farm}} + CF_{\text{off farm}}) / \text{Area under crop (Ha)}$$

The carbon footprint per unit weight (in ton CO_2eq/ton) was calculated as follows.

$$CF_{\text{per unit weight}} = CF_{\text{per unit area}} / \text{Yield (ton/Ha)}$$

3. Results and Discussion

3.1 Carbon footprint of rice and wheat

Data analysis revealed that the average carbon footprint (CF) per unit of rice production in Punjab state was 6.34 ton CO_2eq per hectare (Ha), and the CF per unit weight was 0.91 ton CO_2eq/ton. On the other hand, in the case of wheat, the value for CF was much lower than for rice, i.e., CF per unit area was 1.41 ton CO_2eq/Ha, and the CF per unit weight was 0.28 ton CO_2eq/ton, as shown in Table 2. Similar results were found in study for North Iran where the GHG emissions for rice was 6.09 ton CO2 eq. per ha while that for wheat was only 1.171 ton CO2 eq. per ha (Mohammadi *et al.*, 2014).

Table 2: The carbon footprint of rice and wheat production across different farm categories in Punjab

Farm category	Rice				Wheat			
	Yield (tonha^{-1})	Area (ha)	CF per unit area (ton CO$_2$eqha^{-1})	CF per unit weight (ton CO$_2$eqton^{-1})	Yield (ton Ha^{-1})	Area (ha)	CF per unit area (ton CO$_2$eq ha^{-1})	CF per unit weight (ton CO$_2$eq ton^{-1})
Marginal	6.90	22.01	6.12	0.89	5.11	34.26	1.32	0.26
Small	6.95	65.00	6.19	0.89	4.86	84.95	1.22	0.25
Semi-medium	6.93	129.85	6.44	0.93	4.90	162.68	1.42	0.29
Medium	6.80	231.46	6.35	0.93	4.97	278.72	1.38	0.28
Large	7.02	396.23	6.43	0.92	5.05	434.20	1.46	0.29
Overall	6.94	844.55	6.34	0.91	4.99	994.80	1.41	0.28

Farm category-wise analysis indicated that for paddy, the contribution to CF was the least for marginal farmers (i.e., 6.12 ton CO$_2$eq/Ha, and the CF per unit weight was 0.89 ton CO$_2$eq/ton), while it was the maximum for large farm category (i.e., 6.43 ton CO$_2$eq/Ha, and the CF per unit weight was 0.92 ton CO$_2$eq/ton). In case of wheat, small farm category (1.22 ton CO$_2$eq/Ha and the CF per unit weight was 0.25 ton CO$_2$eq/ton) was the least and again the large farm category (1.46 ton CO$_2$eq/Ha and the CF per unit weight was 0.28 ton CO$_2$eq/ton) was the major contributor to the CF.

3.2 *Share of different inputs to carbon footprint*

The shares of different inputs in GHG emissions indicate the contribution to the global warming impact by crop production. Contribution analysis for the different farm inputs used in rice cultivation is presented in Figure 1.

Among different sources of carbon emissions, methane emissions contributed a highly significant share, i.e., about 61 percent of the total emissions. It may be due to continuously submerged rice cultivation followed in the state. A similar study by Hokazono and Hayashi reported that the direct rice field emissions (mainly CH$_4$) contributed about 75percentto the total global warming potential in conventional systems. Among other sources, electricity use for irrigation formed another 18 percent share followed by soil N$_2$O emissions (10.8 %), plant protection chemicals (7.5 %), i.e., insecticides, weedicides, and fungicides and diesel fuel (6.1 %) involved in all operations, mainly tillage and harvesting, which significantly contribute to the direct emissions from crop production.

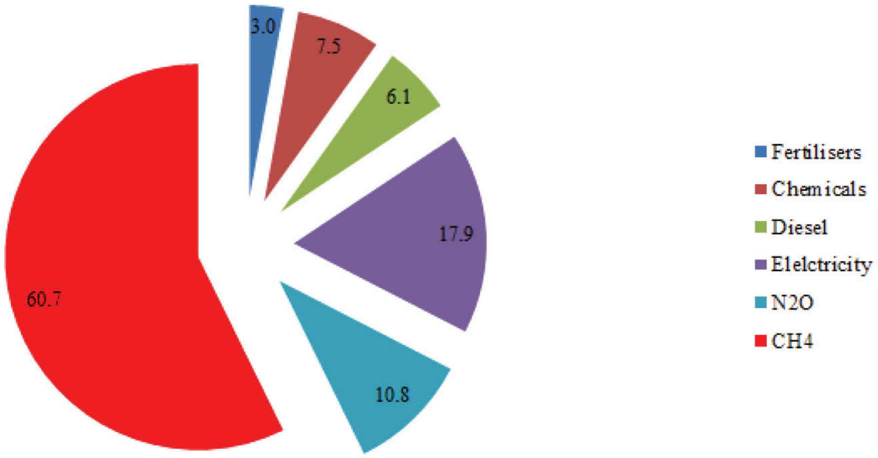


Figure 1: Carbon footprint of rice in Punjab (% share)

Off-farm emissions due to the production of fertilizers had a share of threepercent. In the state, Rice is immediately followed by wheat and the average N fertilization rate (including both urea and DAP) was 36 percent and 18 percent higher than the recommended dose of N for rice and wheat respectively (PAU, 2017). In addition to this, High Yielding Variety (HYV) seeds require higher fertilizer and water inputs leading to higher CF. The increase in the use of fertilizers over time in the state to boost productivity is reflected in the GHG emission trends (Benbi, 2018).

In the case of wheat, direct emissions from N fertilizer were the major contributor to GHG emissions (41.3 %), followed by diesel fuel (28.1 %), electricity energy (10.6 %), while off-farm emissions were from fertilizers (11.8 %), and chemicals (8.1 %) as shown in Figure 2. In earlier studies, the application of fossil energy use has been reported as the primary contributor to GHG emissions (West and Marland, 2002; Liu *et al.*, 2010). Thus, N_2O and diesel fuel are among the most important sources of CO_2 emissions for wheat.

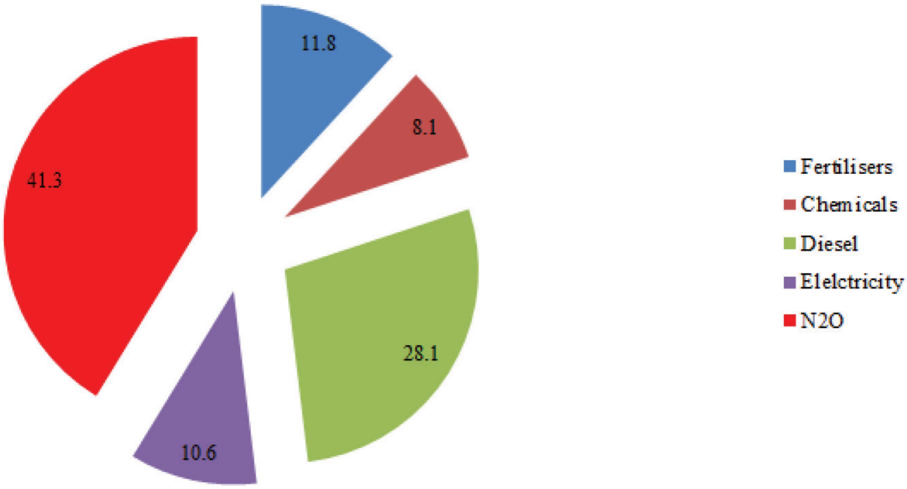


Figure 2: Carbon footprint of wheat in Punjab (% share)

3.3 *Variation of carbon footprint across different farm categories*

The study further calculated the farm category wise share of inputs in carbon emissions. The results are plotted in Figure 3. The results indicated that the share of CH_4 emissions remained more than 60 percent for all the farm categories. Among other contributing inputs, the percentage of fertilizers in terms of on-farm (11.2 %) and off emissions (3.1 %) remained the maximum for marginal farmers because of the overuse of fertilizers, especially urea which is readily available at subsidized rate. Similar results were found in a study at national level where increased use of fertilizer on small holdings was the major reason for higher contribution to the GHG emissions by the small farmers in comparison to large ones (Sinha *et al.*, 2020). N_2O emissions increase exponentially beyond a fertilization rate of 200 Kg N/ ha (Linquist *et al.*, 2011). In the case of Punjab, the fertilization rate is presently below 200 Kg N/ha; however, if the current increasing trend in fertilization continues, the GHG emissions are likely to increase at an accelerated rate. With the declining fertilizer N use efficiency (Benbi, 2018), this might be a possibility in the future if steps to decrease fertilizer use are not taken urgently. Therefore, reducing N fertilizer use is the greatest hotspot for mitigation in the study area. Even though an increase in yield has been suggested as a mitigation measure to justify the negative environmental impacts associated with higher inputs (Ali *et al.*, 2017), the amount of inputs (including water) required to achieve a certain yield level needs to be carefully considered, and region-specific benchmarks need to be set.

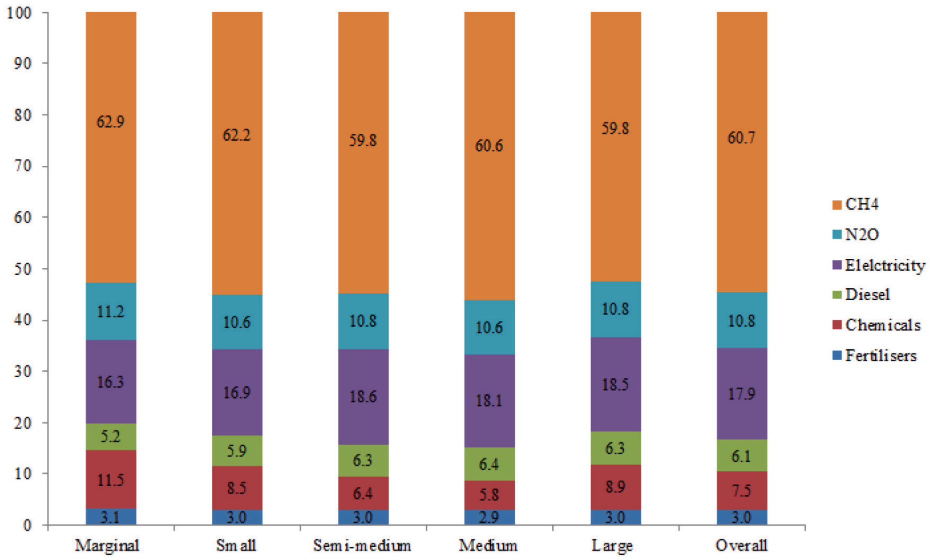


Figure 3: Farm category-wise carbon footprint of rice (% share)

The marginal farmers were observed to be applying high dose of plant protection chemicals leading to a high share of about 12 per cent to the emissions. In case of electricity and diesel use, the large farmers contributed the most to the emissions by using free electricity for pumping irrigation water (18.5 %) and 6.3 per cent, respectively. Earlier study also revealed that more dependency on mechanized means, resulted in higher GHG emissions due to more on-farm fossil fuel use by large farmers (Sinha *et al.*, 2020). Same as in the paddy crop, the marginal farmers in the wheat crop (Figure 4) were the significant contributors to carbon emissions through the use of N fertilizers (about 45 %) and chemicals (12.9 %) on the farm. In comparison, the medium category contributed the most in the form of high use of diesel (31.8 %), followed by large (28.9 %) ones. Like in rice, the large farmers also contributed the most to the emissions by using free electricity (12.8 %). In Punjab, most wheat straw is removed after harvest and used as fodder (Kumar *et al.,* 2019), while rice straw is considered unsuitable as fodder and is removed before sowing the next crop.

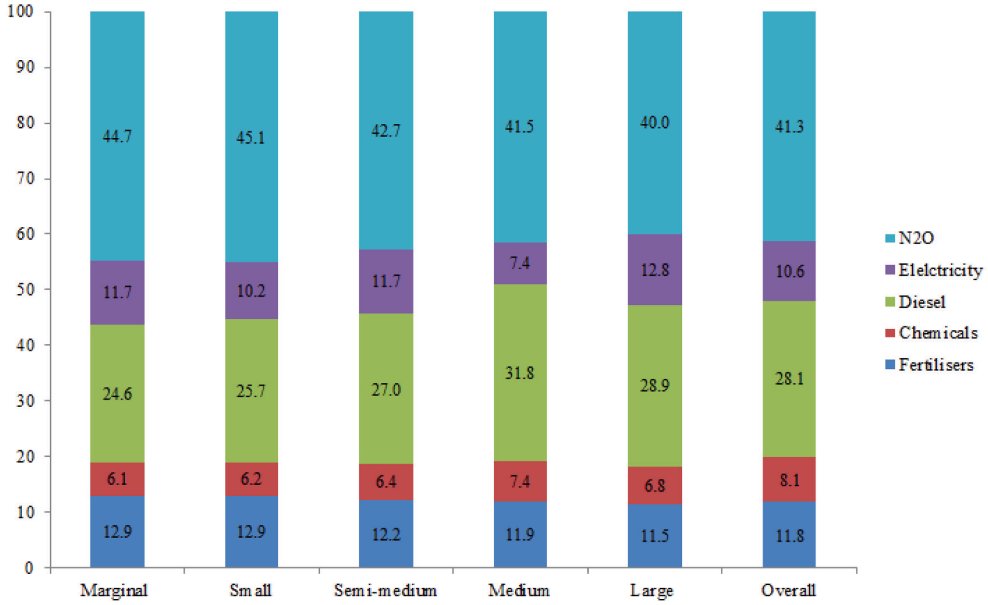


Figure 4: Farm category-wise share carbon footprint of wheat (% share)

Analysis of on-farm and off-farm emissions of rice and wheat revealed that the share of on-farm emissions was higher for rice (95.5 %) than for wheat (80.1 %) because of methane emissions in the case of rice cultivation only (Figure 5 and 6). The off-farm emissions formed about 20 percent share of the total emissions from wheat, and this figure was only 4.5 percent for rice. It was so because of the farmers' practice of applying DAP in wheat (@143 Kg/ha), though the urea dose was almost the same for both crops.

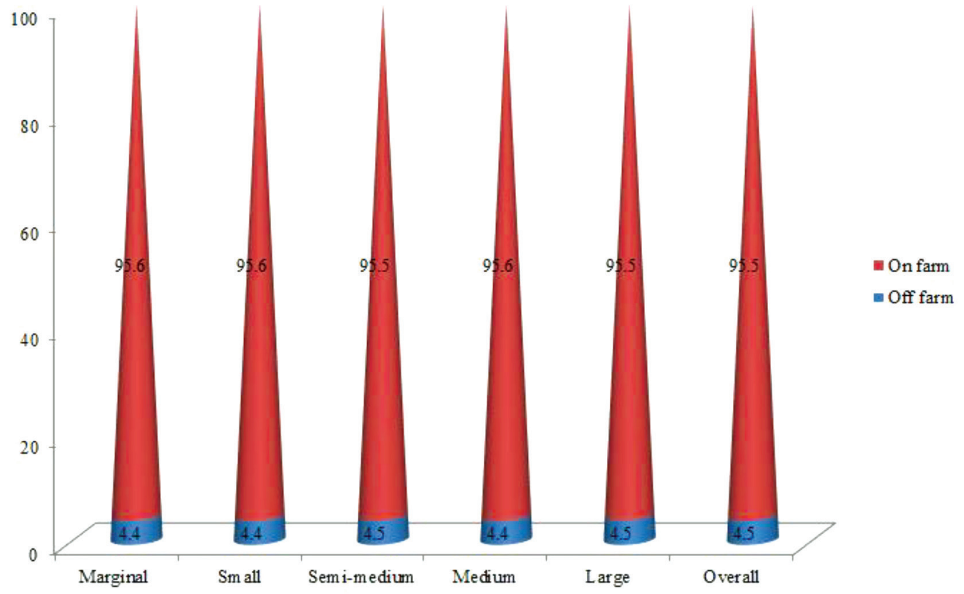


Figure 5: Farm category-wise on and off-farm emissions in rice (% share)

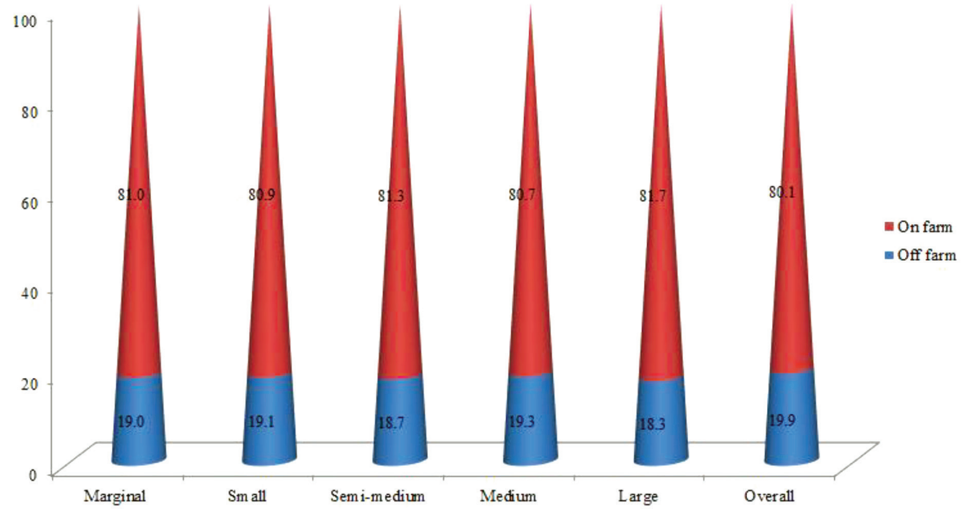
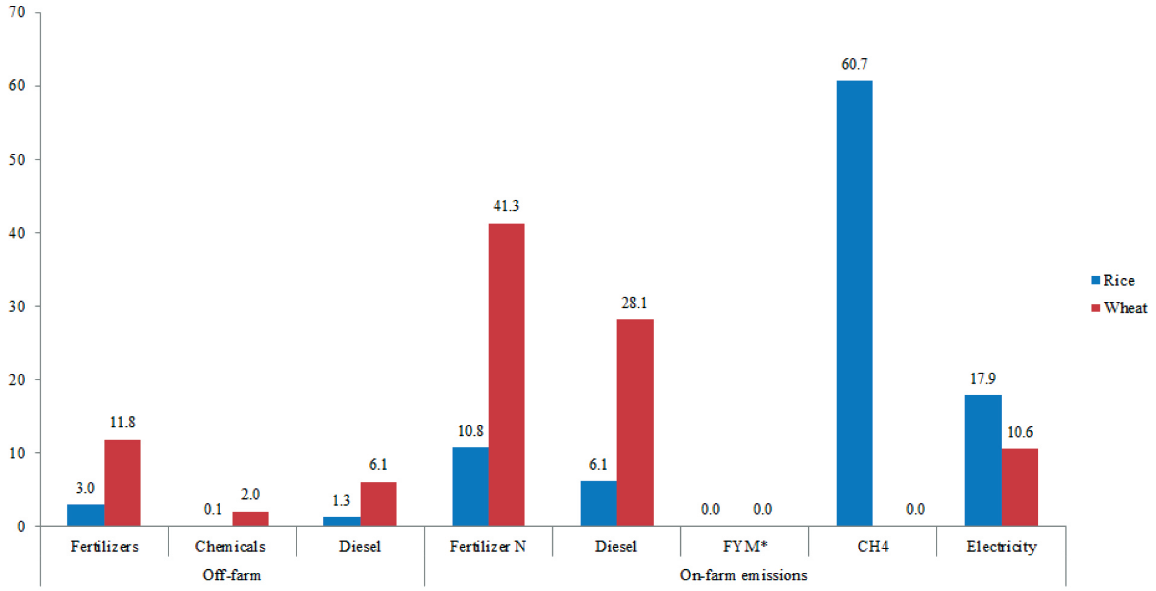


Figure 6: Farm category-wise on and off-farm emissions in wheat (% share)

The component-wise analysis indicated that the major contributors to the higher off-farm wheat emissions were fertilizers (11.83 %), especially P_2O_5, followed by the use of diesel fuel (6.09 %) and plant protection chemicals (2.02 %), while the respective figures for rice were 3.01, 1.33, and 0.12 per cent (Figure 7).



*less than 0.01

Figure 7: Component-wise on-farm and off-farm emissions for paddy and wheat in Punjab (% share of total emissions)

In the case of on-farm emissions, rice cultivation was the leader by being the sole contributor to CH_4 emissions, contributing to as high as about 61 per cent of these on-farm emissions, followed by the use of electricity (17.9 %) for pumping irrigation water. On the other hand, wheat had the lead in on-farm activities for the use of fertilizers (41.28 %), diesel (28.15 %), and electricity (10.6 %), with figures for rice being 10.80 and 6.13 per cent, respectively.

4. Conclusions

Rice production has a higher carbon footprint than wheat production in the Punjab state. Among different sources of carbon emissions, methane emissions for rice (61 %) and direct emissions from N fertilizer (41.3 %) in the wheat crop are the significant contributors. Across farm categories, the share of fertilizers (in terms of on-farm (11.2 %) and off emissions (3.1)) remained the maximum for marginal farmers while large farmers contributed the most to the GHG emissions (18.5 %) by using free electricity to pump irrigation water. The share of on-farm emissions was higher for rice (95.5 %) than for wheat (80.1 %) because of methane emissions in the case of rice cultivation only while higher off-farm wheat emissions were from fertilizers (11.83 %). Punjab agriculture is based on extensive use of fertilizers, agrochemicals, and mechanized means of farming along with paddy cultivation under flooded irrigation conditions.All this point towards a strong need for sustainable management of agro-inputs which will not only offset the associated GHG emissions but will improve the soil health also.Additionally, shifting from conventional tillage to conservation tillage methods like zero-tillage , reduced-tillage and ridge-tillage practices in wheat production and zero–tillage transplanting or non-puddled transplanting and direct seeding in rice can reduce fossil fuel consumption and also be a pathway towards sustainable agriculture.

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Author contributions

All authors have contributed, read and agreed to the published version of the manuscript.

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Conflict of Interest: No

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Research Article

Estimation of crop water requirement and irrigation scheduling of rice in Shivamogga district of Karnataka using FAO CROPWAT

Suprava Nath[1]*, N Devakumar[2], Sitanshu Sekhar Patra[3] and Abhishek Nanda[4]

[1,2]Department of Agronomy, University of Agricultural Sciences, Bangalore, Karnataka, India, 560065
[3]Department of Meteorology and Oceanography, Andhra University, Visakhapatnam, Andhra Pradesh, India, 530003
[4]Department of Agronomy, GBPUA&T, Pantnagar, Uttarakhand, India, 263145

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***Corresponding author:**
E-mail: supravanath96@gmail.com

Abstract

Climate change is expected to have a significant impact on the water needs of rice crop worldwide in the upcoming decades. Proper water management is essential to enhance the crop yield as well as maximising the region's water use efficiency. The objective of this study was to estimate the crop water requirement (CWR) and irrigation scheduling of rice in Shivamogga district of Karnataka using CROPWAT model for a time span of 20 years (2001 to 2020). It was estimated that the crop water requirement of rice was 565.50 mm with the highest and lowest CWR 606.1 and 527.9 mm in 2011 and 2001, respectively. Crop water requirement value showed a slight increasing trend ($R^2 = 0.0544$) throughout the years from 2001 to 2020. Total gross irrigation (TGI) and total net irrigation (TNI) for rice was 491.61 and 344.12 mm, respectively during the study period. The present study is useful for effective planning and management of irrigation water needs of rice in Shivamogga district of Karnataka.

Keywords: Climate change, Crop water requirement, CROPWAT model, Gross irrigation, Irrigation scheduling, Rice

1. Introduction

Despite having 18% of the world's population, India only has 4% of the world's water resources (Dhawan, 2017). Out of total available freshwater in India, 78 per cent of water is consumed by the agricultural sector (Sharma *et al*., 2018; Biswas *et al*., 2022). It is widely acknowledged that the world is experiencing an unprecedented water shortage, and that one of the main factors escalating the situation is poor water management in agriculture (Madani *et al*., 2016). Climate change has shifted India's climate to extremes (Mall *et al*., 2006), changing rainfall patterns and intensity (Wassmann *et al*., 2009), which has a significant impact on crop production, primarily in rainfed areas (Kumar, 2022).

Two basic factors are critical- firstly, agriculture is by far the largest user of freshwater and secondly, water use in agriculture tends to have lower net returns as compared to other competing users of fresh water (Moe and Rheingans, 2006; Taheripour *et al*., 2015). As per estimates, in the future, the world's food systems will need 40–50% more freshwater than they do now to produce the same amount of food (Foley, 2011). Municipal, domestic as well as industrial demand for fresh water will increase by 50-70 per cent during this period. India has one of the world's most vulnerable and unreliable water supplies and experiences considerable water stress (Srinivasan *et al*., 2013). One of the main approaches to these emerging challenges is to focus on improving water productivity in agriculture, as even small improvements could have large implications for local and national water budgets and allocation policies (Hamdy *et al*., 2003).Managing irrigation water starting from the source to its application to the crop holds a crucial place in improving water use efficiency (Evans and Sadler, 2008) at crop level as well as water productivity at field level ultimately increasing more crops per unit drop of water.

Knowledge of crop water requirement (CWR) is one of the crucial factors for improvement of irrigation water management (Laxmi *et al*., 2022; Sharma and Tare, 2022). Modeling of CWR helps in effective irrigation scheduling, water resource planning, and drainage requirement if any and ultimately determines crop production potential (Kambale *et al*., 2022).

In terms of area and food production, rice (*Oryza sativa* L.) is one of the most major cereal crops in the world (Niamatullah *et al*., 2010) followed by wheat (Kumar *et al., 2019*). South East Asia grows and consumes more than 90% of the world's rice. With a yearly per capita consumption of 80 kg of rice, it is a staple grain that provides a richness of nutrients for more than half of the world's population (Godfray *et al*., 2010). In the human diet, rice serves as the primary source of energy (21%), providing 35–60% of all the calories consumed (Depar *et al*., 2011). By 2050, there will be 9.15 billion people on the planet, which will result in a rise in the demand for food, notably rice, as well as an increase in the area under production for this crop to about 29.9 million ha (Crossette, 2010). Irrigated rice is a key component of Asian countries' food security and way of life (Saha *et al*., 2014). On 79 million hectares worldwide, rice is harvested, and transplanted technology accounts for around 75% of that production. To produce one kilo of unmilled rice, rice plants use an average of 2500 litres of water, ranging from 800 to 5000 litres (Bouman, 2009). Rice cultivation consumes between 24 to 30 percent of the world's developed fresh water resources, making it the leading consumer of fresh water worldwide (*Bouman et al.,* 2007; Singh, 2013). The sustainability of the ecosystem supporting irrigated rice is jeopardized by the shrinking water supply for cultivation (Sun *et al.,* 2012).

As CWR depends upon environmental conditions and specific to crop requirements, its estimation at regional level becomes necessary for better management aspect (Doorenbos and Pruitt, 1977). Recently there has been a paradigm shift in calculation of CWR by using computer based simulation models and CROPWAT is such a model. Considering above mentioned points, an experiment on crop water requirement and irrigation scheduling of *kharif* rice by using CROPWAT 8.0 model in Shivamogga district, Karnataka was carried out for 20 years from 2001 to 2020.

2. Material and methods

2.1 Study area

The study area considered here is Shivamogga district of Karnataka, India. Geographical location of Shivamogga is 13.55° N (Latitude) and 75.34°E (Longitude) at an elevation of 631 metres. The area comes under agroclimatic zone XII *i.e.*west coast plains and ghat region (XII).

2.2 Model description and input data

CROPWAT 8.0 for Windows is a computer based program developed by FAO that uses data of soil, climate and crop to calculate crop water and irrigation water requirements. Further, this program helps to create irrigation scheduling approach for several crop management practices as well as the calculation of scheme water supply for various crop patterns. CROPWAT for Windows uses the FAO (1992) Penman-Monteith method for calculation reference crop evapotranspiration.

2.2.1 Climate data

Daily data of maximum temperature, minimum temperature and rainfall were collected from All India Coordinated Research Project on Agro- meteorology, Bengaluru for the year 2001 to 2020. Daily data was converted to monthly data for each year and these monthly data were considered for the modelling of CWR and irrigation scheduling of *kharif* rice from 2001 to 2020 by the use of CROPWAT 8.0 model. CROPWAT calculates ET_0 taking into provided climate data. A sample of computation of ET_0 by CROPWAT is shown in Fig. 1.

2.2.2 Reference evapotranspiration (ET_0)

In CROPWAT, the reference evapotranspiration (ET_0) is calculated directly from meteorological data or estimated by utilizing the Penman-Monteith equation (Allen *et al*., 1998) with monthly climatic data.

$$ET_0 = 0.408\Delta\ (Rn - G) + \gamma\ (900T+273)\ u^2\ (es - ea)\ /\Delta + \gamma(1+0.34u^2)$$

Where,

ET_0: Reference evapo-transpiration (mm day^{-1})

Rn: Net radiation at the crop surface (MJ m^{-2} day^{-1})

G: Soil heat flux density (MJ m^{-2} day^{-1})

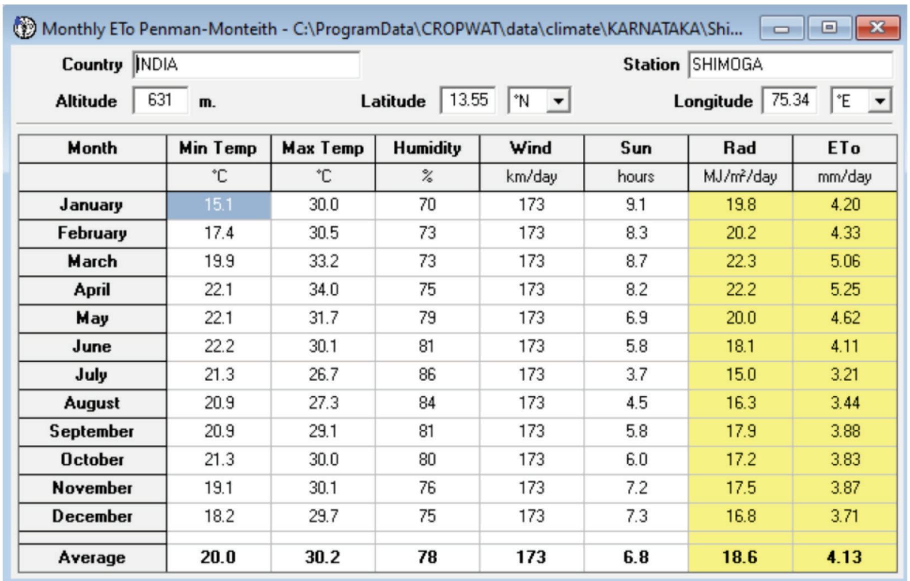
T: Mean daily air temperature at 2 m height (°C) es: Saturation vapor pressure (kPa)

ea: Actual vapor pressure (kPa)

es - ea: Saturation vapor pressure deficit (kPa)

Δ: Slope vapour pressure curve (kPa/°C)

γ: Psychrometric constant (kPa/°C)



Monthly ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\KARNATAKA\Shi...

Country INDIA Station SHIMOGA

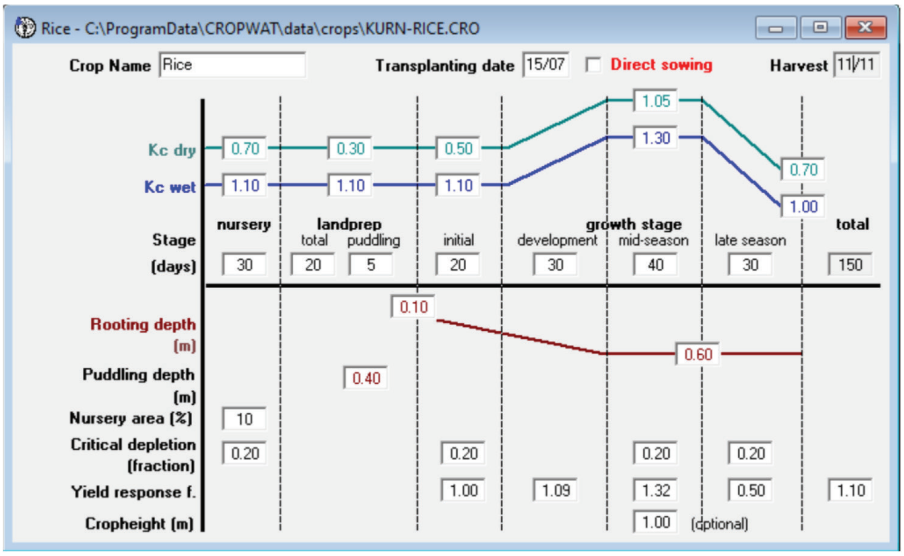
Altitude 631 m. Latitude 13.55 °N Longitude 75.34 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	15.1	30.0	70	173	9.1	19.8	4.20
February	17.4	30.5	73	173	8.3	20.2	4.33
March	19.9	33.2	73	173	8.7	22.3	5.06
April	22.1	34.0	75	173	8.2	22.2	5.25
May	22.1	31.7	79	173	6.9	20.0	4.62
June	22.2	30.1	81	173	5.8	18.1	4.11
July	21.3	26.7	86	173	3.7	15.0	3.21
August	20.9	27.3	84	173	4.5	16.3	3.44
September	20.9	29.1	81	173	5.8	17.9	3.88
October	21.3	30.0	80	173	6.0	17.2	3.83
November	19.1	30.1	76	173	7.2	17.5	3.87
December	18.2	29.7	75	173	7.3	16.8	3.71
Average	**20.0**	**30.2**	**78**	**173**	**6.8**	**18.6**	**4.13**

Fig. 1: Calculation of ET_0 by CROPWAT model

2.2.3 Crop data

The software needs some information about rice crop. By feeding name of the crop and planting date of the particular crop, other informations related to the crop such as harvesting date, crop coefficient value (Kc), rooting depth, length of plant growth stages and yield response factor will be obtained from software itself. Fig. 2 shows crop data related to rice applied in this software.



Rice - C:\ProgramData\CROPWAT\data\crops\KURN-RICE.CRO

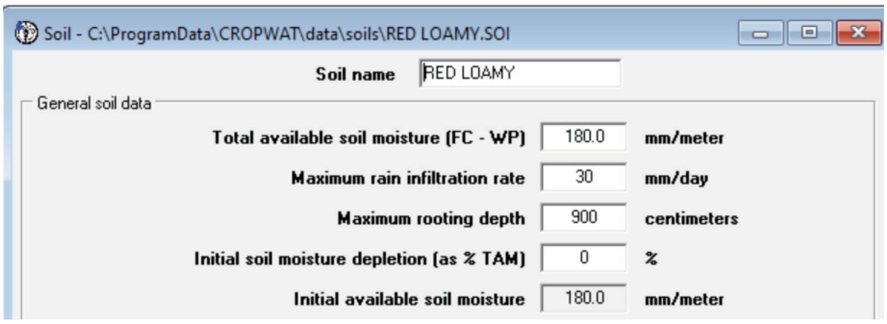
Crop Name Rice Transplanting date 15/07 ☐ Direct sowing Harvest 11/11

	nursery	landprep total	landprep puddling	initial	development	mid-season	late season	total
Kc dry	0.70	0.30		0.50		1.05	0.70	
Kc wet	1.10	1.10		1.10		1.30	1.00	
Stage (days)	30	20	5	20	30	40	30	150
Rooting depth (m)				0.10		0.60		
Puddling depth (m)		0.40						
Nursery area (%)	10							
Critical depletion (fraction)	0.20			0.20		0.20	0.20	
Yield response f.				1.00	1.09	1.32	0.50	1.10
Cropheight (m)						1.00	(optional)	

Fig. 2: Various crop data obtained by CROPWAT model

2.2.4 Soil data

Soil type of the study area is red loamy. The software needs other informations related to soil such as total available soil moisture, maximum rain infiltration rate, maximum rooting depth, initial soil moisture depletion and initial available soil moisture. These informations were obtained from FAO manual 56. Fig. 3 shows application of these information in the software.



Soil - C:\ProgramData\CROPWAT\data\soils\RED LOAMY.SOI

Soil name: RED LOAMY

General soil data

Total available soil moisture (FC - WP): 180.0 mm/meter

Maximum rain infiltration rate: 30 mm/day

Maximum rooting depth: 900 centimeters

Initial soil moisture depletion (as % TAM): 0 %

Initial available soil moisture: 180.0 mm/meter

Fig. 3: Soil related data

3. Results and Discussion

Table 1: Crop water requirement (CWR), effective rainfall (ER) and irrigation requirement (IR) of rice (2001 – 2020) obtained from CROPWAT model

Year	**CWR (mm)**	**ER (mm)**	**IR (mm)**
2001	570.7	650	283.4
2002	535.8	642.5	298.3
2003	543.1	702.2	263.9
2004	527.9	760.1	229.6
2005	594.3	760.1	259
2006	568.8	745.9	201.9
2007	542.4	744.1	235.2
2008	576	684.9	262.2
2009	574	725.5	282
2010	579.8	731.6	278.6
2011	606.1	729.9	306.1
2012	567.9	759.4	256.7
2013	560.7	719.1	248.1
2014	564.3	663.8	280
2015	568.3	649.8	306.9
2016	577.2	707.3	231.6
2017	564.7	681.4	307.2
2018	564.8	661.2	294.8
2019	559.5	759.6	230.8
2020	563.7	653.3	317.1
	565.50	706.59	268.67

3.1 Crop water requirement (CWR)

In Shivamogga district of Karnataka, crop water requirement (CWR) of *kharif* paddy was estimated as 565.50 mm (20 years average from 2001 to 2020). The highest CWR (606.1 mm) was observed in 2011 where as the lowest (527.9 mm) was reported in the year 2001 (Table 1). Crop water requirement value ranges between 527.9 mm to 606.1 mm with slight increasing trend ($R^2=$ 0.0544) throughout the years from 2001 to 2020 (Fig.4).

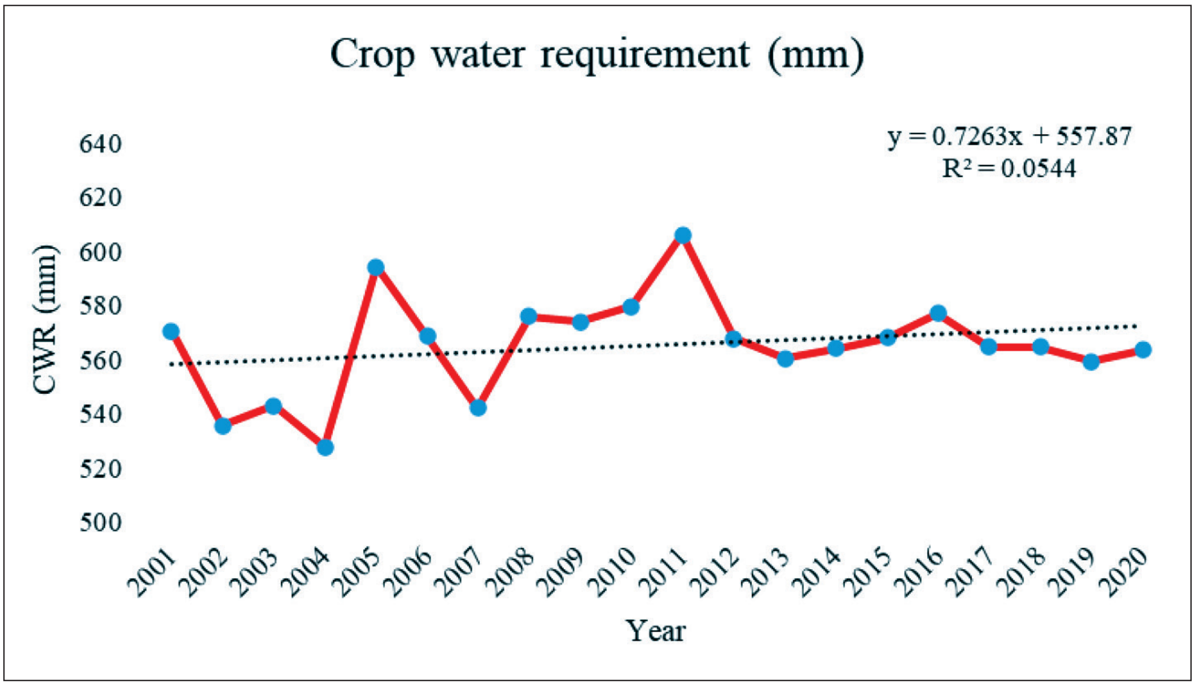


Fig. 4: Crop water requirement of rice (2001 – 2020) obtained from CROPWAT model

3.2 *Effective rainfall (mm)*

An average of 706.59 mm effective rainfall was recorded during the growing season of *kharif* paddy from 2001 to 2020. Both the years 2004 and 2005 received the highest ER (760.1 mm) while 2002 received the lowest ER of 642.5 mm (Table 1). The value of effective rainfall ranges between 642.5 mm to 760.1 mm with slight decreasing trend ($R^2 = 0.0191$) throughout the years from 2001 to 2020 (Fig.5).

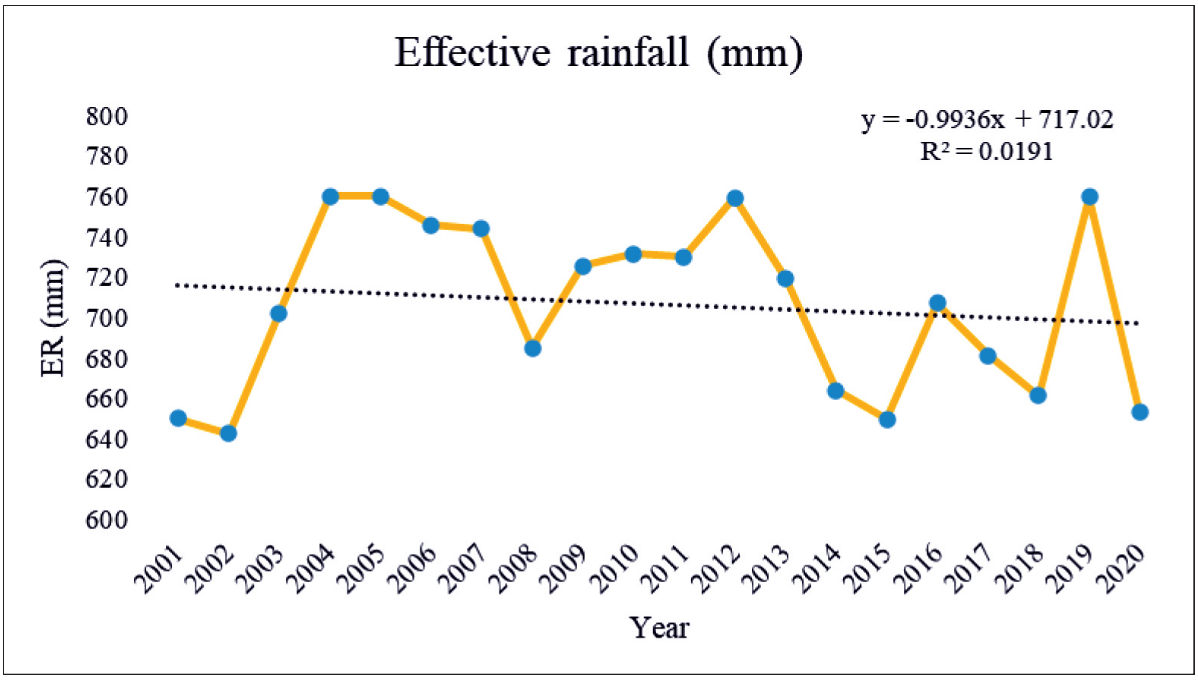


Fig. 5: Effective rainfall for rice (2001 – 2020) obtained from CROPWAT model

3.3 Irrigation requirement (IR)

An average of 268.67 mm of irrigation requirement was needed for *Kharif* paddy from 2001 to 2020 (Table 1). The highest irrigation requirement (317.1 mm) was reported in 2020 as this year experienced lesser amount of effective rainfall. In 2006, the lowest irrigation requirement was 201.9 mm as this year received higher volume of effective rainfall and this fulfilled the crop water need. The value of irrigation requirement showed a slight increasing trend ($R^2 = 0.0627$) throughout years starting from 2001 to 2020 (Fig. 6).

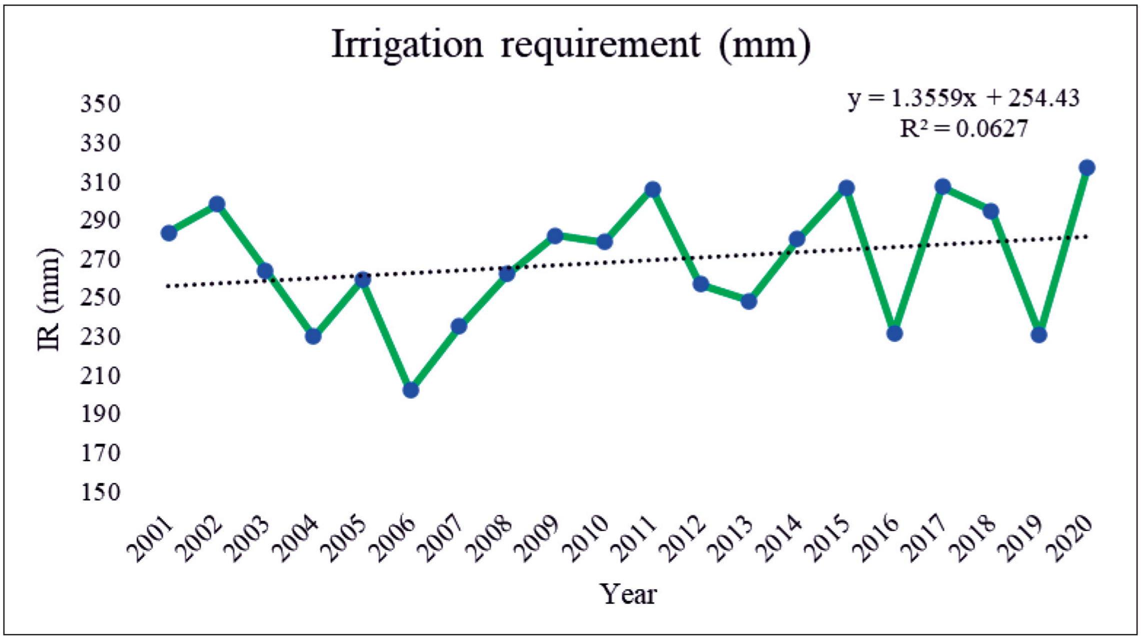


Fig. 6: Irrigation requirement of rice (2001 – 2020) obtained from CROPWAT model

3.4 Scheduling of irrigation by CROPWAT model

On an average, total gross irrigation (TGI) and total net irrigation (TNI) requirement was 491.61 and 344.12 mm, respectively. The highest value of TGI and TNI (693.9 and 485.7 mm, respectively) was recorded in 2011 followed by 2020 (679.9 and 475.9 mm, respectively). As both in 2011 and 2020, effective rainfall was less (50.1 and 65.6 per cent, respectively), gross irrigation and total net irrigation requirement was more. The lowest value of TGI and TNI (275.3 and 192.7 mm, respectively) was reported in 2006 and this was due to the higher per cent effective rainfall (83.4) received in the same year compared to other years (Table 2). There were no irrigation losses throughout the years starting from 2001 to 2020 and hence the average of total irrigation losses (TIL) came to 0 mm (Table 2). 730.04 mm (average of 20 years) of total percolation losses (TPL) was observed with the highest TPL (800 mm) in 2020 which was because of higher gross as well as net irrigation requirement. Average actual water use by crop (AWUC) was found to be 481.52 mm ranging from 446.4 mm in 2004 to 514.5 mm in 2011. Potential water use by the crop (PWUC) was same as that of AWUC as there was no limitation in availability of water required by the crop. Efficiency in irrigation schedule and deficiency irrigation schedule was 100 and 0 per cent, respectively as there was no TIL observed. Total rain water loss was found to be 509.06 mm (20 year average value) ranging from 182.1 mm in 2016 to 1014.7 mm in 2011. Inverse trend of TRL was found for efficient rainfall per cent indicating that years with higher efficient rainfall percent reported to have lower total rain losses. There was no deficit in moisture at harvest throughout the years and that's why value came as 0. Actual irrigation requirement in all the 20 years came negative as rainfall alone was sufficient to raise *kharif* paddy crop in Shivamogga district.

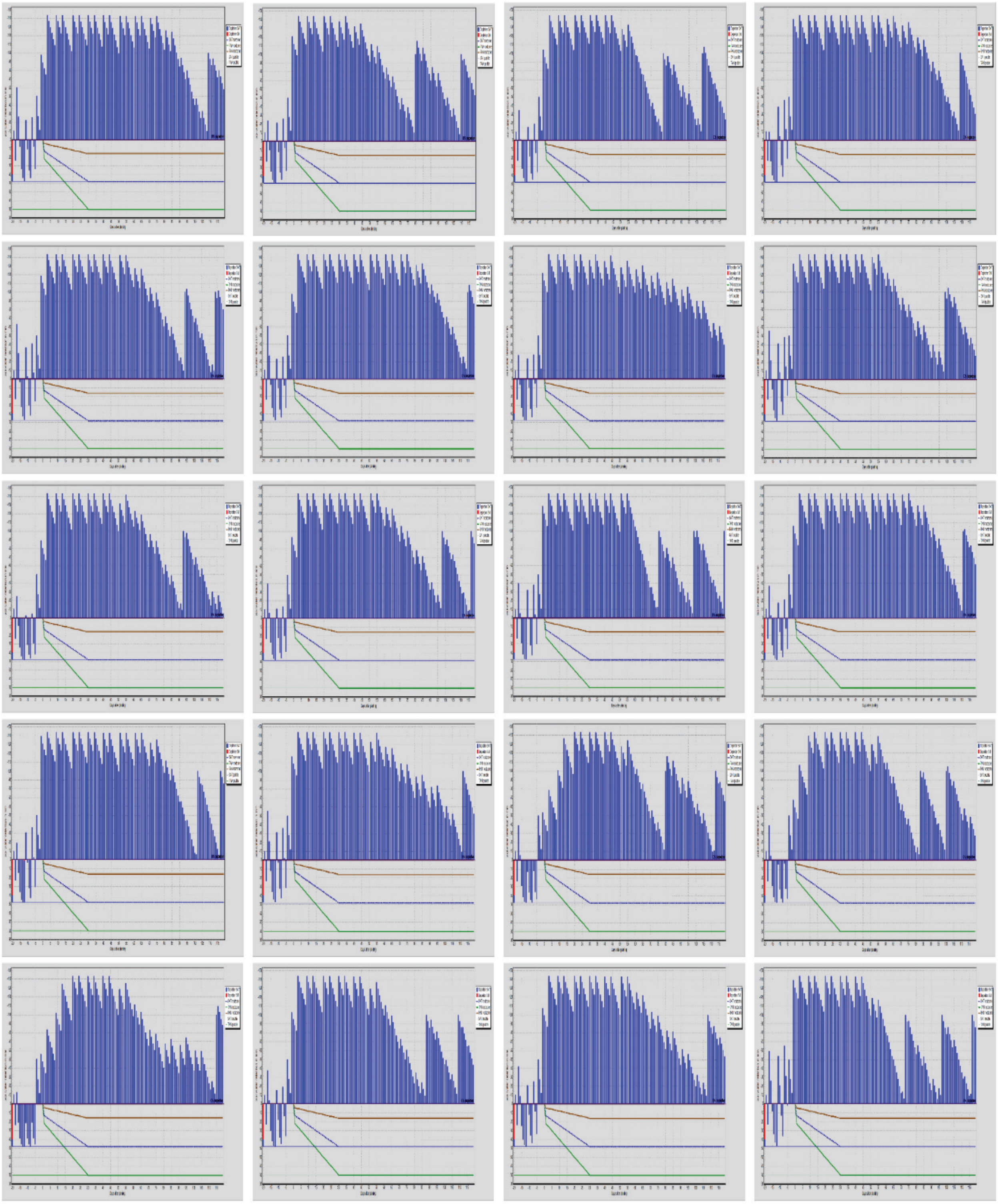


Fig. 4: Daily Soil moisture balance cum irrigation scheduling graphs during *kharif* rice (2001 – 2020) obtained from FAO CROPWAT model.

Table 2: Different parameters related to irrigation scheduling (2001 – 2020) obtained from CROPWAT model

Year	TGI (mm)	TNI (mm)	TIL (mm)	TPL (mm)	AWUC (mm)	PWUC (mm)	EIS(%)	DIS(%)	TRL (mm)	MDH (mm)	AIR (mm)	EfR (%)
2001	557.3	390.1	0	721.8	487.2	487.2	100	0	235.7	0	-513.7	80.9
2002	553.8	387.6	0	719.3	452.7	452.7	100	0	460.5	0	-488.4	67.1
2003	405.4	283.8	0	733.5	460.8	460.8	100	0	608.1	0	-614.6	63.9
2004	411.5	288.1	0	756.7	446.4	446.4	100	0	619.1	0	-687.4	64.7
2005	415.7	291	0	754.7	507.4	507.4	100	0	589.2	0	-656.2	66.4
2006	275.3	192.7	0	729	484.7	484.7	100	0	236.2	0	-706.1	83.4
2007	407.3	285.1	0	779.2	463.5	463.5	100	0	638.5	0	-656.2	63.7
2008	421.1	294.8	0	688.3	487.2	487.2	100	0	287.6	0	-531.9	78
2009	552.9	387	0	778	492.9	492.9	100	0	582.5	0	-607.3	65.4
2010	555.3	388.7	0	715	492.7	492.7	100	0	739.7	0	-546.9	58.4
2011	693.9	485.7	0	749.8	514.5	514.5	100	0	1014.7	0	-504.4	50.1
2012	418.7	293.1	0	723.8	478.3	478.3	100	0	794.7	0	-628.5	58.2
2013	412	288.4	0	764.5	478.5	478.5	100	0	358.3	0	-662.2	76.1
2014	555.6	388.9	0	673.1	482.6	482.6	100	0	267.8	0	-476.5	78.2
2015	561.9	393.3	0	689.1	484.9	484.9	100	0	333.3	0	-449.9	73.7
2016	418.8	293.2	0	634.3	492.2	492.2	100	0	182.1	0	-554.8	85.2
2017	564.3	395	0	731.8	481.6	481.6	100	0	636.5	0	-554.3	61.9
2018	555.7	389	0	722.4	482.4	482.4	100	0	376.6	0	-508.7	72.5
2019	415.8	291	0	736.4	478.2	478.2	100	0	680.5	0	-630.2	62
2020	679.9	475.9	0	800	481.6	481.6	100	0	539.5	0	-546.5	65.6
Mean	**491.61**	**344.12**	**0**	**730.04**	**481.52**	**481.52**	**100**	0	509.06	0	-576.24	68.77

(TGI=Total gross irrigation, TNI=Total net irrigation, TIL=Total irrigation losses, TPL=Total percolation losses, AWUC=Actual water use by crop, PWUC=Potential water use by crop, EIS=Efficiency irrigation schedule, DIS=Deficiency irrigation schedule, TRL=Total rain loss, MDH=Moist deficit at harvest, AIR=Actual irrigation requirement, EfR=Efficiency rain)

Conclusion

Crop water requirement (CWR) of *kharif* rice for Shivamogga district was computed using FAO CROPWAT 8.0 Model based on Penman Monteith equation from 2001 to 2020 and CWR was 565.50 mm (average of 20 years). Irrigation requirement for rice to raise the crop in *kharif* season was 268.67 while effective rainfall was 706.59 mm. On an average, total gross irrigation (TGI), total net irrigation (TNI), total percolation losses (TPL), actual water use by the crop (AWUC), Potential water use by the crop (PWUC), total rain losses (TRL), actual irrigation requirement (AIR) was 491.61, 344.12, 730.04, 481.52, 481.52, 509.06 and -576.24 mm, respectively was observed for irrigation scheduling in rice crop. These findings can be used to improve water productivity, irrigation efficiency which will enable to get more rice productivity in the Shivamogga district of Karnataka.

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Compliance with ethical standards: No

Conflict of Interest: No

Author contributions: Designing of experiment, data collection, analysis and preparation of manuscript by all of four authors

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Research Article

Relative effectiveness of alpha lattice design and randomized complete block design in oats breeding experiment

Sanjay Kumar Sanadya, Vinod Kumar Sood, Sawan Kumar and Gaurav Sharma

Department of Genetics and Plant Breeding, College of Agriculture, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur (HP) -176062 India.

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****Corresponding author:***
E-mail: s8769258944@gmail.com,
sanjaypbg94@gmail.com

Abstract

To decrease errors and increase the precision and efficacy of crop improvement programmes, a quality experimental design is required in addition to breeding methods. In this study, ninety-six oat genotypes used to examine the relative efficiency of randomized complete block design (RCBD) and alpha lattice design (ALD). Effectiveness of ALD over RCBD was determined for green forage yield per plant and seed yield per plant. Genotypes were sown in three replications during two consecutive years 2019-20 and 2020-21. The results of each year of experiment showed >1.0 relative efficiency for ALD while in pooled environment of each trait relative efficiency changed drastically might be due to high and significant genotype X environment interaction for studied traits. Multi-environment trials are the major concerned for evaluation of entries for economic traits. So as a consequence RCBD should be substituted by ALD in crop field experiments.

Keywords: Alpha lattice design, Randomized complete block design, Relative efficiency, Crop improvement, Oats

1. Introduction

One of the basic principles in experimental design is that of reduction of experimental error. In the last 50 years or more, there has been a phenomenal increase in the creation and introduction of new experimental designs, owing in large part to an ever-expanding area of applications as well as the mathematical beauty and challenge that some of these designs bring. While many designs originated in agricultural field experiments, it is now clear that these designs, as well as changes, expansions, and scientific breakthroughs, were stimulated by applications in almost every sort of experimental study (Hinkelmann and Kempthorne, 2005). For example, in field research, randomized complete block design (RCBD) is being used frequently. This approach incorporates all three principles of experimentation: randomization, replication, and local control. The experimental units are divided into groups (referred to as blocks) in these designs so that the experimental units within each block are as homogenous as feasible. A Randomized Full Block (RCB) design is a complete block in the sense that each block is a complete replication, as the name indicates (Gupta *et al.*, 2016). Scientists in developed countries objurgate the capability of RCBD while dealing with major field experiments. One of the disadvantages of RCBD is that it is only acceptable for genotypes ranging twenty-five to thirty in a single block due to heterogeneity in experimental units within blocks. RCBD has indeed been replaced with a resolvable incomplete block designs developed (Patterson and Williams, 1976; William and Talbot, 1993).

The approach of creating some forms of resolvable incomplete block designs, such as balanced incomplete block (BIB) or partially balanced incomplete block (PBIB) designs is known as lattice design. BIB designs often require a high number of replications and are not accessible for all parameter combinations. Lattice designs were first created for large-scale agricultural trials (Yates, 1936), when a large number of genotypes need to be compared with greater accuracy. When the number of genotypes (g) or block size (k) does not fulfill the precise requirements for one of the lattice designs, we can use alpha designs to create resolvable incomplete block designs (Sharma and Das, 1985). Alpha designs are resolvable incomplete block designs with a block size that is a multiple of the number of entries/treatments or genotypes (Patterson and Williams, 1976; John and Williams, 1995). Despite the fact that these designs cannot attain balance, they are widely employed in plant breeding because they are quite flexible in terms of the number of entries to be assessed and the suitable size of incomplete block, as well as providing sufficient error control. Furthermore, by eliminating treatments from an alpha design with a greater number of treatments, these designs may easily be modified to situations where the number of entries is not an exact multiple of block size. In any crop improvement porgramme, multi-environmental replicated trials for evaluation of large number of entries or genotypes is the most crucial step for the identification of best entries which exploit environmental and standard error in very limited extent (Kumar *et. al.,* 2019a). So that entries can show their actual phenotypic effect and improve the precision level. The goal of this study was to examine the relative efficiency of alpha lattice design (ALD) vs. randomized complete block design (RCBD) in terms of economic traits such as green forage yield and seed yield of oat genotypes.

2. Materials and methods

2.1 Experimental materials

Since the main objective of present experiment was to explore the benefits of sub-blocks within super block in ALD over RCBD. Therefore, diagnostic study of experiments on oat crop was conducted in the Fodder experimental farm, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India in alpha lattice design (ALD) with 3 replications, 96 genotypes and 12 blocks (*k*) during, 2019-20 and 2020-21. Data were recorded for two economic traits as green forage yield per plant (g) and seed yield per plant (g). The collected data on yield was analyzed in randomized complete block design and alpha lattice design using statistical software PROC GLM SAS (Statistical Analysis Software, 2013).

2.2 Randomized complete block design

All of the treatments in the experiment appear once in each block in this design. Therefore, the number of treatments is equal to the block size furthermore, because each block is a complete replication, the number of blocks equals the number of treatments replicated. The linear mathematical model in randomized complete block design is: $y_{ij}=\mu+\tau_i+\beta_j + e_{ij}$ Where y_{ij} is the response of variable; μ is the general mean effect; τ_i is the effect of the i^{th} treatment (fixed); β_j is the effect of the j^{th} block (fixed); e_{ij} is random error associated with response.

2.3 Alpha lattice design

The emphasis was on RCB designs feature full blocks in the sense that all treatments occur exactly once in each block. However, it is impossible to build blocks that contain as many experimental units without affecting by soil factors and maintain homogeneity when genotypes or treatments size is big. As a result, resolvable block designs (lattice, augmented designs) are performed in entire replications is an intriguing aspect and alpha lattice one of them to minimize soil heterogeneity and adjust mean performance of each treatment involves in experiment within block. This design resembles as randomized complete block designs however, there are blocks inside replications and the treatments are randomized within blocks within each replication. It allows the investigator to eliminate some of the variability between blocks within replications. The linear mathematical model in alpha lattice design is: Where y_{iju} is the response of variable; μ is the general mean effect; τ_i is the effect of the i^{th} treatment; β_j is the effect of the j^{th} block; e_{iju} are uncorrelated random error components with response. The impact of Alpha Lattice design over RCBD was assessed by relative efficiency in term of the size of the experimental error and improvement in precision or efficiency manner. An estimated relative efficiency (ERE) less than 1 indicates that an ALD over RCBD is not efficient, while value greater than 1 suggests that ALD is more efficient design than RCBD.

3. Results and Discussion

3.1 Analysis of variance (randomized complete block design) of economic traits in oats

Analysis of variance (RCBD) for both the years and pooled analysis of economic traits are presented in (Tables 1 and 2). Mean square of the replications had high significant differences for seed yield per plant, non-significant for green forage yield per plant in both the years. Mean square of year in the pooled data had highly significantly differences seed yield per plant and green forage yield per plant. Interaction between replication × years was non-significant for both seed yield per plant and green forage yield per plant. The highly significant genotypic differences observed among both seed yield per plant and green forage yield per plant in both years and pooled data indicate that the germplasm pool used in this study could be a rich source of genetic diversity for breeding purposes. Thus the germplasm can be used to identify genotypes with high levels of green forage and grain yield potentiality.

Table 1. Analysis of variance (RCBD) for studied traits in oats during two consecutive years

Sources of variation	df	2019-20		2020-21	
		Seed yield per plant	**Green forage yield per plant**	**Seed yield per plant**	**Green forage yield per plant**
Replications	2	17.18**	12.61	8.67**	10.95
Genotypes	95	66.66**	736.79**	9.23**	842.40**
Error	190	1.34	27.79	2.23	53.75

**Significant at 1% level; *significant at 5% probability level

Table 2. Pooled analysis of variance (RCBD) for studied traits in oats

Sources of variation	df	Seed yield per plant	Green forage yield per plant
Replications	2	10.39	2.37
Years	1	81.87**	38702.90**
Replication x year	2	15.47	21.19
Genotypes	95	35.38**	885.98**
Pooled error	475	9.53	171.25

**Significant at 1% level; *significant at 5% probability level

3.2 Analysis of variance (alpha lattice design) of economic traits in oats

Analysis of variance (alpha lattice design) for both the years and pooled of economic traits are presented in (Tables 3 and 4). Mean square of the blocks had non-significant differences for both seed yield per plant and green forage yield per plant in both the years and pooled data. Similar as RCBD, mean square of the replications had highly significant differences for seed yield per plant, non-significant for green forage yield per plant in both the years. Interaction between replication × years was found to be significant for the trait seed yield per plant. Mean square of the year in the pooled data had highly significantly differences for both the traits in pooled. The highly significant genotype × year interaction was observed for both seed yield per plant and green forage yield per plant indicate that wide range of variations between genotypes and between years and that different reacted differently to varying environment. This information shows that oat genotypes responded to G × E interaction over the environments. The highly significant genotypic differences observed for both seed yield per plant and green forage yield per plant in both years and pooled data indicate that the germplasm pool used in this study could be a rich source of genetic diversity therefore, can be used to identify genotypes with high levels of green forage and grain yield potentiality.

Table 3. Analysis of variance (alpha lattice design) for studied traits in oats during two consecutive years

Sources of variation	**df**	**2019-20**		**2020-21**	
		Seed yield per plant	**Green forage yield per plant**	**Seed yield per plant**	**Green forage yield per plant**
Replications	2	17.18**	12.61	8.67**	10.94
Blocks (unadjusted)	33	1.52	27.00	2.48	60.01
Genotypes	95	57.46**	658.64**	8.45**	756.41**
Error	157	1.30	27.95	2.18	52.43

**Significant at 1% level; *significant at 5% probability level

Table 4. Pooled analysis of variance (alpha lattice design) for studied traits in oats

Sources of variation	**df**	**Seed yield per plant**	**Green forage yield per plant**
Genotypes	95	34.28**	874.17**
Years	1	81.87**	38702.90**
Replication x year	4	12.93**	11.78
Blocks	11	1.77	43.82
Genotype x year	95	40.20**	690.89**
Pooled error	369	1.78	40.67

**Significant at 1% level; *significant at 5% probability level

Relative efficiency of ALD versus RCBD

Coefficient of determination (R^2) is a measure of the goodness of fit of a model. In present study, the alpha lattice design in year 2019-20, 2020-21 and pooled showed coefficient of determination more than 0.90 except seed yield per plant in 2020-21 (0.74). Hence, can be considered as very high and fall under the accepted range. The relative efficiency less than one indicate that the alpha lattice design is less efficient than the RCBD. In this case the experiment is analyzed as RCBD and means are not adjusted for block effects. Relative efficiency of alpha lattice design for error mean square (EMS) was higher for seed yield per plant (1.03) as compared to RCBD during 2019–20 (Table 5). Coefficient of variation (CV) was also higher for seed yield per plant (1.01) whereas equal in green forage yield per plant (1.00). Relative efficiency of alpha lattice design (Table 5) during 2020–21 for error mean square (EMS) was higher (1.02) for both the traits and for coefficient of variation (CV) was reported also higher for green forage yield per plant (1.01) and seed yield per plant (1.01). Relative efficiency of alpha lattice design (Table 5) of pooled analysis for error mean square (EMS) was much higher for seed yield per plant (5.34) and green forage yield per plant (4.21) drastic improvement in relative efficiency based on error mean square is could be due to high standard error of differences and significant differences among genotypic mean performance, high significant replication difference and qualitative (crossover) genotype × environment interaction. Whereas for relative efficiency based on coefficient of variation (CV) was reported much higher for seed yield per plant (2.31) and green forage yield per plant (2.05) which indicate that analysis in alpha lattice design resulted in reducing the experimental error and thus enhancing the capability of the researcher to detect significant differences among the ninety-six oat genotypes.

Table 5. Relative efficiency of alpha lattice design *vs* RCBD for studied traits in oat during two consecutive years and pooled environments

Parameters		Seed yield per plant	Green fodder yield per plant
2019-20	EMS (RCBD)	1.34	27.79
	R^2	0.96	0.93
	EMS (Alpha lattice)	1.30	27.95
	R^2	0.97	0.94
	Relative efficiency	1.03	0.99
	CV (RCBD)	10.50	9.36
	CV (Alpha lattice)	10.35	9.39
	Relative efficiency	1.01	1.00
2020-21	EMS (RCBD)	2.23	53.74
	R^2	0.68	0.89
	EMS (Alpha lattice)	2.18	52.43
	R^2	0.74	0.91
	Relative efficiency	1.02	1.02
	CV (RCBD)	12.68	10.08
	CV (Alpha lattice)	12.53	9.96
	Relative efficiency	1.01	1.01
Pooled	EMS (RCBD)	9.53	171.25
	R^2	0.43	0.60
	EMS (Alpha lattice)	1.78	40.67
	R^2	0.92	0.93
	Relative efficiency	5.34	4.21
	CV (RCBD)	27.08	20.28
	CV (Alpha lattice)	11.72	9.89
	Relative efficiency	2.31	2.05

Many studies had investigated alpha lattice design in field experiments (Masood et al. 2008; Kashif et al. 2011; Abd El-Mohsen and Abo-Hegazy 2013; Masood et al. 2018; Anwaar et al. 2019 and Kumar et al. 2020). They came to the conclusion that alpha lattice design is more efficient than RCBD and might be used to replace it in regional and international trials. Masood et al. (2006 and 2007) compared alpha lattice design efficiency and found that alpha lattice design enhanced efficiency by 9 and 14 percent when compared to RCBD. Abd El-Mohsen and Abo-Hegazy (2013) performed research in wheat during the 2010-11 and 2011-12 growing seasons and came to the conclusion that RCBD should be replaced by alpha lattice in agricultural field trials when the numbers of genotypes are more than ten and error mean square is much higher. Masood et al. (2018) reported 6-8 % high relative efficiency of alpha lattice design against randomized complete block design in wheat field trials. In wheat trial experiments it was also concluded that the relative efficiency of ALD was more efficient than RCB design (Kumar *et al.,* 2019b; Kumar *et al.,* 2020).

This study demonstrated that employing alternate designs can result in considerable gains in managing inconsistency or variability when large numbers of genotypes are involved. According to the statistical analysis of the yield data from all of the tests, utilizing RCBD did not increase experimental accuracy, since it was less successful than alpha lattice design. In the examination of oat genotypes, the alpha lattice design generated superior results than the randomized complete block design. In comparison to the conventional design of randomized entire blocks, the experimental designs employed reduced total number of experimental plots. CV based relative efficiency in pooled data increase precision more than 100 % for both green forage yield per plant and seed yield per plant. This is especially beneficial in terms of improved experiment management. Findings of this study suggested that alpha lattice design better suited to the field trials than the traditional RCBD in agricultural research.

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Author's contribution

Designed and performed the experiments (SKS); supervised (VKS) and wrote as well revised the manuscript (SKS, SK and GS).

Compliance with ethical standards

NA

Conflict of interest

No

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Research Article

Impact of priming and storage containers on enzyme activities of naturally aged seeds of Barley (*Hordeum vulgare* L.)

Siddu Appasaheb Kurubar[1], Axay Bhuker[1] and Sukham Madaan[2]

[1]*Department of Seed Science & Technology, CCS Haryana Agricultural University, Hisar-125004*

[2]*Regional Research Station, Kaul, CCS Haryana Agricultural University, Hisar-125004*

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Corresponding author:
E-mail: bhuker.axay@gmail.com

Abstract

The study was conducted on six barley varieties *viz.* BH 885, BH 946, BH 393, BH 902, DWRB 92 and DWRB 101 at CCS HAU, Hisar during 2020-21. The results revealed that maximum catalase activity (243.168 and 157.981umoles/g FW), peroxidase activity (22.33 and 35.03 units/g FW), superoxide activity (22.03 and 35.03 nmoles/g FW) and dehydrogenase activity (0.213 and 0.245 OD/g/ml) were estimated in the seeds primed with ZnO NPs @ 100ppm in cloth and polythene bag, respectively in variety DWRB 92. Among the varieties, DWRB 92 recorded highest catalase activity (217.168 umoles/g FW) in cloth bag while BH 393 recorded maximum catalase activity (232.961 umoles/g FW) in polythene bag. Minimum catalase activity was observed in DWRB 101(60.351 umoles/g FW) in cloth and BH 885 recorded least (121.418 umoles/g FW) in polythene bags. Maximum peroxidase activity (21.22 and 31.56 units/g FW) was estimated in BH 885 while minimum (12.71 and 22.54 units/g FW) in BH 946 in cloth and polythene bag, respectively. Maximum SOD activity (18.033 and 25.033 nmoles/g FW) was measured in DWRB 92 and minimum (12.712 and 22.537 nmoles/g FW) in BH 946 in cloth and polythene bag, respectively. Maximum DHA activity (0.170 and 0.206 OD/g/ml) was recorded in DWRB 101 and least in BH 946 (0.234 and 0.281 OD/g/ml) in cloth and polythene bag. It is concluded that among the various seed priming treatments, priming with ZnO NPs@100ppm at 25°C for 24 hours maintained higher enzyme activity. Barley seed quality can be maintained by storing the seeds at optimum moisture content (<8%) in polythene bags (>700gauge) with germination upto 94.61% as compare to cloth bags (85.89%).

Keywords: Nano-particles, priming, *Hordeum vulgare*, storage container, Catalase, Peroxidase

1. Introduction

Barley (*Hordeum vulgare* L.) is one of the main cereal crop and ranks fourth among grains with production of 156.12 million tonnes after maize, rice and wheat in India as well as world (Anonymous, 2019). Russia ranks first in barley production which contributes about 14 per cent of the world production while India contributes 1.12 per cent in global barley production to the tune of 1.75 million tonnes (Anonymous, 2019). Barley is an important source of carbohydrates (77.7%), protein (9.9%), fat (1.2g), vitamins *viz.,* niacin and pyridoxine and minerals *viz.,* calcium, iron and manganese. The crop is also used as animal fodder, as a source of fermentable material for beer and certain distilled beverages and as a component of various health foods. Barley grown for malt purpose is called malting barley as opposed to feed barley. Seed is an important component and plays a crucial role in agricultural production as well as in the national economy. Seed deterioration starts once the seed attains physiological maturity in the field. Seed deterioration will lead to some of physiological changes like loss of germination potential, decrease in mean germination time and loss of vigour (Helmer *et al.* 1962). Storage containers or packaging materials mostly influences the seed longevity during storage condition (Oyekale *et al.,* 2012). The use of proper storage containers during storage is one of the most important aspects during storage and maintaining seed quality until the next cropping season. The container properties greatly influence the interaction of seed with the surrounding environment. The rate of entry and exit of moisture content from the storage container will influence the seed longevity (Walters, 2007). Since the seed is hygroscopic in nature, absorbs moisture under ambient storage conditions until seed attains the equilibrium moisture content with surrounding environment. High temperature along with more moisture content enhances the rate of seed deterioration (Roberts, 1972). To overcome all these factors, it is essential to store the seeds in moisture-proof containers such as polythene bags with or without desiccating agents to maintain the seed quality (Vijayalakshm and Malabasari, 2018). The better moisture barrier properties of the storage container are an essential to maintain the germination of seed for longer durations (Fu, 2018). Since seed is a living entity, deterioration is inevitable. Rate of deterioration will be higher under stored seed, however, can be slow down by application of seed quality enhancement techniques *i.e.* priming, coating, pelleting and hardening. Seed priming is one of the scientific techniques used for enhancing the quality of seed at post-harvest season. It is the process of controlled hydration of seeds to a level that allows pre-germination metabolic activity to continue while preventing actual radicle emergence (Vanangamudi, 2014). Seeds are treated with different kinds of chemicals such as inorganic salts (halo-priming), sugars (osmo-priming), plant hormones (hormonal priming), nano-particles (nano-priming) and bioagents (bio-priming). Most of the priming treatments involve imbibing seed with a restricted amount of water to allow sufficient hydration and advancement of metabolic processes but preventing actual seed germination. Seed priming has also been investigated as a pre-sowing or mid-storage treatment for seed batches that have lost vigour due to insufficient storage conditions (Pan and Basu, 1985; Singh *et al.,* 2001).

Superoxide dismutase (SOD), glutathione reductase (GR) and catalase (CAT) are main enzymes which are involved in cell detoxification (Bailly, 2004; Mittler, 2002). The behaviour of seed with different priming treatments depends on various physiological and biochemical factors. There is ample scope for investigating mechanism involved behind the beneficial and adverse effects of seed priming on seed quality. Nanotechnology is a branch of science which deals with the synthesis and application of nano particles having size 1–100 nm (Jasrotia *et al.*, 2018; Roco 2003). Now a days, nanotechnology is emerging as a promising approach to be incorporated in agriculture to improve productivity of different crops through seed treatment with nano particles, their foliar spray on plants, nano-fertilizers for balanced crop nutrition, nano-herbicides for effective weed control, nano-insecticides for plant protection, early detection of plant diseases and nutrient deficiencies using diagnostics kits and nano-pheromones for effective monitoring of pests (Kashyap *et al.*, 2022; Singh *et al.*, 2021). Zinc is essential for plant's enzyme system as it acts as cofactors, metal components and other regulatory factors of many enzymes (Kushwaha *et al.*, 2021; Prasad *et al.,* 2012) which comes in the fourth position after nitrogen, phosphorous and potassium. Nano-priming can be applied to seeds through priming in order to improve seed quality parameters by enhancing various enzyme activities of seed. Less antioxidant enzymes and more lipid peroxidation activities were observed in primed seeds as compared to unprimed seeds in sweet corn (Chang and Sung, 1998). Since enzyme activities in seeds are directly related with the seed quality and a very little information is available on priming effects on enzyme activities naturally aged seeds in barley. Therefore, the present study was planned to assess the effect of different storage containers and priming on nine months naturally aged seeds of barley.

2. Materials and Methods

The study was conducted on seeds of six barley varieties *viz.* BH 885, BH 946, BH 393, BH 902, DWRB 92 and DWRB 101 procured from the Department of Genetics and Plant Breeding, CCS HAU, Hisar during June, 2020. The seeds (2kg seed of each variety) were stored in cloth bags and polythene bags having 700gauge thickness under ambient conditions (Figure 2) at optimum moisture content (<8%) for nine months. After nine months of storage the seeds were primed with GA_3 (50, 100 and 150ppm, Ethanol (1, 3 and 5%) and ZnO nano-particles (50, 100 and 150ppm) at 25°C for 24 hours and then dried to original moisture content (<8%) under ambient conditions. Enzyme activities *viz*., Dehydrogenase activity, Catalase Assay, Superoxide dismutase Assay (SOD), Peroxidase Assay (POX) were estimated in primed seeds.

Dehydrogenase activity test (OD $g^{-1}ml^{-1}$): One gram of seed sample was taken from each variety and treatment which is replicated three times. The grounded powder of 200mg from each sample was added to a centrifuge tube. Thereafter, 5ml of 0.5% tetrazolium solution was also added it. The mixture was incubated at 38°C for 3 to 4 hours. Tetrazolium chloride (Tz) is reduced to red coloured compound formazan in the seed embryo in the presence of dehydrogenase enzyme. After 4 hours, the mixture was centrifuged for 10mins at 10,000rpm and supernatant was discarded. Then, 10ml of acetone was added to centrifuge tube in order to extract formazon. The tubes were kept at room temperature for 16 hours after that centrifuged at 10,000 rpm for 10mins. Spectrophotometer absorbance was estimated at 520nm taking acetone as blank solution. These observations were indicated as optical density (O.D.) as per the procedure given by Kittock and Law (1968).

Extraction of antioxidant enzymes: One-gram sample of seed from each treatment was placed in a pre-chilled pestle and 5 ml of cold extraction solution containing 0.1 M phosphate buffer (pH 7.0), 2.5 mM DDT, and 1 mM EDTA was added to it. The sample was pulverized thoroughly using a mortar by adding few glass abrasives. After that, the homogenate was placed in a centrifuge tube and was centrifuged at 10,000 rpm for 10 minutes. This whole process of enzyme extraction was performed at temperature of 0-4°C. The resulting supernatant was utilized in various anti-oxidant enzyme tests to determine the activities of superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD).

Catalase Assay: In a test-tube, a mixture of chemicals containing 0.55ml of 0.1M potassium phosphate buffer (pH 7.0), 0.4ml of 0.2 M H O, was prepared and 50 µl of enzyme extract was added to it. The whole reaction mixture was incubated at 37°C for a minute. The reaction was stopped by adding 3 ml of 5% (w/v) potassium dichromate and glacial acetic mixture in 1:3 v/v ratio. After that, test tubes were kept in a hot water bath for 10 minutes then gradually cooled. Dichromate acetate solution was used as the blank. Finally, the absorbance was recorded at 570 nm. The amount of H_2O_2 reacted in the mixture was calculated by subtracting the absorbance of other samples from the control. One unit of enzyme activity was given as the amount of enzyme that catalyzes the oxidation of 1 mole H_2O_2 per min. Catalase activity was determined according to the procedure suggested by Sinha (1972).

Superoxide dismutase Assay (SOD): In a test tube, the chemicals 2.5 ml of 60 mM Tris-HCl (pH 7.8), 0.1 ml of 420 mM L-methionine, 0.1 ml of 1.8mM NBT, 0.1 ml of 3.0 mM EDTA were mixed in the serially. The reaction mixture was then made up of 3ml by mixing 0.1 ml of enzyme extract with 0.1 ml of 90uM riboflavin in the test tube. The solution was thoroughly mixed and placed 30 cm below the light source, which consisted three 20 W fluorescent lights. A blank solution containing only the buffer without any enzyme extract was prepared. The reaction was begun by turning on the light and ended by turning it off after 40 minutes of incubation. Once the reaction was completed, the tubes were covered with black material in order to prevent further reaction. The blank is a non-irradiated reaction mixture which hadn't developed any colour. Only the reaction mixture without any enzyme extract developed maximum colour, and its absorbance reduced with increase in volume of enzyme extractin the mixture. At 560 nm, the absorbance was measured. The ability of superoxide dismutase to prevent the photochemical reduction of nitro blue tetrazolium (NBT) was measured using the Beauchamp and Fridovich (1971).

The enzyme activity was estimated in units of g FW, and % inhibition was estimated using the formula given by Asada *et al.,* (1974):

Per cent inhibition $= \frac{V-v}{v} \times 100$

Where,

V-Rate of reaction in absence of SOD

v-Rate of reaction in presence of SOD

One enzyme unit is defined as the amount of enzyme that inhibits the NBT photo reduction by 50%.

Peroxidase Assay: It was initiated by mixing 2.75 ml of 50 mM phosphate buffer (pH 6.5), 0.1 ml of 0.5% hydrogen peroxide, 0.1 ml of 0.2% O-dianisidine dye. Then, the mixture was added with 0.05 ml of enzyme extract. The same mixture without H_2O_2, was taken as a blank. Change in the absorbance was estimated at 430 nm for 3 min and one unit of POD was defined as the quantity of enzyme required to cause O.D. change per minute according to the procedures given by Shannon *et al.* (1966).

Synthesis of Zinc oxide nano-particles: ZnO nanoparticles were prepared as the procedure of Moghaddam *et al.* (2009), in the laboratory of Department of Seed Science and Technology, CCS HAU Hisar. The procedure involves, preparation of 0.45 M aqueous solution of Zinc nitrate $Zn\ (NO_3)_{2.}2H_2O$ and 0.9M aqueous NaOH in distilled water. After that, the beaker containing NaOH solution was heated at 55^0C temperature. The $Zn\ (NO_3)_{2.}$ $2H_2O$ solution was added dropwise slowly up to 40 mins to the above solution. After this the beaker was sealed and kept for 2 hours. Then precipitated ZnO NPs was cleaned with deionized water and ethanol then dried in the air atmosphere at about 60^0C.

Characterization of Zinc oxide nano-particles: The characterization of synthesized ZnO NPs was done by FESEM (Field Emmision Scanning Electron Microscope) and HRTEM (High Resolution Transmission Electron Microscope). As per the results of SEM and TEM, synthesized ZnO NPs had the characteristics with average particle size 35.25nm with purity of 99.9% The particles were white in colour having spheroidal and ellipsoidal shape with inter-planar spacing of 0.85nm (Figure 1).

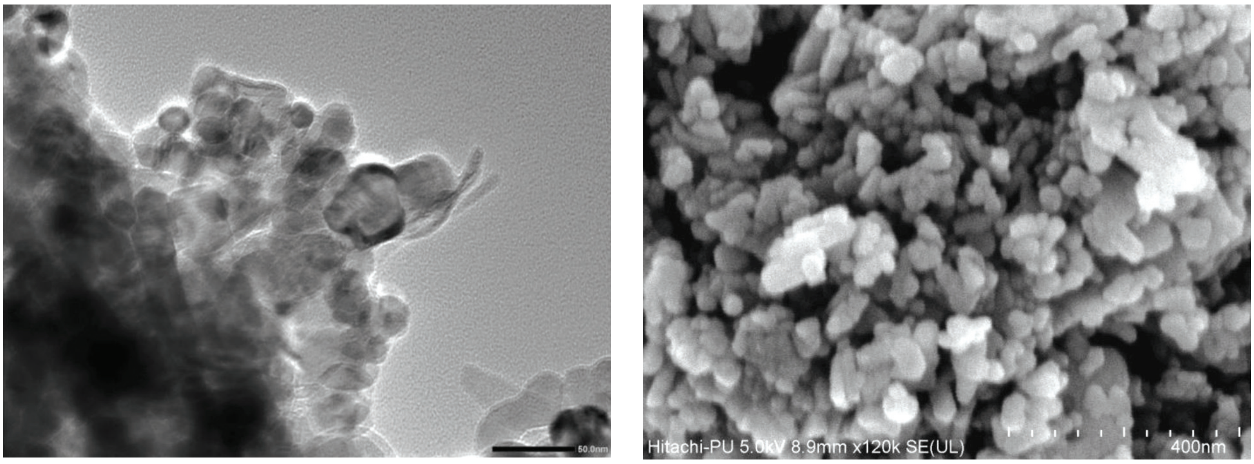

Figure: 1 High resolution transmission electron microscope (HRTEM) and Filed emission scanning electron microscope (FESEM) image of ZnO NPs

The experiment was conducted in completely randomized design (CRD) and data recorded from study were analyzed according to standard method of Panse and Sukhatme (1985) and by using the online statistical tool developed by Sheoran (2010).

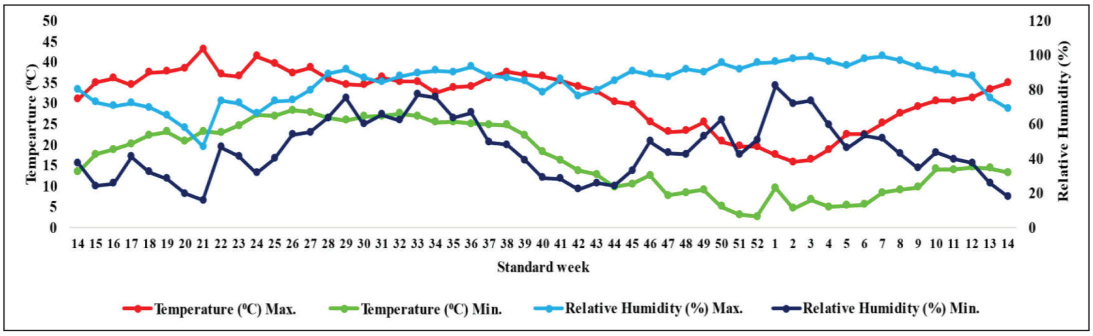

Figure 2: Average weather data of Hisar during storage period (2020-21)

3. Results and Discussion

The data revealed that the priming treatments significantly enhanced catalase, peroxidase superoxide and catalase activities of primed seeds except 5% ethanol. Maximum catalase activity (243.168 and 157.981umoles/g FW), peroxidase activity (22.33 and 35.03 units/g FW), superoxide activity (22.03 and 35.03 nmoles/g FW) and dehydrogenase activity (0.213 and 0.245 OD/g/ml) were estimated in the seeds primed with ZnO 100ppm while minimum catalase activity (114.105 and 141.980 umoles/g FW), peroxidase activity (13.00 and 20.15units/g FW), superoxide activity (15.361 and 20.147 moles/g FW) and dehydrogenase activity (0.140 and 0.197 OD/g/ml) were recorded in seeds primed with 5% ethanol in cloth and polythene bag, respectively (Table 1-4). Although, ethanol at lower concentration (1&3%) showed positive effect on enzyme activities but at higher concentration (5%), it resulted in decrease in enzyme activities. Among the varieties, DWRB 92 recorded the highest catalase activity (217.168 umoles/g FW) in cloth bag while BH 393 recorded maximum catalase activity (232.961 umoles/g FW) in polythene bag. Minimum catalase activity was observed in DWRB 101(60.351 umoles/g FW) in cloth and BH 885 recorded least (121.418 umoles/g FW) in polythene bags. Maximum peroxidase activity (21.22 and 31.56 units/g FW) was estimated in BH 885 while minimum (12.71 and 22.54 units/g FW) in BH 946 in cloth and polythene, bag respectively. Maximum SOD activity (18.033 and 25.033 nmoles/g FW) was measured in DWRB 92 and minimum (12.712 and 22.537 nmoles/g FW) in BH 946 in cloth and polythene bag, respectively. Maximum DHA activity (0.170 and 0.206 OD/g/ml) was recorded in DWRB 101 and least in BH 946 (0.234 and 0.281 OD/g/ml) in cloth and polythene bag stored seeds. The antioxidant enzyme activity such as catalase, peroxidase, superoxide and dehydrogenase activity in stored seeds significantly increased after priming treatments. Only ethanol 5% priming showed the detrimental effect apart from that all other priming treatments increased the enzyme activity. All these four enzymes showed highest activity in ZnO 100ppm priming followed by GA_3 100ppm as compared to other treatments. Ethanol priming also increased the enzymatic activity significantly at lower concentrations (1% and 3%) but higher concentration is toxic which resulted in lower enzyme activities. The significant difference was also observed between cloth and polythene bag which may be due to higher initial activity of enzymes as a result of less deterioration in polythene bag. These results are in accordance with the reports of Rawat *et al.*, (2018) who reported that wheat (variety UP2526) seed treated with four different nano-particles (TiO_2, ZnO, nickel and Chitosan) @ 50ppm and 300 ppm concentration for 4, 6 and 8 hours durations showed better root length, shoot length, seedling length, shoot dry weight, seedling dry weight, seedling vigour index-I and seedling vigour index-II as compared to control. Vijayalaxmi *et al.*, (2013) also conducted an experiment to elucidate the effect of TiO_2 nanoparticles on naturally aged seeds of maize at various concentrations *viz.*, 200, 400, 600, 800 and 1000 mg/kg and reported that seeds treated with 200 mg/ kg recorded significantly higher germination (88%), shoot length (20.52 cm), root length (11.91 cm), dry weight (1.34 g), dehydrogenase activity (0.784 OD value) over the control. Itroutwar *et al.,* (2020) reported that seeds primed with ZnO nano-particles @ 100 mg/L showed maximum improvement in seed quality parameters *viz.*, shoot length (13.0 cm), shoot width (3.4 mm), root length (20.7 cm), root width (1.0 mm), leaf length (60 mm), leaf width (16.0 mm), vigour index (2931.9) and dry matter production (5.33 gm) as compared to ionic control (zinc acetate) and control (hydro-priming). The seeds stored in the polythene bag showed significantly higher enzyme activity as compared to cloth bag. Polythene bag (>700gauge thickness) maintained seed moisture content constant throughout the storage period which resulted in higher enzyme activities. Pavani *et al.,* (2020) reported that ZnO nano-particles have been found to induce the activities of Guaiacol peroxidase, Glutathione Reductase, Catalase and increase in the ascorbic acid and hydrogen peroxide contents in mungbean crop. Nano-particles increases enzymes activities *viz.,* catalases, superoxidase dismutase and guaiacol-peroxidase due to reduction in Reactive oxygen species (ROS) levels in seeds and hence reduces cell damage (Guha *et al.,* 2018). Nano-particles increase water uptake by the seeds which activate germination and increase enzymes activities in phases I and II of germination process (Joshi *et al.*, 2018). Major ROS-scavenging enzymes include superoxide dismutase, glutathione reductatse and catalase. Superoxide dismutase is a key enzyme in the regulation of the quantity of superoxide radicals and peroxides. Hydrogen peroxide

Table 1: Effect of storage container and priming treatments on catalase activity (umoles/g FW) of barley varieties

Treatments(T)	Cloth bag							Polythene bag						
	BH 946	BH 902	BH 393	BH 885	DWRB101	DWRB92	Mean	BH 946	BH 902	BH 393	BH 885	DWRB101	DWRB92	Mean
Control	164.28	112.56	90.75	100.98	39.86	190.61	116.51	194.63	157.64	154.99	104.07	152.05	115.92	146.55
GA_3 50ppm	210.25	179.53	115.97	133.19	64.79	211.54	152.55	213.36	166.57	181.05	131.00	174.98	123.98	165.16
GA_3 100ppm	182.34	133.62	120.47	124.91	78.57	246.24	147.69	219.89	176.69	167.92	120.13	192.11	144.52	170.21
$GA_3$150ppm	170.21	120.56	99.68	111.04	51.92	203.67	126.18	202.69	164.69	161.05	113.00	161.98	122.85	154.38
Ethanol 1%	205.42	206.42	107.42	124.81	53.08	218.47	152.61	211.56	171.57	170.92	117.13	167.11	132.98	161.88
Ethanol 3%	215.30	222.30	218.30	129.27	65.21	231.60	180.33	219.56	178.57	176.92	125.13	172.11	138.98	168.54
Ethanol 5%	157.42	200.42	86.09	98.14	36.75	183.80	114.11	189.56	151.57	150.92	99.00	148.98	111.85	141.98
ZnO 50ppm	219.45	178.16	117.31	121.01	61.49	215.30	152.12	215.69	171.50	175.05	123.00	173.98	139.85	166.51
ZnO100ppm	239.58	204.29	129.44	134.88	83.36	243.17	172.45	220.29	181.69	229.74	144.13	196.11	157.98	288.32
ZnO200ppm	227.45	185.16	124.65	112.68	68.49	227.30	157.62	202.69	164.69	161.05	137.59	152.58	125.54	157.36
Mean	199.17	174.30	121.01	119.09	60.35	217.17	148.52	208.99	168.52	232.96	121.42	169.20	131.45	172.09
C.D. (P=0.05)	Container=0.876,Variety=1.518,Treatment=1.959,ContainerxVariety =2.146, ContainerxTreatment=2.771, VarietyxTreatment= 4.779, ContainerxVarietyxTreatment= 6.787													

Table 2: Effect of storage container and priming treatments on peroxidase activity (Units/g FW) of barley varieties

Treatments (T)	Cloth bag							Polythene bag						
	BH 946	BH 902	BH 393	BH 885	DWRB101	DWRB92	Mean	BH 946	BH 902	BH 393	BH 885	DWRB101	DWRB92	Mean
Control	8.68	14.76	12.52	16.30	13.44	16.10	13.63	17.22	21.92	21.08	27.00	26.02	23.11	22.72
GA_3 50ppm	13.85	21.30	19.26	22.39	17.92	21.11	19.31	23.14	25.84	26.00	33.92	29.94	28.03	27.81
$GA_3$100ppm	16.00	24.61	20.38	27.42	21.01	23.26	22.11	26.14	29.84	28.34	37.92	32.94	34.70	31.65
$GA_3$150ppm	11.60	16.68	14.44	19.22	15.36	20.03	16.22	19.14	24.84	24.00	28.92	28.94	25.03	25.15
Ethanol 1%	12.45	18.91	16.87	19.82	15.43	19.82	17.22	22.14	26.84	29.00	29.59	27.28	27.03	26.98
Ethanol 3%	14.45	21.91	18.87	22.49	18.43	21.82	19.66	25.14	27.84	31.00	32.92	28.28	29.03	29.04
Ethanol 5%	8.27	13.68	12.44	15.56	12.70	15.36	13.00	15.14	18.84	18.00	24.92	22.94	21.03	20.15
ZnO 50ppm	14.60	18.68	17.44	23.22	18.36	20.03	18.72	23.14	25.84	26.00	33.92	30.94	31.03	28.48
ZnO100ppm	16.60	24.68	20.44	27.56	21.36	22.33	22.11	35.03	30.84	29.00	37.59	33.94	35.03	33.57
ZnO200ppm	10.60	15.68	15.44	18.22	16.36	18.03	15.72	19.14	22.84	24.00	28.92	28.94	25.03	24.81
Mean	12.71	19.09	16.81	21.22	17.04	19.76	17.77	22.54	25.55	25.64	31.56	29.02	27.91	27.04
C.D. (P=0.05)	C=0.415, V=0.720, CxV=1.018, T =0.929, CxT=1.314, VxT= 2.275, CxVxT= NS													

Table 3: Effect of storage container and priming treatments on superoxide dismutase (nmoles/g FW) of barley varieties

Treatments	Cloth bag							Polythene bag						
	BH 946	**BH 902**	**BH 393**	**BH 885**	**DWRB101**	**DWRB92**	**Mean**	**BH 946**	**BH 902**	**BH 393**	**BH 885**	**DWRB101**	**DWRB92**	**Mean**
Control	8.68	14.76	12.52	16.30	13.44	16.10	13.63	17.22	21.92	21.08	27.00	26.02	23.11	22.72
GA_3 50ppm	13.85	76.56	19.26	22.39	17.92	21.11	28.52	23.14	25.84	26.00	33.92	29.94	28.03	27.81
GA_3 100ppm	16.00	24.61	20.38	27.42	20.67	23.26	22.06	26.14	29.84	28.00	37.92	32.94	32.03	31.15
GA_3 150ppm	11.60	16.68	14.44	19.22	15.36	20.03	16.22	19.14	24.84	24.00	28.92	28.94	25.03	25.15
Ethanol 1%	12.45	18.91	16.87	19.82	15.43	19.82	17.22	22.14	26.84	29.00	35.92	27.28	29.03	28.37
Ethanol 3%	14.45	21.91	18.87	22.49	18.43	21.82	19.66	25.14	27.84	31.00	39.92	28.28	27.03	29.87
Ethanol 5%	8.27	17.68	12.44	15.56	12.70	15.36	13.67	15.14	18.84	18.00	24.92	22.94	21.03	20.15
ZnO 50ppm	14.60	18.68	17.44	23.22	18.36	20.03	18.72	23.14	25.84	26.00	33.92	30.94	31.03	28.48
ZnO 100ppm	16.60	19.68	20.44	25.22	21.36	22.03	20.89	35.03	30.84	29.00	35.92	33.94	35.03	33.30
ZnO 200ppm	10.60	15.68	15.44	18.22	16.36	18.03	15.72	19.14	22.84	24.00	28.92	28.94	25.03	24.81
Mean	12.71	24.51	16.81	20.99	17.00	19.76	18.63	22.54	25.55	25.61	32.73	29.02	27.64	27.18
C.D(P=0.05)	C=0.992, V=1.719, T =2.219, CxV=2.431, CxT=3.138, VxT= 5.436, CxVxT=7.689													

Table 4: Effect of storage container and priming treatments on Dehydrogenase activity (OD/g/ml) of barley varieties

Treatments	Cloth bag							Polythene bag						
	BH 946	**BH 902**	**BH 393**	**BH 885**	**DWRB101**	**DWRB92**	**Mean**	**BH 946**	**BH 902**	**BH 393**	**BH 885**	**DWRB101**	**DWRB92**	**Mean**
Control	0.210	0.204	0.186	0.164	0.142	0.151	0.176	0.256	0.243	0.210	0.196	0.178	0.183	0.211
GA_3 50ppm	0.230	0.234	0.211	0.194	0.163	0.174	0.201	0.276	0.273	0.235	0.226	0.199	0.206	0.236
GA_3 100ppm	0.280	0.276	0.281	0.239	0.211	0.212	0.250	0.326	0.315	0.265	0.271	0.247	0.244	0.278
GA_3 150ppm	0.220	0.209	0.201	0.184	0.157	0.167	0.190	0.266	0.248	0.225	0.216	0.193	0.199	0.225
Ethanol 1%	0.225	0.222	0.205	0.188	0.166	0.168	0.196	0.281	0.261	0.229	0.221	0.205	0.210	0.235
Ethanol 3%	0.246	0.248	0.236	0.212	0.195	0.195	0.222	0.302	0.287	0.260	0.245	0.227	0.237	0.260
Ethanol 5%	0.194	0.187	0.165	0.156	0.133	0.140	0.163	0.240	0.226	0.189	0.188	0.169	0.172	0.197
ZnO 50ppm	0.235	0.230	0.221	0.198	0.171	0.174	0.205	0.281	0.269	0.245	0.230	0.207	0.206	0.240
ZnO 100ppm	0.274	0.273	0.267	0.240	0.207	0.213	0.246	0.314	0.308	0.279	0.264	0.242	0.245	0.275
ZnO 200ppm	0.224	0.220	0.200	0.175	0.151	0.164	0.189	0.270	0.259	0.224	0.213	0.197	0.199	0.227
mean	0.234	0.230	0.217	0.195	0.170	0.176	0.204	0.281	0.269	0.236	0.227	0.206	0.210	0.238
C.D.(P=0.05)	C=0.003, V=0.006, CxV=0.008, T =0.007, CxT=0.01, VxT= NS, CxVxT= NS													

(H_2O_2) can react in the Haber-Weiss reaction forming hydroxyl radicals which cause lipid peroxidation (Mittler *et al.,* 2004). Catalase is implicated in the removal of H_2O_2. Removal of H_2O_2 through a series of reactions is known as an ascorbate- glutathione cycle in which ascorbate and glutathione participate in a cyclic transfer of reducing equivalents resulting in the reduction of H_2O_2 to water (H_2O) using electrons derived form nicotinamide adenine dinucleotide phosphate (Goel and Sheoran, 2003). Seed deterioration is mainly caused by lipid peroxidation which can be is prevented through enhancement in dehydrogenase activity and lower peroxide formation by priming (McDonald, 1999). It is concluded from the study that seed priming with nano-particles at optimum concentration has a potential to enhance the seed quality particularly in poor storer seeds. As Dehydrogenase, Catalase, Superoxide dismutase and Peroxidase activity in seeds are directly related with the seed quality. Hence, seed quality of barley may be enhanced through seed priming with ZnO @100ppm and GA_3 @100ppm at 25°C for 24 hours. Further selection of storage containers also plays a crucial role in storage, storage of barley seeds found to be beneficial in maintaining seed quality in polythene bags (>700gauge) with moisture content (<8%).

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Author's Contribution

Siddu Appasaheb Kurubar: Execution of field/lab experiments and data collection

Axay Bhuker: Designing of the experiments, Analysis of data and interpretation

Sukham Madaan: Preparation of the manuscript

Declaration of interest statement

The authors declare no conflict of interest.

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Short Communication

Effect of nutrients omission on yield, nutrient uptake and economics of *rabi* sorghum in vertisols under rainfed and irrigated conditions

Mohammed Azharuddin BR*, Bandiwaddar TT and Shaila HM

University of Agricultural Sciences, Dharwad, Karnataka, India, 580001

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****Corresponding author:*** *E-mail: azharuddinazhu0801@gmail.com*

Sorghum (*Sorghum bicolor* L. Moench) is one of the important staple food crops for millions of individuals in semi-arid areas. Sorghum is considered as the king of millets and fourth important cereal crop in the country after rice, wheat and maize. It is widely grown in Africa, China and India. In India, sorghum is produced on an area of 4.82 m ha with production of 4.77 mt and a productivity of 1194 Kg ha^{-1} (Anonymus, 2020). Use of high NPK fertilizer, free from micronutrients, limited use of organic manures and restricted recycling of crop residues are some important factors, which have contributed towards accelerated exhaustion of secondary and micronutrients from soil. Nutrient limitations in soils have prompted an intense decrease in yield on a large number of the farms. This is caused by declining soil fertility, which inevitably leads to low agricultural productivity status (Bindraban *et al.*, 2015).

To meet out the uptake of nutrient by crop, soil reserves alone is not adequate and it is important to supply required nutrients through external sources. The nutrient omission plot technique is a tool for determining the measure of fertilizer (N, P and K) needed for attaining a targeted yield. The nutrient omission experiment on *rabi* sorghum might help in arriving at optimum fertilizer recommendations and improve the productivity, nutrient use efficiency and sustainability. Hence, the present investigation is carried out with an objective to assess the impact of nutrients omission on growth and productivity of *rabi* sorghum.

A field experiment was conducted to study the effect of nutrients omission on yield, nutrient uptake and economics of *rabi* sorghum during *rabi* 2020-2021 on clay loam soil under All-India Coordinated Research Project on sorghum, at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad (15^0 29' N, 74^0 59' E 689m altitude). The experiment was laid out in split plot design with three replications. The experiment consists of two main plots *viz.*, Rainfed (M_1) and Irrigated (M_2) and nine sub plots viz.,S_1 - No Omission (50:25 Kg NP ha^{-1} + FYM @ 3 t ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1}),S_2 - FYM Omission (50:25 Kg NP ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1}), S_3 - N omission (25 Kg P_2O_5 ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1} + FYM @ 3 t ha^{-1}), S_4 - P omission (50 Kg N ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1} + FYM @ 3 t ha^{-1}), S_5 - Zn omission (50:25 Kg NP ha^{-1} + FYM @ 3 t ha^{-1}), S_6 - NP omission ($ZnSO_4$ @ 15 Kg ha^{-1} + FYM @ 3 t ha^{-1}), S_{7-} N, Zn Omission (25 Kg P_2O_5 + FYM @ 3 t ha^{-1}), S_8 - P, Zn Omission (50 Kg

N ha^{-1} + FYM @ 3 t ha^{-1}) and S_9– Control(N, P, K, Zn and FYM Omission). The field was prepared and line sowing was carried out. *Rabi* sorghum variety CSV – 29 R was sown using 7.5 Kg ha^{-1}seeds on November 18th, 2020 with a spacing of 45cm x 15cm. Nitrogen, phosphorus and zinc were applied in the form of urea, single super phosphate and $ZnSO_4$, respectively, at the time of sowing. Common irrigation was given to both the main plots (M_1 and M_2) immediately after sowing to ensure the proper germination and establishment of the crop. Irrigations were given only for M_2 at booting, flowering and milky stage. The observations (yield, nutrient and economics) recorded were subjected to statistical analysis as described by Gomez and Gomez (1984).

Results indicated that significantly higher grain yield (44.87 q ha^{-1}), stover yield (8.52 t ha^{-1}), total nutrient uptake (93.86 Kg N ha^{-1}, 28.51 Kg P_2O_5 ha^{-1} , 94.04 Kg K_2O ha^{-1}, and 226.24 g Zn ha^{-1}) were recorded under irrigated condition as compared to rainfed condition (Table 1 and 2). The increase in grain yield, stover yield and total nutrient uptake might be due to favourable moisture condition, which helped for better translocation of photosynthates and nutrients resulting in better growth and development. Similar findings were also repoted by Anilkumar *et al.* (2017) that soil application of recommended dose of fertilizer (RDF) along with enriched FYM gave higher grain yield (4.287 t ha^{-1}) and fodder yield (7.51 t ha^{-1}) of *rabi* sorghum. Among the nutrient omissions, application of 50:25 kg NP ha^{-1} + FYM @ 3 t ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1} (S_1) recorded significanlty higher grain yield (4.956 t ha^{-1}) and stover yield (9.55 t ha^{-1}). The per cent reduction in grain and stover yield was to an extent of 26.7% and 28.5% respectively, due to omission of nitrogen. While,the per cent reduction in grain and stover yield was to the tune of 31.9 and 34.9 respectively, due to omission of both nitrogen and phosphorous. These results are associated with the findings of Joshi *et al.* (2016) that omission of nutrients such as N, P, K and Zn showed significant effects on grain yield.However, omission of Zn did not affect much on grain and stover yield.

The application of 50:25 Kg NP ha^{-1} + FYM @ 3 t ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1} (S_1) recorded significanlty higher total nutrient uptake (109.97 Kg N ha^{-1}, 32.63 Kg P_2O_5 ha^{-1}, 109.33 Kg K_2O ha^{-1} and 283.63 g Zn ha^{-1}). Higher nutrient uptake is due to higher content of nitrogen, phosphorus, potassium and zinc and total dry matter production and its accumulation in grain. These results are supported by findings of Sujathamma *et al.* (2014) that application of 100 per cent RDF recorded the highest N, P, K uptake both by grain and stover. While, omission of NP caused the lowest uptake of total N (69.05 Kg ha^{-1}), total P (21.07 Kg ha^{-1}) and total Zn (215.50 g ha^{-1}). This might be due to the synergetic and antogonistic effects among nutrients. Omission of P and other nutrients reduces the absorption of N because of imbalance in the nutrient supply. Omission of N reduces the phosphorus content in crop (Singh, 2016). These results are supported with the findings of Kumar *et al.* (2018) that omission of N and P reduced the nutrient uptake because nitrogen and phosphorus are the most yield limiting nutrient, which resulted in lower yields and lower uptake of nutrients. The lowest uptake of nutrients were recorded in N omitted plots due to less production of yields. Among the interactions, application of 50:25 Kg NP ha^{-1} + FYM @ 3 t ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1} along with irrigation (M_2S_1) recorded significantly higher grain yield (5.473 t ha^{-1}), higher stover yield (10.80 t ha^{-1}) (Table 1), higher total nutrient uptake (119.31 KgN ha^{-1}, 36.49 KgP_2O_5 ha^{-1}, 122.80 Kg K_2O ha^{-1} and 287.22 g Zn ha^{-1}) as given in Table 2. The higher yield might be due to better photosynthates and translocation of nutrients. These results are in line with the findings of Atnafu *et al.* (2021) that maize grain yield obtained was highest for application of NPK and the lowest recorded in N omitted treatment followed by control. The grain yield levels obtained for different fertilizer treatments were ranked as NPK >NPK+ >NP >PK >NK illustrating N deficincy as the most yield limiting nutrient followed by P and K in order. Significantly higher gross returns (₹ 115786 ha^{-1}), net returns (₹ 77085) and BC ratio (2.99) were recorded under irrigated condition compared to rainfed condition (Table 3). Among the nutrient omissions, application of 50:25 Kg NP ha^{-1} + FYM @ 3 t ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1} (S_1) recorded significanlty higher gross returns (₹ 128146). While, application of 50:25 Kg NP ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1} (S_2) recorded significanlty higher net returns (₹ 88057) and BC ratio (3.41) compared to other nutrient omission treatments. Among interaction effects, application of 50:25 Kg NP ha^{-1} + FYM @ 3 t ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1} with irrigation (M_2S_1) recorded significanlty higher gross returns (₹ 142013). While, application of 50:25 Kg NP ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1} (M_2S_2) recorded significanlty higher net returns (₹ 101540) and BC ratio (3.77). The improvement in economic returns was mainly due to higher grain and stover yields. The results are in line with findings of Singh (2016) that nitrogen and phosphorus were proved to be the most limiting nutrient in crop production. Thus the development of genotypes with high nutrient use efficiency can be achieved as has also been reported in wheat (Kumar *et al.,* 2019), rice (Zhang *et al.,* 2020) and maize (Atnafu *et al.,* 2021) among other crops.

Table 1: Effect of nutrient omission on grain yield and stover yield of *rabi* sorghum under rainfed and irrigated conditions

Treatments	**Irrigation [No irrigation (M_1) and Irrigated (M_2)]**					
Nutrient Management	**Grain yield (q ha^{-1})**			**Stover yield (t ha^{-1})**		
	M1	**M2**	**Mean**	**M1**	**M2**	**Mean**
S_1 - No Omission (50:25 Kg NP ha^{-1} + FYM @ 3 t ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1}) [RPP]	44.38	54.73	49.56	8.30	10.80	9.55
S_2 - FYM Omission (50:25 Kg NP ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1})	43.02	53.10	48.06	8.10	10.63	9.37
S_3 - N omission (25 Kg P_2O_5 ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1} + FYM @ 3 t ha^{-1})	32.67	40.03	36.35	5.90	7.77	6.83
S_4 - P omission (50 Kg N ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1} + FYM @ 3 t ha^{-1})	38.67	48.20	43.43	6.73	8.33	7.53
S_5 - Zn omission (50:25 Kg NP ha^{-1} + FYM @ 3 t ha^{-1})	40.57	50.65	45.61	7.47	9.80	8.63
S_6 - NP omission ($ZnSO_4$ @ 15 Kg ha^{-1} + FYM @ 3 t ha^{-1})	30.22	37.30	33.76	5.57	6.87	6.22
S_{7-} N, Zn Omission (25 Kg P_2O_5 + FYM @ 3 t ha^{-1})	32.40	39.76	36.08	5.33	7.33	6.33
S_8 - P, Zn Omission (50 Kg N ha^{-1} + FYM @ 3 t ha^{-1})	36.21	44.66	40.44	6.53	8.60	7.57
S_9 – Control (N, P, K and Zn Omission)	29.13	35.40	32.27	5.03	6.53	5.78
Mean	36.36	44.87		6.55	8.52	
	S.Em±		CD at 5%	S.Em±		CD at 5%
Irrigation (I)	0.69		4.24	0.07		0.44
Nutrient (N)	1.01		2.91	0.19		0.55
Interaction (I x N)	1.43		4.12	0.27		0.78

Recommended package of practice 50:25 Kg NP ha^{-1} + FYM @ 3 t ha^{-1} + ZnSO4 @ 15 Kg ha^{-1} (RPP); M1 – Rainfed condition (No irrigation), M2 – Irrigated Condition

Based on the experimental results, it could be concluded that application of 50:25 Kg NP ha^{-1} + FYM @ 3 t ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1} along with protective irrigation at booting, flowering and milky stage significanlty recorded higher grain yield, stover yield, total nutrient uptake, higher protein content, higher gross returns, net returns and BC ratio of *rabi* sorghum. Nitrogen and phosphorus are the most limiting factors to enchance the grain yield, stover yield and for total nutrient uptake. Further, omission of either nitrogen or phosphorus showed a greater reduction in economic returns.

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Compliance with ethical standards: NA

Conflict of interest: No

Author's contribution

Conceptualization of research (MABR); Designing of the experiments (MABR, BTT); Contribution of

Table 2: Effect of nutrient omission on total nutrient uptake of *rabi* sorghum under rainfed and irrigated conditions

Treatments	**Irrigation [No irrigation (M_1) and Irrigated (M_2)]**											
Nutrient Management	**Nitrogen (Kg ha^{-1})**			**Phosphorus (Kg ha^{-1})**			**Potassium (Kg ha^{-1})**			**Zinc (g ha^{-1})**		
	M_1	**M_2**	**Mean**	**M_1**	**M_2**	**Mean**	**M_1**	**M_2**	**Mean**	**M_1**	**M_2**	**Mean**
S_1 - No Omission (50:25 Kg NP ha^{-1} + FYM @ 3 t ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1}) [RPP]	100.64	119.31	109.97	28.76	36.49	32.63	95.87	122.80	109.33	280.05	287.22	283.63
S_2 - FYM Omission (50:25 Kg NP ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1})	97.59	116.08	106.84	27.45	35.02	31.24	91.17	117.47	104.32	253.28	260.92	257.10
S_3 - N omission (25 Kg P_2O_5 ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1} + FYM @ 3 t ha^{-1})	70.03	82.19	76.11	20.05	25.47	22.76	64.63	83.23	73.93	222.77	230.62	226.70
S_4 - P omission (50 Kg N ha^{-1} + $ZnSO_4$ @ 15 Kg ha^{-1} + FYM @ 3 t ha^{-1})	84.77	99.73	92.25	23.35	29.02	26.19	76.27	94.63	85.45	232.74	240.19	236.47
S_5 - Zn omission (50:25 Kg NP ha^{-1} + FYM @ 3 t ha^{-1})	90.74	109.43	100.08	25.92	33.17	29.55	83.30	107.77	95.53	203.81	210.92	207.36
S_6 - NP omission ($ZnSO_4$ @ 15 Kg ha^{-1} + FYM @ 3 t ha^{-1})	64.16	73.94	69.05	18.88	23.26	21.07	61.20	75.50	68.35	212.17	218.83	215.50
S_{7} N, Zn Omission (25 Kg P_2O_5 + FYM @ 3 t ha^{-1})	66.59	79.92	73.26	19.24	24.89	22.07	60.63	80.33	70.48	182.71	187.20	184.96
S_8 - P, Zn Omission (50 Kg N ha^{-1} + FYM @ 3 t ha^{-1})	81.16	96.39	88.77	22.36	28.6	25.46	73.73	94.97	84.35	210.85	217.86	214.35
S_9 - Control(N, P, K and Zn Omission)	58.53	67.74	63.14	16.51	20.75	18.63	54.93	69.67	62.30	176.84	182.40	179.62
Mean	79.36	93.86		22.50	28.51		73.53	94.04		219.47	226.24	
For comparing means	S.Em ± CD at 5%			S.Em ± CD at 5%			S.Em ± CD at 5%			S.Em ± CD at 5%		
Irrigation (I)	1.33	8.11		0.35 2.17			1.04	6.32		0.08 0.49		
Nutrient (N)	2.22 6.39			0.67 1.94			2.23 6.44			0.51 1.48		
Interaction (I x N)	3.14	9.04		0.9 2.75			3.16 9.12			0.72 2.10		

Recommended package of practice 50:25 Kg NP ha-1 + FYM @ 3 t ha-1 + ZnSO4 @ 15 kg ha-1 (RPP); M1 – Rainfed condition (No irrigation) , M2 – Irrigated Condition

Table 3: Effect of nutrient omission on economics of *rabi* sorghum under rainfed and irrigated conditions

Treatments	Irrigation [No irrigation (M_1) and Irrigated (M_2)]											
Nutrient Management	Cost of cultivation (Rs)			Gross Returns (Rs)			Net returns (Rs)			B:C ratio		
	M_1	M_2	Mean	M_1	M_2	Mean	M_1	M_2	Mean	M_1	M_2	Mean
S_1 - No Omission (50:25 Kg NP ha^{-1} + FYM @ 3 t ha^{-1} + ZnSO$_4$ @ 15 Kg ha^{-1}) [RPP]	40726	41046	40886	114280	142013.33	128146.67	73554	100967.3	87260.67	2.80	3.46	3.13
S_2 - FYM Omission (50:25 Kg NP ha^{-1} + ZnSO$_4$ @ 15 Kg ha^{-1})	36226	36546	36386	110800	138086.67	124443.33	74574	101540.6	88057.33	3.05	3.77	3.41
S_3 - N omission (25 Kg P$_2$O$_5$ ha^{-1} + ZnSO$_4$ @ 15 Kg ha^{-1} + FYM @ 3 t ha^{-1})	40187	40507	40347	83666.67	103920.00	93793.33	43479.67	63413	53446.33	2.08	2.56	2.32
S_4 - P omission (50 Kg N ha^{-1} + ZnSO$_4$ @ 15 Kg ha^{-1} + FYM @ 3 t ha^{-1})	39214	39534	39374	98533.33	122706.67	110620	59319.33	83172.67	71246.00	2.51	3.10	2.80
S_5 - Zn omission (50:25 Kg NP ha^{-1} + FYM @ 3 t ha^{-1})	39751	40071	39911	104180	130993.33	117586.67	64429.00	90922.33	77675.67	2.61	3.27	2.94
S_6 - NP omission (ZnSO$_4$ @ 15 Kg ha^{-1} + FYM @ 3 t ha^{-1})	38675	38995	38835	77646.67	95793.33	86720	38971.67	56798.33	47885.00	2.01	2.45	2.23
S_{7-} N, Zn Omission (25 Kg P$_2$O$_5$ + FYM @ 3 t ha^{-1})	39212	39532	39372	81946.67	102153.33	92050	42734.67	62621.33	52678.00	2.08	2.58	2.33
S_8 - P, Zn Omission (50 Kg N ha^{-1} + FYM @ 3 t ha^{-1})	38239	38559	38399	92706.67	115466.67	104086.67	54467.67	76907.67	65687.67	2.42	2.99	2.71
S_9 – Control (N, P, K and Zn Omission)	33200	33520	33360	74233.33	90946.67	82590	41033.33	57426.67	49230.00	2.23	2.71	2.47
Mean	38381	38701		93110.37	115786.67		54729.26	77085.56		2.42	2.99	
For comparing means				S.Em ± CD at 5%			S.Em ± CD at 5%			S.Em ± CD at5%		
Irrigation (I)				1700.1110344.97			1700.114 10344.97			0.042 0.25		
Nutrient (N)				2551.83 7350.95			2551.83 7350.95			0.067 0.19		
Interaction (I x N)				3608.83 10395.81			3608.833 10395.81			0.095 0.27		

Recommended package of practice 50:25 Kg NP ha^{-1} + FYM @ 3 t ha^{-1} + ZnSO4 @ 15 Kg ha^{-1} (RPP); M1 – Rainfed condition (No irrigation), M2 – Irrigated Condition experimental materials (MABR, BTT); Execution of field/lab experiments and data collection (MABR, BTT); Analysis of data and interpretation (MABR, BTT, SHM); Preparation of the manuscript (MABR, BTT).

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Short Communication

An approach to climate resilient agriculture farming system using rice landraces collected from Tamil Nadu

Ashok Subiramaniyam[1*], Sarankumar Chandran[2], Kuttimani Ramalingam[3] and Senthil Alagarswami[3]

[1]*Department of Crop Physiology,Adhiparasakthi Agricultural College, Kalavai- 632 506, Tamil Nadu, India*
[2]*Department of Plant Breeding and Genetics, Horticultural College, Kalavai- 632 506, Tamil Nadu, India,*
[3]*Department Crop Physiology, Tamil Nadu Agricultural University, Coimbatore-641 003, Tamil Nadu, India*

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****Corresponding author:*** *E-mail: ashok.tnau.ac.in@gmail.com*

Rice (*Oryza sativa* L.) is the foremost important food crop in the world, especially in Asiatic Continent. Asia accounts for 90 per cent and 92 per cent of the world's rice area and production, respectively. Among all the Asian countries, India is the prominent rice-growing country, it occupies 23.3 per cent of gross cropped area and contributes 43 per cent of total food grain production and 46 per cent of total cereal production. India has the world's largest land area for cultivation of rice (44 million ha) and is second in production as per the data of the union agriculture ministry 2020-2021 (102.36 million tonnes) next to China, accounting for 20 per cent of all world's rice production. It continues to play a vital role in the national food grain supply. It is the staple food of nearly half of the world's population. It ranks third after wheat and maize in terms of worldwide production.

Drought is one of the important factors that limit the productivity of rice in the fragile environments of South India. The existing modern varieties of rice do not perform well under drought stress conditions. India is home to wide varieties of rice cultivars, landraces, and many lesser-known varieties that have been under cultivation for ages by farmers as well as local entrepreneurs. Droughts have obvious consequences in terms of yield reductions, especially if droughts occur during key stages in the rice growth cycle in which plant development is particularly sensitive to water requirements. But droughts may also limit the area under cultivation, such as in the case of delayed monsoon onset. In Tamil Nadu, there are many landraces available some of them have highly tolerant to environmental stresses, such as drought and heat, and are used by the people in that area traditionally. Although the yield capacity of traditional varieties is limited this is compensated by other appreciable characteristics such as high nutritional value, good cooking qualities including pleasurable aroma, and sufficient volume of a cooked meal with less quantity of raw rice. On-farm and in-market management responsiveness of landraces and high-yielding traditional varieties is about 30–35 % more than modern varieties. The seed of traditional varieties costs 2.5 times lesser than that of modern varieties. Therefore, improvement of the heritage of traditional varieties of rice and rice landraces could well be the foundation for future research endeavors in especially agricultural disciplines for authenticated results to future food needs. These rice landraces should be identified before they disappear. Knowing their existence and significance through ancient literature could pave way for a fruitful venture in the collection and characterization of these traditional rice varieties. There is a future need to expand the genetic base of the rice crop by introgressing genes from diverse sources. Thus, it is a need to collect, exploit and evaluate the untapped germplasm. With this background, the current study was conducted with a hypothesis that the screening and selection of rice landraces tolerant to drought stress based on the physiological and biochemical mechanisms may pave the way to develop the elite lines tolerant to drought stress.

Table 1. Detail of studied genotypes with their origin and special character

Sl. No.	Variety	Origin	Specific note
1	Rascadam	Tamil Nadu, India	Landrace, Maturity duration (120-125days)#
2	Kothamallisambha	Tamil Nadu, India	Landrace, Maturity duration (130-135 days)**
3	Kattusambha	Tamil Nadu, India	Landrace, Maturity duration (120-125 days)***
4	Kallundai	Tamil Nadu, India	Landrace, Maturity duration 120 days#
5	Kuliyadichan	Tamil Nadu, India	Landrace, drought-tolerant, Maturity duration (120 days)##
6	Milagusambha	Tamil Nadu, India	Landrace, Maturity duration (150 days)***
7	N 22	Eastern India	Short duration of maturity (80-95 days), deep-rooted, drought and heat tolerant aus rice cultivar*
8	IR 64	IRRI, Philippines	Maturity duration (115 days), hybrid variety with high yield, rainfed lowland areas, semi dwarf, susceptible to abiotic stress*.

*Vikram*et al.* (2016), #Vishnu Varthini *et al.* (2015), ##Vanniarajan *et al.* (2015), **Keerthivarman*et al.* (2019), ***Asish *et al.* (2020)

The field experiment was conducted at the farm of Bagadudurai block (Field No.NF2/3) of Agricultural Research Station (ARS), Tamil Nadu Agricultural University (TNAU), Bhavanisagar, Erode district, (11.29° N latitude and 77.80° E longitude). The field was ploughed to fine tilth and puddle. Uniform-sized plots (3.7x1.7 m) were prepared. Basal application of fertilizers applied before transplanting of 21 days seedlings. Three replications per treatment per genotype were maintained and watered up to the flowering stage of drought imposition (Table 2). Rewatering was also done after 30 days after drought at the reproductive stage. The crop was applied with a recommended dose of fertilizers and other cultivation operations including plant protection measures were carried out as per recommended package of practices for rice. In this study, a separate set of plots with three replications were maintained. Reproductive stage drought was imposed on the 75th day after sowing. Soil moisture content was monitored using a moisture meter (Delta-T Soil moisture kit - Model: SM150, Delta-T Devices, Cambridge) periodically and re-watering was done when the soil moisture reached below 20 per cent and leaves were completely rolled and started drying at tips and margins.

Table 2. Soil moisture (% mineral) content measured during drought under field condition

Genotypes	Vegetative stage stress			Reproductive stage stress		
	Before stress	10 DAS	Before re-watering (25 DAS)	Before stress	12 DAS	Before re-watering (30 DAS)
Rascadam	55	30	15	52	28	17
Kothamalli samba	56	30	16	53	29	17
Kaattu samba	56	29	15	53	29	16
Kallundai	57	32	17	55	27	17
Kuliyadichan	55	27	15	53	26	18
Milagu samba	56	30	16	53	26	18
N22	57	29	15	53	27	18
IR64	56	26	16	53	29	19

DAS: Days after stress

The photosynthetic rate was measured using a portable photosynthesis system (LI-6400 XT; LI-COR Inc. Lincoln, Nebraska, USA). The photosynthetic rate was measured at a light intensity of 1500 µmol m^{-2} s^{-1} PAR, a leaf temperature of 32° C and a constant CO_2 concentration of 390 µmol CO_2 mol^{-1} in a chamber provided with buffer volume. The measurements at specified growth stages were recorded on the top most fully expanded leaf from three plants between 9.30 am to 11.00 am to avoid the effects of photo-inhibition. The average values were computed and expressed as µmol CO_2 m^{-2} s^{-1}. Transpiration rate was measured using Portable Photosynthesis System (LI-6400XT, LicorInc, Nebraska, USA) and expressed as mmol H_2O $m^{-2}s^{-1}$. Stomatal conductance was measured using Portable Photosynthesis System (LI- 6400XT, LicorInc, Nebraska, USA) and expressed as mol H_2O $m^{-2}s^{-1}$. Chlorophyll fluorescence was measured using a chlorophyll fluorescence meter (opti-sciences OS1p). The key fluorescence parameters *Fo* (Initial fluorescence), *Fm* (Maximum fluorescence), *Fv* (Variable fluorescence), and the ratio of *Fv/Fm* were automatically calculated. *Fv/Fm* ratio has been proportional to quantum yield and shows a high degree of relationship with photosynthesis.

Crop plants' ability to acclimatize to varied environments is linked to their ability to adjust at the level of photosynthesis, which impacts biochemical and physiological processes and, as a result, the overall development and production of the plant (Chandra and Pental, 2003). Decreasing photosynthetic rate (Pn) is a common response of plants to water deficit stress. This response could be attributed to either stomatal closure or metabolic impairment (França *et al*., 2000). Drought stress decreases the rate of photosynthesis (Kawamitsu *et al*., 2000). Alterations in various photosynthetic attributes are good indicators of a plant's drought tolerance as they show correlations with growth. In this study, under drought conditions, kuliyadichan recorded a higher photosynthetic rate of 29.36 and 30.21 µmol CO_2 m^{-2} s^{-1} at vegetative and reproductive stages, respectively compared to other rice landraces (Table 3). The lesser reduction in the photosynthetic rate was observed in rascadam (7.06, 7.04 %) at both the stages, respectively compared to other genotypes over their respective control due to drought. This reduction in photosynthetic rate might be attributed to lower stomatal conductance to conserve water under drought conditions and consequently, CO_2 fixation is reduced and photosynthetic rate decreases, resulting in less assimilate production for growth and yield of plants. Under drought, diffuse resistance of the stomata to CO_2 entry is most likely the principal factor limiting photosynthesis (Boyer, 1970). The results obtained in this investigation for transpiration rate and stomatal conductance are consistent with Boyer's observations (Boyer, 1970).

Table 3. Impact of drought stress on photosynthetic rate (µmol CO_2 m^{-2} s^{-1})in rice genotypes under field condition

Genotypes	**Vegetative stage stress**			**Reproductive stage stress**		
	Control	**Stress**	**Mean**	**Control**	**Stress**	**Mean**
Rascadam	31.14	28.94	30.04	32.40	30.12	31.26
Kothamallisambha	25.84	22.14	23.99	28.41	21.03	24.72
Kattusambha	23.41	17.58	20.50	27.24	19.56	23.40
Kallundai	28.41	25.36	26.89	32.34	29.41	30.88
Kuliyadichan	32.04	29.36	30.70	32.84	30.21	31.53
Milagusambha	30.12	27.52	28.82	28.64	24.53	26.59
N22	28.56	25.01	26.79	30.84	26.95	28.90
IR64	27.14	15.42	21.28	28.45	17.42	22.94
Mean	28.33	23.92	26.12	30.15	24.90	27.52
	G	T	G x T	G	T	G x T
SEd	0.99	0.49	1.39	1.05	0.52	1.48
CD (0.05)	2.01	1.01	2.85	2.14	1.07	3.02

Closing the stomata to limit transpiration causes an increase in leaf temperature, which leads to an increase in the differential in water vapor pressure between the plant and the air, which reduces transpiration efficiency. Plant respiration may also be increased as a result of this. As a result, increasing water efficiency through stomatal closure is a net positive (Lawlor, 2002). Water stress can also be mitigated by increasing the amount of water available to the plant by reducing transpiration through partial stomatal closure (Alves and Setter, 2000).

The process of water loss from a plant in the form of water vapor from leaves and other aerial components is known as transpiration. As a response to drought stimuli, transpiration is known to decrease under water stress (de Souza *et al*., 2005). Concerning transpiration rate in the present study, a substantial decrease (Table 4) was observed under drought across the landraces. Even though a sharp decline in transpiration rate, the kuliyadichan recorded a lesser reduction in transpiration rate at vegetative state (4.57 %) under drought over its control and it was 40.43, 55.96 per cent in tolerant check N 22 and susceptible check IR 64, respectively. But at reproductive stage drought, the recovery from the water stress was quick in milagusambha which recorded a lesser reduction (6.63 %) in transpiration rate compared to other genotypes. Drought stress in maize resulted in significant decreases in net photosynthesis (33.2 %), transpiration rate (37.8 %), stomatal conductance (25.5 %), water use efficiency (50.8 %), intrinsic water use efficiency (11.5 %), and intercellular CO_2 (5.8 %) when compared to irrigated conditions, according to Anjum *et al.* (2011).

Table 4. Impact of drought stress on transpiration rate (mmol H_2O m^{-2} s^{-1}) in rice genotypes under field condition

Genotypes	Vegetative stage stress			Reproductive stage stress		
	Control	**Stress**	**Mean**	**Control**	**Stress**	**Mean**
Rascadam	12.32	10.43	11.38	14.21	12.31	13.26
Kothamallisambha	12.73	8.52	10.63	12.24	6.73	9.49
Kattusambha	11.55	6.63	9.09	12.82	7.57	10.20
Kallundai	12.85	11.86	12.36	13.68	12.70	13.19
Kuliyadichan	13.14	12.54	12.84	14.26	13.06	13.66
Milagusambha	12.93	12.02	12.48	13.58	12.68	13.13
N22	11.87	7.07	9.47	12.64	6.51	9.58
IR64	12.15	5.35	8.75	13.76	3.45	8.61
Mean	12.44	9.30	10.87	13.40	9.38	11.39
	G	T	G x T	G	T	G x T
SEd	0.42	0.21	0.60	0.45	0.23	0.64
CD (0.05)	0.87	0.43	1.23	0.92	0.46	1.31

In the present study, irrespective of the genotypes and stages, drought stress caused a decrease in stomatal conductance up to 31.75 %. The landrace kuliyadichan recorded higher values (1.07 mol H_2O m^{-2} s^{-1}) for stomatal conductance followed by rascadam (1.06 mol H_2O m^{-2} s^{-1}) and kallundai (0.88 mol H_2O m^{-2} s^{-1}) at the reproductive stage (Table 5). Leaf water potential and stomatal conductance (gs) are correlated under drought, largely as a result of an attempt to conserve available water. Lower Pn can also be attributed to cumulative, non-stomatal, and biochemical effects of stress.

When photosystem II efficiency was assessed in terms of chlorophyll fluorescence, it was discovered that water stress induced during the reproductive stage had a significant impact on PS II efficiency, as evidenced by a decrease in the Fv/Fm ratio in all rice genotypes. Photosystem II (PSII), the photosynthetic apparatus, is important in the response of leaf photosynthesis to environmental stressors, particularly drought stress. The impacts of water stress on the photochemical system were evident in the late stages of stress by considerable declines in PSII's maximum quantum yield coupled with increases in minimum fluorescence levels. These changes could indicate a problem with PSII (Osmond, 1994). Crop photosynthesis is directly reflected in the dynamic changes in chlorophyll fluorescence (Maxwell and Johnson, 2000). In the present study, kuliyadichan was found to be associated with higher PSII efficiency as it had shown a lesser reduction of 6.25 and 13.58 % over control in vegetative and reproductive stages, respectively (Table 6) tolerant check N 22 (17.33, 20.51 %) and susceptible check IR 64 (36.84, 34.62 %). This finding in kuliyadichan is confirmed by prior research by Shangguan *et al.* (2000), which found that PSII is somewhat robust to water shortages, being unaffected (or) only affected under extreme drought conditions (Saccardy *et al.*, 1998). Also, according to Havaux (1992), Photosystem II is more resistant to drought stress than heat stress.

Table 5. Impact of drought stress on stomatal conductance (mol H_2O m^{-2} s^{-1})in rice genotypesunder field condition

Genotypes	Vegetative stage stress			Reproductive stage stress		
	Control	Stress	Mean	Control	Stress	Mean
Rascadam	0.73	0.69	0.71	1.13	1.06	1.10
Kothamallisambha	0.72	0.58	0.65	0.88	0.75	0.82
Kattusambha	0.57	0.45	0.51	0.72	0.58	0.65
Kallundai	0.70	0.67	0.69	0.95	0.88	0.92
Kuliyadichan	0.76	0.72	0.74	1.14	1.07	1.11
Milagusambha	0.68	0.65	0.67	0.88	0.82	0.85
N22	0.62	0.51	0.57	0.79	0.64	0.72
IR64	0.63	0.43	0.53	0.73	0.56	0.65
Mean	0.68	0.59	0.63	0.90	0.80	0.85
	G	T	G x T	G	T	G x T
SEd	0.02	0.01	0.03	0.03	0.02	0.05
CD (0.05)	0.05	0.02	0.07	0.07	0.03	0.09

Table 6. Impact of drought stress on Fv/Fm in rice genotypes under field condition

Genotypes	Vegetative stage stress			Reproductive stage stress		
	Control	Stress	Mean	Control	Stress	Mean
Rascadam	0.81	0.70	0.76	0.81	0.67	0.74
Kothamallisambha	0.74	0.53	0.64	0.78	0.56	0.67
Kattusambha	0.72	0.55	0.64	0.76	0.52	0.64
Kallundai	0.77	0.69	0.73	0.80	0.67	0.74
Kuliyadichan	0.80	0.75	0.78	0.81	0.70	0.76
Milagusambha	0.79	0.70	0.75	0.80	0.68	0.74
N22	0.75	0.62	0.69	0.78	0.62	0.70
IR64	0.76	0.48	0.62	0.78	0.51	0.65
Mean	0.77	0.63	0.70	0.79	0.62	0.70
	G	T	G x T	G	T	G x T
SEd	0.03	0.01	0.04	0.03	0.01	0.04
CD (0.05)	0.05	0.03	0.08	0.05	0.03	0.08

Considering the above results of this experiment, it is concluded that rice landraces, being adapted to harsh environments, have the inherent ability to withstand drought situations. And Kuliyadichan, Rascadam, and Milagusamba performed better in terms of physiological parameters like photosynthetic rate, stomatal conductance, transpiration rate, and Fv/Fm ratio which ultimately contributed to better tolerance compared to other landraces and check varieties taken for this study. Hence, the traits which are conferring better tolerance in these landraces may be studied further to unravel the actual mechanisms responsible for drought tolerance and to exploit these traits for the crop improvement program.

Author contributions

All the authors contributed to the article and approved the submitted version.

Compliance with ethical standards

Yes

Conflict of interests

No commercial or financial relationships that could be construed as a potential conflict of interest.

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Short Communication

Differential response of wheat cultivars to grain damage by Rice Weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae)

Rohit Kumar, Surender Singh Yadav, Sunita Yadav, Puneet Ranga, Harish Kumar and Vikram Singh[1]

Department of Entomology, CCS Haryana Agricultural University, Hisar-125004 (Haryana)
[1]Department of Genetics & Plant Breeding, CCS Haryana Agricultural University, Hisar-125004 (Haryana)

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****Corresponding author:*** *E-mail: puneet98114@hau.ac.in*

In India, post-harvest losses of about 10.0 per cent of total food grains have been reported due to unscientific storage, rodents, insect-pests, micro-organisms etc. In India as much as 25% losses in food grains have been estimated to occur during storage and 4.93% in case of wheat only (Jha *et al.,* 2015). Stored product pests have the capacity to infest both raw and processed agricultural products. More than a dozen stored grain pests attack wheat and other cereals in storage. Among these the weevils *viz.,* rice weevil, *Sitophilus oryzae* (L.), grain weevil, *S. granarius* (L.) and maize weevil, *S. zeamais* (M.) are classified as the most important primary pests of stored wheat (Rees, 2004; Beckett *et al.*, 2007). Among weevils, rice weevil has been identified as most widespread and destructive one. This weevil species has a relatively short developmental period and hence its high populations can build up in a short duration (Aitken, 1975). It is an internal feeder which feeds by boring into the grains. Adults of the weevil feed preferentially on the endosperm and thus reducing the carbohydrate content but larvae feed mainly on the germ portion of the grains and remove proteins and vitamins (Belloa, *et al.*, 2000). This weevil is able to cause losses to the tune of up to 80% under prolonged storage conditions (Park *et al.*, 2004). Grain damage in wheat due to *S. oryzae* was found to be as much as 27.16 ± 10.31 per cent (Mehta *et al.*, 2021). Damage to grains by the larvae makes them prone to infestation by secondary feeders and pathogens, thereby leading to increased damage to the grains.

The prevention of losses in stored grains due to insect-pests is of paramount importance. Among various means and methods of preventing grain damage from insects is developing resistant and tolerant varieties (Kumar *et al.*, 2019). The screening of different varieties of wheat against *S. oryzae* can be a very effective tool in the management of this stored grain pest as the different varieties shows different level of susceptibility (Tiwari and Sharma, 2002). Sarin and Sharma (1983) have revealed that all the stored grain pests exhibit the phenomenon of preference and non-preference for the grains of different varieties. A number of varieties have exhibited resistance to *S. oryzae* in lab experiments (Swamy *et al.*, 2014). There has been little emphasis in breeding for grain resistance to insect pests of stored grain products. This aspect can be achieved by screening the various varieties available for cultivation in different region of the country. As far as the susceptibility of different varieties of wheat to *S. oryzae* is concerned, very scanty literature is available. Keeping the above facts in view, investigations were carried out by screening of different varieties of wheat for ovipositional preference (choice and no choice test), adult emergence and grain damage (number and weight basis). The data collected from present study will help in identifying resistant and susceptible reactions of selected wheat varieties against *S. oryzae*, which can also be useful in further breeding programme.

The present investigations on rice weevil with reference to screening of different varieties of wheat for ovipositional preference (choice and no choice test), adult emergence and grain damage (number and weight basis) were carried out at Department of Entomology, CCSHAU, Hisar during August to October 2017 in laboratory conditions. The minimum and maximum temperature during the period of study ranged from 20.64 to 35.73°C. The morning and evening relative humidity varied from 82 to 58 per cent during the period. The healthy, clean, genetically pure, disease and insect free grains of fifteen varieties of wheat *viz.,* WH1105, WH1124, WH1142, WH283, WH542, WH711, WH1080, WH1025, WH157, DBW17, DPW62150, HD2967, PBW343, C306 and WH147 were procured from the Wheat & Barley Section, Department of Genetics and Plant Breeding, CCSHAU, Hisar. These varieties were further examined to remove foreign material, if any.

The adults of *S. oryzae* were collected from granaries of wheat from local market to initiate stock culture. The collected adults of rice weevil were identified and released in the plastic containers of two litre capacity along with wheat grains. The stock culture was maintained on wheat variety WH1105. For the development of weevils, fresh grains were provided periodically as and when required. Males and females were identified on the basis of form of rostrum. In male weevils, it was comparatively thick, rough and less curved whereas in female, it was thin, shining and slightly curved. In lateral view, the pygidium of the female was found to be straight whereas it was conspicuously curved in male. The details of different methodologies used were furnished as hereunder.

The adults of *S. oryzae* were collected from granaries of wheat from local market to initiate stock culture. The collected adults of rice weevil were identified and released in the plastic containers of two litre capacity along with wheat grains. The stock culture was maintained on wheat variety WH 1105 providing fresh grains as and when required. Males and females were identified on the basis of rostrum structure. For oviposition preference tests, 50 g wheat grains of each variety were taken in ovipositional cage (for choice test) and in separate 250 g capacity containers (for no choice test) with three replications each. The number of pairs of adults released was 100 and 5, respectively for choice test and no choice test. A total of 250 grains of each variety were selected randomly and observations on total number of eggs deposited on grains of each variety were recorded at 15, 30 and 45 days after infestation in both the tests. Similarly, the adult emergence was recorded by releasing newly emerged five pairs of rice weevils in 250 g capacity plastic containers having 50 g wheat grains with three replications separately for each variety. Observations on the number of adult emerged were recorded after 30, 45 and 60 days after release of weevils. The newly emerged adults were counted and these were removed regularly to check further breeding. Adult emergence was recorded to find out the host preference for breeding. Grain damage (%) and weight loss (%) was assessed from 250 grains of each variety after 30, 45 and 60 days of release by using the below formulae:

$$\text{Grain damage (\%)} = \frac{\text{Number of damaged grains}}{\text{Total number of grains used}} \times 100$$

The grain damage on weight loss basis (%) was estimated by the following formula suggested by Adams and Schulten (1978) with the help of single pan electric balance.

$$\text{Weight loss (\%)} = \frac{(Wu \times Nd) - (Wd \times Nu)}{Wu \times (Nd + Nu)} \times 100$$

(Wu-Weight of undamaged grains, Nu-Number of undamaged grains, Nd- Number of damaged grains, Wd-Weight of damaged grains).

Under both choice test and no choice tests, WH 1105 and C 306 exhibited minimum ovipositional preference for *S. oryzae* as well as minimum adult emergence of 66.68 adults and 76.01 adults emerging from 250 grains of C 306 and WH 1105, respectively. The grain damage (%) was also found to be minimum in theses cultivars with damage of 14.12% (C 306) and 15.11% (WH 1105). Similar trend was found in weight loss (%) due to infestation in C 306 (5.65%) and WH 1105 (6.19%).

Varieties WH147 and DPW62150 were found to be preferred by *S. oryzae* with ovipositioning to the tune of 368.78 and 321.89 eggs/250grains. Adult emergence was also maximum in these varieties with adult emergence of 118.33 adults and 112.01 adults emerging from 250 grains of WH147 and DPW62150, respectively. WH147 exhibited maximum grain loss (%) and weight loss (%) with losses 25.53 and 9.84, respectively. According to Gomez *et al.* (1982) the chemical factors may be responsible for the avoidance of the adult female to lay eggs on the wheat grains. The current findings are in support with those of Arve *et al.* (2014) who reported that the number of eggs laid on different varieties varied from 146.00 to 407.83 and 194.33 to 318.50 eggs under free choice and no choice test, respectively. Earlier, Khan *et al.* (2014) and Pradeep *et al.* (2015) observed the similar trend of increase in population of adult with the increase in storage period on wheat and sorghum, respectively. Khan and Halder (2012) also observed that population of adult rice weevil increased gradually as the increase in storage period. The current findings are parallel with those of Khan *et al.* (2014), Pradeep *et al.* (2015) who observed that the per cent grain damage of *S. oryzae* increased with the duration of storage progressed. Adams (1976) revealed that *S. oryzae* caused 18.30 per cent losses to stored grains. Mehta *et al.* (2021) reported the grain damage due to *S. oryzae* in wheat in the tune of 9.92±4.85 to 27.16±10.31 per cent, whereas the weight loss (%) due to infestation was found to be in the range of 2.66±0.53 to 14.82±0.38. The findings of Tiwari *et al.* (1989) and Laskar and Ghosh (2004) on per cent grain damage and weight loss in different varieties of wheat due to *S. oryzae* also support the present findings.

Different varieties exhibit differential response to insect pests and on the basis of studies it can be concluded that the wheat cultivars WH1105, WH1124, WH1142 and C306 are least preferred by *S. oryzae* on the basis of their ovipositional preference, adult emergence and infestation levels on different wheat cultivars under consideration.

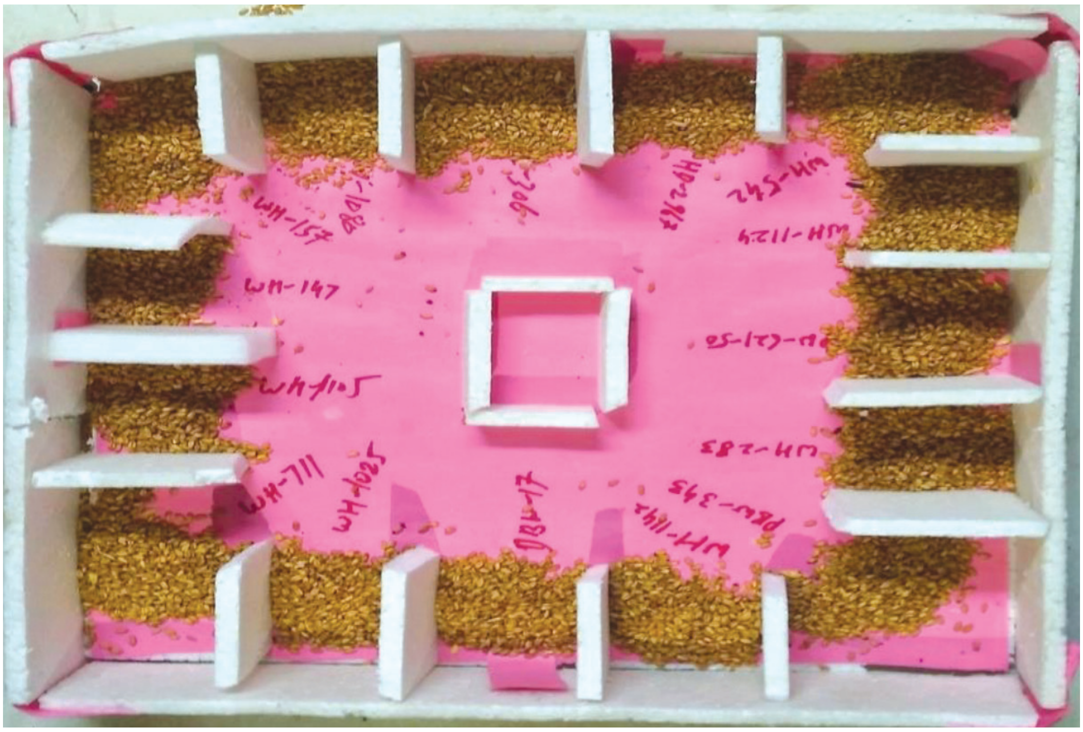

Fig 1. Ovipositional cage for performing choice test

Table 1. Ovipositional preference of rice weevil, *S. oryzae* on different varieties of wheat under choice and no choice conditions

Variety	**Ovipositional preference (No. of eggs laid/250 grains)**							
	Choice conditions				**No choice conditions**			
	15 DAI*	**30 DAI**	**45 DAI**	**Mean**	**15 DAI**	**30 DAI**	**45 DAI**	**Mean**
WH 1105	185.00 (13.64)**	184.33 (13.61)	207.33 (14.43)	**192.22 (13.89)**	184.33 (13.60)	176.00 (13.30)	191.00 (13.84)	**183.78 (13.58)**
WH 1124	249.33 (15.79)	238.00 (15.44)	246.67 (15.73)	**244.67 (15.65)**	206.00 (14.39)	204.00 (14.31)	215.67 (14.72)	**208.56 (14.47)**
WH 1142	199.33 (14.15)	193.67 (13.95)	204.00 (14.31)	**199.00 (14.39)**	202.33 (14.25)	206.00 (14.38)	210.33 (14.51)	**206.22 (14.38)**
WH 283	285.00 (16.88)	275.00 (16.60)	279.33 (16.74)	**279.78 (16.74)**	251.67 (15.88)	249.67 (15.83)	259.33 (16.14)	**253.56 (15.95)**
WH 542	252.33 (15.90)	277.33 (16.67)	282.33 (16.80)	**270.66 (16.46)**	222.33 (14.92)	234.67 (15.34)	247.67 (15.76)	**234.89 (15.34)**
WH 711	274.00 (16.58)	262.00 (16.21)	265.67 (16.30)	**267.22 (16.36)**	270.00 (16.44)	264.67 (16.29)	267.00 (16.36)	**267.22 (16.36)**
WH 1080	288.67 (17.02)	277.33 (16.68)	286.67 (16.95)	**284.22 (16.88)**	243.00 (15.61)	248.67 (15.80)	264.67 (16.30)	**252.11 (15.90)**
WH 1025	207.33 (14.40)	206.33 (14.36)	214.00 (14.65)	**209.22 (14.47)**	250.67 (15.85)	261.33 (16.18)	277.33 (16.67)	**263.11 (16.23)**
WH 157	292.00 (17.11)	285.33 (16.91)	289.33 (17.02)	**288.89 (17.01)**	233.67 (15.31)	222.33 (14.90)	234.67 (15.34)	**230.22 (15.18)**
DBW 17	258.33 (16.10)	264.67 (16.30)	285.33 (16.91)	**269.44 (16.44)**	262.67 (16.22)	256.67 (16.04)	264.33 (16.25)	**261.22 (16.17)**
DPW 62150	330.33 (18.20)	318.67 (17.87)	316.67 (17.82)	**321.89 (17.96)**	302.33 (17.41)	288.00 (16.99)	300.67 (17.34)	**297.00 (17.25)**
HD 2967	203.67 (14.30)	211.33 (14.54)	213.67 (14.65)	**209.56 (14.50)**	254.33 (15.97)	254.33 (15.98)	256.33 (16.03)	**255.00 (15.99)**
PBW 343	288.67 (17.01)	275.33 (16.61)	291.33 (17.09)	**285.11 (16.90)**	315.33 (17.78)	311.33 (17.67)	318.67 (17.88)	**315.11 (17.78)**
C 306	161.67 (12.72)	160.00 (12.69)	178.33 (13.39)	**166.67 (12.93)**	187.67 (13.73)	190.33 (13.83)	208.00 (14.42)	**195.33 (13.99)**
WH 147	378.67 (19.47)	359.00 (18.97)	368.67 (19.23)	**368.78 (19.22)**	311.67 (17.68)	300.67 (17.34)	312.67 (17.68)	**308.34 (17.57)**
Mean	**256.95 (15.95)**	**252.55 (15.83)**	**261.95 (16.13)**	257.16 (15.99)	**246.53 (15.67)**	**244.58 (15.61)**	**255.27 (15.95)**	**248.78 (15.74)**
C.D. (P=0.01)	**(1.43)**	**(1.26)**	**(1.21)**	**(0.97)**	**(1.27)**	**(1.19)**	**(1.42)**	(0.52)

* DAI – days after infestation **Figures in the parentheses are square root transformed values

Table 2. Adult emergence of rice weevil, *S. oryzae* on different varieties of wheat

Variety	Adult emergence (adults/50 g wheat grains)			
	30 DAI*	**45 DAI**	**60 DAI**	**Mean**
WH 1105	0.00	47.67 (6.98)	104.33 (10.26)	**76.01 (7.69)**
WH 1124	0.00	57.67 (7.68)	111.67 (10.60)	**84.68 (9.14)**
WH 1142	0.00	57.33 (7.64)	110.33 (10.53)	**83.84 (9.09)**
WH 283	0.00	62.67 (7.98)	132.00 (11.53)	**97.33 (9.75)**
WH 542	0.00	63.67 (8.03)	115.67 (10.80)	**89.67 (9.42)**
WH 711	0.00	63.33 (8.02)	132.33 (11.54)	**97.83 (9.78)**
WH 1080	0.00	64.67 (8.10)	135.67 (11.68)	**100.17 (9.88)**
WH 1025	0.00	59.00 (7.74)	139.67 (11.84)	**99.33 (9.79)**
WH 157	0.00	65.33 (8.14)	142.33 (11.97)	**103.83 (10.05)**
DBW 17	0.00	59.00 (7.74)	151.67 (12.35)	**105.33 (10.05)**
DPW 62150	0.00	64.00 (8.06)	160.00 (12.67)	**112.01 (10.36)**
HD 2967	0.00	54.67 (7.45)	127.33 (11.17)	**91.01 (9.31)**
PBW 343	0.00	66.00 (8.18)	156.33 (12.54)	**111.17 (10.36)**
C 306	0.00	43.67 (6.68)	89.67 (9.52)	**66.68 (8.10)**
WH 147	0.00	71.00 (8.48)	165.67 (12.91)	**118.33 (10.69)**
Mean	**0.00**	**59.98 (7.78)**	**131.64 (11.46)**	95.82 (9.56)
C.D. (P=0.01)	--	**(0.44)**	**(0.76)**	(0.47)

*DAI – days after infestation ; **Figures in the parentheses are square root transformed values.

Table 3. Grain damage and weight loss (%) by rice weevil, *S. oryzae* (L.) on different varieties of wheat

Variety	Grain damage (%)				Weight loss (%)			
	30 DAI*	**45 DAI**	**60 DAI**	**Mean**	**30 DAI**	**45 DAI**	**60 DAI**	**Mean**
WH 1105	6.27 (14.47)**	13.47 (21.51)	25.60 (30.38)	**15.11 (22.12)**	2.89(9.79)	5.47 (13.49)	10.21 (18.85)	**6.19 (14.04)**
WH 1124	7.40 (15.70)	17.07 (24.39)	30.80 (33.69)	**18.42 (24.59)**	3.19 (10.31)	5.99 (14.16)	11.86 (20.13)	**7.01 (14.87)**
WH 1142	7.52 (15.80)	13.87 (21.85)	26.93 (31.24)	**16.10 (22.96)**	3.22 (10.35)	6.31 (14.54)	11.39 (19.71)	**6.97 (14.86)**
WH 283	7.87 (16.28)	20.67 (27.02)	36.53 (37.17)	**21.69 (26.82)**	3.91 (11.40)	7.07 (15.42)	14.17 (22.10)	**8.38 (16.30)**
WH 542	7.87 (16.28)	22.53 (28.33)	32.27 (34.60)	**20.89 (26.40)**	3.75 (11.11)	6.93 (15.25)	13.27 (21.33)	**7.98 (15.90)**
WH 711	7.73 (16.13)	22.00 (27.94)	34.40 (35.89)	**21.38 (26.65)**	3.60 (10.93)	6.60 (14.88)	13.59 (21.61)	**7.93 (15.81)**
WH 1080	7.43 (15.72)	21.07 (27.31)	33.86 (36.14)	**20.79 (26.39)**	3.73 (11.05)	6.42 (14.66)	12.36 (20.57)	**7.50 (15.43)**
WH 1025	7.81 (16.20)	20.80 (27.12)	37.20 (37.57)	**21.94 (26.96)**	3.95 (11.46)	6.10 (14.29)	12.14 (20.38)	**7.40 (15.38)**
WH 157	7.60 (15.95)	21.20 (27.39)	35.60 (36.61)	**21.47 (26.65)**	4.05 (11.61)	7.76 (15.41)	14.56 (22.43)	**8.79 (16.48)**
DBW 17	7.47 (15.84)	19.73 (26.35)	32.93 (35.01)	**20.04 (25.73)**	4.03 (11.57)	7.25 (15.61)	14.19 (22.12)	**8.49 (16.43)**
DPW 62150	8.67 (17.10)	22.27 (28.13)	36.00 (36.86)	**22.31 (27.36)**	4.86 (12.72)	8.12 (16.55)	15.47 (23.14)	**9.48 (17.47)**
HD 2967	6.93 (15.25)	19.60 (26.26)	32.13 (34.52)	**19.55 (25.34)**	3.24 (10.36)	6.68 (14.97)	11.53 (19.84)	**7.15 (15.06)**
PBW 343	8.40 (16.83)	23.73 (29.14)	37.86 (37.96)	**23.34 (27.98)**	4.24 (11.87)	8.01 (16.43)	15.51 (23.17)	**9.25 (17.16)**
C 306	5.87 (13.98)	11.70 (19.90)	24.80 (29.85)	**14.12 (21.25)**	2.64 (9.34)	5.22 (13.20)	9.10 (17.54)	**5.65 (13.36)**
WH 147	9.64 (18.05)	25.47 (30.29)	41.47 (40.07)	**25.53 (29.47)**	5.02 (12.94)	8.53 (16.97)	15.96 (23.99)	**9.84 (17.96)**
Mean	7.63 (15.97)	19.68 (26.19)	33.23 (35.17)	20.18 (25.78)	**3.75 (11.12)**	**6.83 (15.05)**	**13.02 (21.06)**	**7.87 (15.77)**
C.D. (P=0.01)	(1.71)	(1.63)	(1.33)	(1.75)	(0.92)	(0.94)	(1.37)	(0.62)

*DAI – days after infestation; **Figures in the parentheses are square root transformed values.

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Compliance with ethical standards

NA

Conflict of Interest

The authors declare that they have no conflict of interest.

Author contributions

RK, SSY, SY & VS designed the experiments; VS helped in procuring the grains of wheat varieties, RK & PR collected & analysed the data and prepared the manuscript: SSY & HK helped in preparing the final version of the manuscript.

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Short Communication

Effect of dolomite and calcite on growth, yield and economics of rice in strongly acidic soils of Kanyakumari district

David Israel Mansingh[1] and S Suresh[2]

[1]*Department of Soils and Environment, Tamil Nadu Agricultural University, Madurai 625 104.*
[2]*Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Killikulam 628252.*

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****Corresponding author:*** *E-mail: mansinghdavid@gmail.com*

Rice (*Oryza sativa* L.) is one of the chief grains of India. India is the world's first producer of rice and the largest exporter of rice in the world. In India the rice cultivated area with 45.8mha, production with 124.37 mt and average productivity of 2.72 t ha^{-1} (Indiastat, 2021). The country increased production from 53.6 million tons in financial year 1980 to 120 million tons in financial year 2020-21 (Ministry of Agriculture and Farmers Welfare, India, 2021). In Tamil Nadu the rice cultivated area with 2.04 mha, production with 6.88 mt and average productivity of 3.38 t ha^{-1} (Indiastat, 2021). Rice crop has got wide physical adaptability. Hence, it is grown on diverse soil, climatic and hydrological conditions. Demand for rice is growing every year. To sustain present self-sufficiency of food and to meet future food requirements, India has to increase rice yield per unit area. Soil acidity is an important yield limiting factors for crop production. In India acid soils occupy about 49 m ha area, of which 26 m ha has pH below 5.5 and 23 m ha has pH between 5.6 and 6.5 (Behera and Shukla, 2015). Acid soils exhibit both nutrient deficiency and toxicity, leading to restricted plant growth. Soil acidity affects the resources, goods, and services offered by the soils for human beings (Mol and Keesstra, 2012) and thereby reduce the sustainability which needs to be corrected by proper management decisions. Correcting soil acidity with proper amendments and addition of required nutrients are important to achieve a higher yield of crops. Addition of different amendments improves soil pH and thereby the availability of nutrients (Moon *et al.,* 2014). Use of liming materials like calcite ($CaCO_3$) and dolomite ($CaCO_3.MgCO_3$) is a practical way for correction of soil acidity (Goulding, 2016). It has been the traditional material used for acid soils. Liming increases the soil pH, improves the availability of plant nutrients and crop growth, increases nutrient uptake, stimulates biological activity, decreases soil acidity and reduces the toxicity of some elements (Reddy and Subramanian, 2016).

The application of dolomite and calcite is potential and cost effective in reducing soil acidity. The present investigation was carried out to study the amelioration capacity of dolomite and calcite in strongly acidic soil and its influence on growth, yield and economics of rice crop. A field experiment was conducted in farmers' fields at Gananadhasapuram village of Thovalai taluk (strongly acidic soil) during *Pishanam* season, Kanyakumari district, Tamil Nadu with test crop of rice (TPS 3) to study the effect of dolomite and calcite on growth, yield and economics of rice in strongly acidic soils. The experiment was laid out in randomized block design with three replications and ten treatments. The treatment combinations include, treatment T_1 is absolute control, the treatment T_2 was the application of recommended dose of fertilizers with $ZnSO_4$ @ 25 Kg ha^{-1}, For the treatments from T_3, T_5, T_7 and T_9, dolomite at different levels based on lime requirements 0.25 LR (2.12 and 0.8 t ha^{-1}) (T_3), 0.50 LR (4.24 and 1.6 t ha^{-1}) (T_5), 0.75 LR (6.36 and 2.4 t ha^{-1}) (T_7) and 1.0 LR (8.48 and 3.2 t ha^{-1}) (T_9), respectively for pishanam season along with recommended dose of fertilizers and $ZnSO_4$ was tested. For the treatments T_4, T_6, T_8 and T_{10}, calcite at different levels based on lime requirement 0.25 LR (2.32 and 0.88 t ha^{-1}) (T_4), 0.50 LR (4.63 and 1.76 t ha^{-1}) (T_6), 0.75 LR (6.95 and 2.64 t ha^{-1}) (T_8) and 1.0 LR (9.25 and 3.22t ha^{-1}) (T_{10}) during pishanam season along with recommended dose of N, P, K fertilizers and $ZnSO_4$ was tested. The experimental plot size was 4 x 3 m. Soil samples collected from field before cultivation of rice were analyzed for pH – 5.1 (Jackson, 1973), organic carbon – 4.5 per cent (Walkley and Black, 1934), available N– 210 Kg ha^{-1} (Subbiah and Asija, 1956), phosphorus – 8.4 Kg ha^{-1} (Jackson, 1973), potassium– 107 Kg ha^{-1} (Stanford and English, 1949), exchangeable Ca - 2.3 and Mg – 3.4 c mol (p^+) Kg^{-1} (Jackson, 1973) and lime requirement (Shoemaker *et al.,* 1961) by using standard procedures. Randomised Block design (RBD) and analysis of variance (ANOVA) was adopted for statistical analysis and interpretation of the data. Five plants from each plot were selected at random, tagged and growth and yield parameters were recorded. The grains collected from the net plot area of different treatments were dried, threshed and after drying grain yield was recorded at 12 per cent moisture from each plot and expressed as Kg ha^{-1}. The straw yield from each plot was also recorded. The net return was worked out for all the treat mental combinations. The cost of inputs, labour charges and prevailing market rates of farm produce were taken into consideration for working out the economics. Cost benefit analysis were worked out for all the treatments. The data collected were statistically analyzed as suggested by Gomez and Gomez (2010).

The data pertaining to the effect of liming and fertilizers application on the growth parameters *viz.,* plant height and number of tillers m^{-2} at tillering, active tillering, panicle initiation and at harvest of rice is presented in Table 1. During pishanam season dolomite, calcite and fertilizers application significantly increased the plant height and number of tillers m^{-2} of rice at tillering, active tillering, panicle initiation and at harvest stage. Significant difference in plant height was absorbed at the critical crop growth stages of rice. The highest plant height (36.9, 55.1, 75.4 and 100 cm) and number of tillers m^{-2} (298, 325, 396 and 411) at tillering, active tillering, panicle initiation and at harvest stages respectively, during pishanam season in the strongly acidic soil was recorded by the application of RDF + $ZnSO_4$ @ 25 Kg ha^{-1} + dolomite (0.75 LR) (T_7) followed by the application of RDF + $ZnSO_4$ @ 25 Kg ha^{-1} + calcite (0.75 LR) (T_8). This increase in growth parameters may be attributed to the improvement in nutrients availability in soil during growth period of rice upon 75% of LR of dolomite application in strongly and acidic soils due to maintenance of optimum pH for higher productivity of rice. The improved supply of nutrients to plants due to liming might have resulted in acceleration of photosynthesis process, carbohydrates metabolism, protein synthesis, synthesis of growth promoting substances, cell division and cell elongation which resulted in increase of plant height and number of tillers m^{-2}. The findings were supported by Ferdous *et al.* (2018). The yield contributing characters such as number of productive tillers m^{-2}, thousand grain weight and grain and straw yield were influenced significantly due to application of dolomite and calcite, NPK fertilizers and $ZnSO_4$ (Table 2).

In the present study, the application of dolomite and calcite had significantly exhibited its superiority to increase the number of productive tillers m^{-2}, thousand grain weight, grain and straw yield of rice. The highest productive tillers m^{-2} (375), thousand grain weight (26.6 g), grain (7.09 t ha^{-1}) and straw yield (10.3 t ha^{-1}) of rice was recorded with RDF + 25 Kg $ZnSO_4$ + Dolomite @ 0.75 LR (T_7) followed by T_8 (356, 26.2 g, 6.85 and 8.53 t ha^{-1} of productive tillers m^{-2}, thousand grain weight, grain and straw yield respectively), which received RDF + 25 Kg $ZnSO_4$ + Calcite @ 0.75 LR in the pishanam season.

The yield benefits can be ascribed to the increase in soil pH upon dolomite and calcite along with the associated improvement in nutrients availability, reduced Fe availability and many other attributes of soil fertility (Manoj-Kumar *et al.,* 2012; Singroha *et al.,* 2022). The application of dolomite and calcite in acid soil significantly increased the yield. The above results are in agreement with the findings of Crusciola *et al.* (2010), Osundwa *et al.* (2013) and Arenjungla *et al.* (2021).

Table 1. Effect of dolomite and calcite on growth attributes during the growth stages of rice

Treatments	Plant height (cm)				Number of tillers m^{-2}			
	Tillering	**Active tillering**	**Panicle initiation**	**Harvest**	**Tillering**	**Active tillering**	**Panicle initiation**	**Harvest**
T_1 - Control	20.6	37.4	55.8	76.1	189	204	254	282
T_2 - RDF + $ZnSO_4$ @ 25 Kg ha^{-1}	33.0	50.6	70.8	91.4	246	255	303	382
T_3 - T_2 + Dolomite (0.25 LR)	33.4	51.6	72.6	93.9	266	292	318	352
T_4 - T_2 + Calcite (0.25 LR)	33.2	51.1	72.7	93.5	253	281	311	337
T_5 - T_2 + Dolomite (0.50 LR)	34.7	52.9	74.7	96.9	280	303	329	370
T_6 - T_2 + Calcite (0.50 LR)	34.6	52.7	73.6	95.7	266	300	326	363
T_7 - T_2 + Dolomite (0.75 LR)	36.9	55.1	75.4	100	298	325	396	411
T_8 - T_2 + Calcite (0.75 LR)	35.9	54.1	74.5	99.0	293	314	344	381
T_9 - T_2 + Dolomite (1.0 LR)	29.7	48.9	67.6	91.2	226	252	274	326
T_{10} - T_2 + Calcite (1.0 LR)	27.5	44.9	66.1	90.8	200	226	270	311
SEd	0.70	1.32	1.25	2.33	28.6	17.5	12.7	10.2
CD (P=0.05)	1.5	2.8	2.6	4.9	60.0	37.0	27.0	21.0

CD = Critical difference; SEd = Standard error of deviation

Table 2. Effect of dolomite and calcite on yield attributes and yields of rice

Treatments	**No. of Productive tillers m^{-2}**	**Thousand grain weight (g)**	**Grain yield (t ha^{-1})**	**Straw yield (t ha^{-1})**
T_1 - Control	280	23.5	2.46	4.24
T_2 - RDF + $ZnSO_4$ @ 25 Kg ha^{-1}	318	25.1	4.59	7.79
T_3 - T_2 + Dolomite (0.25 LR)	332	25.7	5.25	8.03
T_4 - T_2 + Calcite (0.25 LR)	323	25.3	4.97	8.02
T_5 - T_2 + Dolomite (0.50 LR)	352	26.1	6.33	8.11
T_6 - T_2 + Calcite (0.50 LR)	337	25.9	5.66	8.10
T_7 - T_2 + Dolomite (0.75 LR)	375	26.6	7.09	10.3
T_8 - T_2 + Calcite (0.75 LR)	356	26.2	6.85	8.53
T_9 - T_2 + Dolomite (1.0 LR)	304	24.7	4.39	7.06
T_{10} - T_2 + Calcite (1.0 LR)	295	24.6	3.85	6.45
SEd	11.2	0.48	0.19	0.07
CD (P=0.05)	23.5	1.0	0.40	0.20

CD = Critical difference; SEd = Standard error of deviation

Higher crop productivity with lesser cost of cultivation could result in better economic parameters like net returns and B:C ratio. The identified treatment should be economically viable so that farmers can to sustain the higher income. The cost of cultivation, gross return, net return and B:C ratio were worked out for the different treatments in terms of soil management and fertilizers application in acidic soil (Fig. 1). The maximum and economic yield with high net return and B:C ratio (Rs. 54, 018 and 1.86, respectively) was recorded with application of dolomite @ 0.75 LR along with RDF and $ZnSO_4$ (T_7) in the strongly acidic soil (pH 5.1). The high economic return could be realized if liming is applied in acidic soil was also reported by Kumar *et al.* (2014) and Kumar (2015). From this study, it can be concluded that application of dolomite @ 0.75 LR (6.36 t ha^{-1}) (T_7) along with recommended dose of fertilizers and $ZnSO_4$, could be considered as a better option for achieving higher productivity of rice and profitability of strongly acidic soils in the high rainfall zone of Kanyakumari district.

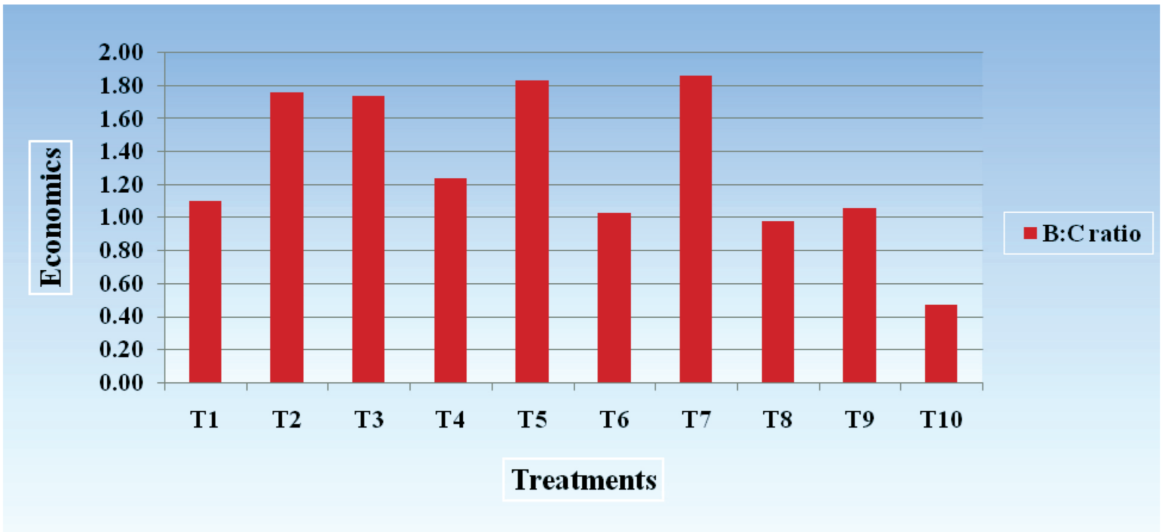

Fig 1. Effect of dolomite and calcite on benifit: bost ratio of treatments

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Authors, contributions

Designing of experiment, data collection, analysis and preparation of manuscript has been done by both the authors.

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Short Communication

Evaluating the effect of bio-fertilizers in mitigating GHGs in puddled rice (*Oryza sativa.* L)

Chelvi Ramessh[1], R Durai Singh[2], P Kannan[3] and R Surya[4*]

Agricultural College & Research Institute, Tamil Nadu Agricultural University, Madurai.

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***Corresponding author:** *E-mail: suryar275@gmail.com*

Rice (*Oryza sativa* L.) is the important cereal food grain crop grown extensively in tropical and sub-tropical region of the world (Kumar *et al.*, 2014). The staple food for more than 50% of the world's population is rice. Rice is raised over 114 countries and accounts for nearly 11% of the world's agricultural land. India ranks first in terms of area (45.1 M ha) and second in production (104.80 million tones) behind China. To meet the demand by 2050, India must produce roughly 140 million tonnes of rice (Statista, 2021). With 50 and 60 per cent of CH_4 and N_2O emissions coming from agriculture (Rivera JE and Chará, 2021), it is thought to be a significant source of GHGs. Methane (CH_4) and nitrous oxide are two of the main GHGs that are emitted when rice is conventionally transplanted (N_2O). It has been determined that rice fields are a significant source of CH_4, accounting for 11% of CH_4 emissions worldwide (Smith *et al.,* 2007). Furthermore, there are variances in the quantity of greenhouse gas emissions from various rice establishment techniques. Emission of GHGs from rice fields is very sensitive to rice management strategies. Bio-fertilizers proved to be a promising option for rice production, besides, have the advantages of lowering the methane emission in transplanted rice. Hence, a study has been conducted to quantify the GHG emission and mitigation potential of BGA (Cyanobacteria) and Azolla in puddled rice.

The field experiment was conducted at Agricultural College & Research Institute, Madurai during *samba*, 2021 in C block and Field Number 47. The experimental soil was sandy clay loam in texture with alkaline pH (8.14) and EC (0.2 dSm^{-1}). Soil organic carbon was medium (0.5%) in status and soil available nitrogen was found to be low (206 Kg ha^{-1}), whereas, the available phosphorous (35.2 Kg ha^{-1}) and potassium (358 Kg ha^{-1}) were high in the experimental soil.In this study, the treatments *viz*,T_1 : SRI method of rice cultivation with organic farming standard of package , T_2 : SRI method of rice cultivation with inorganic farming standard of package SOP, T_3 : T_1+BGA application @ 10 Kg ha^{-1}, T_4 : T_2+ BGA application @ 10 Kgha^{-1},T_5 -T_1+*Azolla* application @ 250 Kg ha^{-1},T_6 -T_2+ *Azolla* application @ 250 Kg. were arranged in Randomized Block Design with four replications using the variety, ADT 54 with a plot size of 5×4 m. Seeds were soaked with *Bacillus subtilis* @ 10 g, *Azospirillum* @ 30 g and Phosphobacteria @30 g per Kg of seeds. Well decomposed FYM @ 1.25 Kg, neem cake @ 50 g and gypsum @ 100 g per m^2 were applied as basal 10 days after sowing. Green manure crop (*Sesbania aculeata*) was raised before rice transplanting and incorporated in-situ at flowering stage.

It was followed by application of neem cake @ 250 Kg ha^{-1} and Gypsum @ 500 Kg ha^{-1}as basal. Seedlings were dipped with *Azospirillum* (1 Kg ha^{-1}) + *Phosphobacteria* (1 Kg ha^{-1}) in 40 liters of water for 15-30 minutes before transplanting. CH_4 and N_2O flux were determined using the IRGA Sensor closed-chamber technique. The closed chamber in this system contains a small infrared CO_2 gas analyzer. This system does not need air tubes or pumps for circulating air, so it is expected to offer the advantages of mobility and durability. This system was verified by a comparison with measurements made by using a closed-dynamic-chamber (CDC) system. Gas sampling began at active tillering and flowering stages. The accumulated gases inside the chambers were collected using 100 mg plastic syringes after one hour of chamber closure and followed by infusion into an empty aluminum foil gas collecting bag. The sampling time was between 9:00 a.m. and10:00 a.m. during each sampling day. The gas samples were transported to the laboratory for analysis by gas chromatography within a few hours. The concentrations of CH_4 and N_2O were analyzed with a gas chromatograph meter equipped with an electron capture detector for N_2O analysis and a flame ionization detector for CH_4 analysis. The plant height was measured from the ground level to the tip of the top most fully opened leaf or flag leaf at active tillering and panicle initiation stages, while, at harvest stage, it was measured up to the tip of the panicle. The mean values were expressed in cm. Four 0.25 m^{-2} quadrants were randomly placed in each net plot, and the total number of tillers was counted at tillering, panicle initiation, and harvest stages and expressed as No. m^{-2}. The LAI of rice was calculated at the tillering and panicle initiation stages using the formula.

Where,

L = Maximum length of 3rd leaf blade from the top (cm)

B = Maximum breadth of the same leaf (cm)

K = Constant factor (0.75)

N= Number of leaves per plant.

The number of panicle bearing tillers in each of the net plot (0.25 m^{-2}) was counted at four random locations and expressed as No. m^{-2}. After threshing, cleaning, drying and winnowing, the grain yield from each net plot area was recorded. The final grain yield was calculated at 14 per cent moisture content and expressed in Kg ha^{-1}. The non-significant treatments were denoted by NS, and the significant treatments were calculated at 5 per cent probability level

The effect of treatments on the growth, yield parameters and yield of rice, ADT 54 was significant. Among the treatments, SRI method of rice cultivation with inorganic farming (T_2) has recorded significantly taller plants (133 cm), higher number of tillers plant^{-1} (19.8), maximum LAI (5.73), more productive tillers (328 m^{-2}) and maximum grain yield (5285 Kg ha^{-1}) (Table 1). This was comparable with SRI with inorganic farming + BGA 10 Kg ha^{-1} (T_4), SRI with inorganic farming + Azolla 250 Kg ha^{-1}and SRI with organic farming + *Azolla* 250 Kg ha^{-1}. As regards SRI with organic farming practices, addition of bio-fertilizers, either *Azolla* or BGA had significant influence on the above said parameters. SRI with organic farming resulted in significantly lower yield (3350 Kg ha^{-1}) with less panicles m^{-2} which was followed by SRI with organic farming + BGA 10 Kg ha^{-1} and SRI with organic farming + *Azolla* 250 Kg ha^{-1}.

Table 1. Effect of treatments on growth, yield attributes and yield

Treatment	**Plant height (cm)**	**No.of tillers plant $^{-1}$**	**LAI**	**Panicles m^{-2}**	**Grain yield (Kg/ha)**
T_1 - SRI with organic farming	121.3	12.8	4.80	196	3350
T_2 - SRI with inorganic farming	133.0	19.8	5.73	328	5285
T_3 - SRI with organic farming + BGA 10 Kg ha^{-1}	119.8	14.5	5.10	240	3675
T_4 _SRI with inorganic farming + BGA 10 Kg ha^{-1}	129.8	21.0	6.05	324	5387
T_5 - SRI with organic farming + Azolla 250 Kg ha^{-1}	124.8	16.8	4.93	268	3900
T_6 - SRI with inorganic farming + Azolla 250 Kg ha^{-1}	125.7	17.0	6.13	348	5650
SEd	4.59	1.91	5.45	21	252
CD (*P=0.05*)	9.60	3.98	0.28	42	526

Methane emission was estimated during tillering and flowering stage of rice using IRGA sensor in closed chamber method. Emission of methane was less during flowering stage compared to the vegetative stage (Table 2; Fig.1). At active tillering stage, the values ranged from as low as 4.14 mg m^{-2} hr^{-1} in SRI with inorganic farming + *Azolla* 250 Kg ha^{-1} to as high as 5.33 mg m^{-2} hr^{-1} in SRI with organic farming. This was due to liberation of photosynthetic oxygen in paddy water by *Azolla* and BGA (Malyan *et al.* 2016) which increased the dissolved oxygen concentration in flooded water, and eventually decreased the CH_4 emission from paddy soil by enhancing the CH_4 oxidation (Ali *et al.* 2015) and Malyan *et al.* (2019) observed that application of Azolla along with reduced dose of N fertilizer lowered the GHG intensity in rice by 16 to 19%.

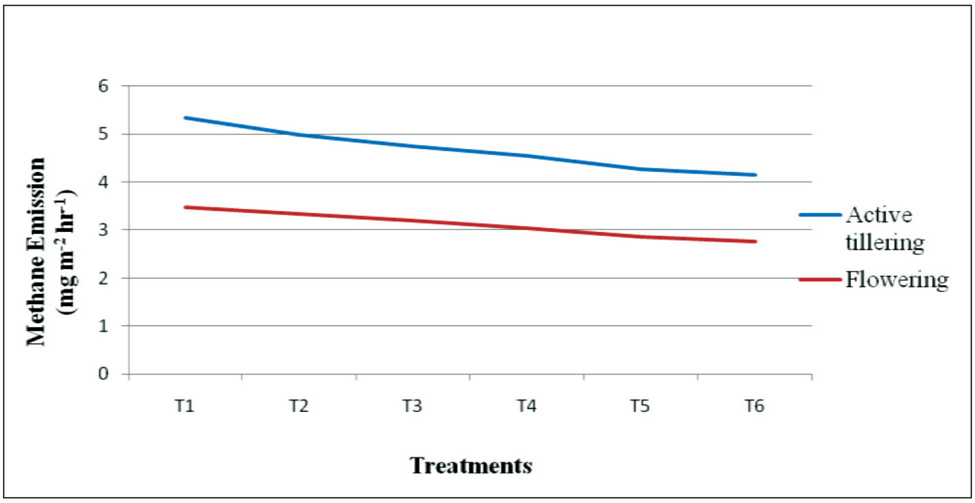

Fig 1. Effect of treatments on methane emission during active tillering and flowering stage

Table 2. Effect of treatments on methane emission and soil nutrient status

Treatment	Methane Emission (mg m^{-2} hr^{-1})		Available Nutrients (Kg ha^{-1})			
	Active Tillering	Flowering	SOC (g kg^{-1})	N	P	K
T$_1$ - SRI with organic farming	5.33	3.47	5.6	206	36.7	360
T$_2$-SRI with inorganic farming	4.97	3.34	5.4	204	34.4	362
T$_3$ - SRI with organic farming + BGA 10 Kg ha^{-1}	4.74	3.19	5.7	212	38.4	363
T$_4$ _SRI with inorganic farming + BGA 10 Kg ha^{-1}	4.54	3.04	5.6	208	36.3	364
T$_5$ - SRI with organic farming + Azolla 250 Kg ha^{-1}	4.25	2.86	5.9	219	38.5	363
T$_6$ – SRI with inorganic farming + Azolla 250 Kg ha^{-1}	4.14	2.77	5.6	214	37.9	366
SEd	0.18	0.10	0.09	2.4	0.6	3.1
CD (P=0.05)	0.55	0.33	0.28	7.1	1.9	NS

Application of *Azolla* significantly reduced the methane emission irrespective of organic and inorganic nutrient management. As regards BGA, there was no significant influence on methane emission when it was added to organic or inorganic practices. The similar trend followed during the flowering stage also. Rose *et al.* (2014) reported that the bio-fertilizer containing plant growth promoting microorganisms could replace between 23 and 52 % of nitrogen (N) fertilizer without loss of yield. Ali *et al.* (2014) also reported that *Anabaena azollae* in combination with urea and silicate fertilization decreased the total seasonal CH_4 flux by 12 % and increased rice grain yield by 10.6 %.

Adoption of organic nutrient management practices, *Azolla* @ 250 Kg ha^{-1} recorded higher soil organic carbon of 5.9 g Kg^{-1}, which was statistically comparable with the same organic combination with BGA @ 10 Kg ha^{-1}. With regard to soil available nitrogen and phosphorous, the same combination registered higher values (219 & 38.5 Kg ha^{-1}) which was statistically comparable with other organic nutrient management practices with bio-fertilizer combinations and inorganic nutrient management practice with *Azolla* 250 Kg ha^{-1}. The soil available potassium did not show any variation among the nutrient management practices.

The cost of cultivation was comparatively higher (Rs. 60000 ha^{-1}) under organic farming practices which may be due to the higher cost of organic inputs. The gross return was high (Rs. 118650 ha^{-1}) in SRI with inorganic farming + *Azolla* 250 Kg ha^{-1} due to the higher grain yield which was reflected in the BCR too (Table 3).

Table 3. Effect of treatments on cost economics and BCR

Treatments	Cost of cultivation (Rs ha^{-1})	Gross Return (Rs ha^{-1})	B:C
T_1 - SRI with organic farming	52000	70350	1.35
T_2-SRI with inorganic farming	46500	110985	2.39
T_3 - SRI with organic farming + BGA 10 Kg ha^{-1}	56000	77175	1.38
T_4 _SRI with inorganic farming + BGA 10 Kg ha^{-1}	48000	113140	2.36
T_5 - SRI with organic farming + Azolla 250 Kg ha^{-1}	60000	81900	1.37
T_6- SRI with inorganic farming + Azolla 250 Kg ha^{-1}	50000	118650	2.37

Grain yield of ADT 54 was higher in SRI with inorganic farming + *Azolla* 250 Kg ha^{-1} with very less methane emission during active tillering and flowering stages with higher post harvest soil fertility status. However, the B:C Ratio was higher at SRI with inorganic farming and it was closely followed by SRI with inorganic farming + Azolla 250 Kg ha^{-1}. Hence, SRI with inorganic farming + Azolla 250 Kg ha^{-1} may be recommended for getting higher yield, reduced methane emission, higher post harvest soil fertility status and higher BCR for rice variety, ADT 54.

Author contributions

All the authors contributed to the article and approved the submitted version.

Compliance with ethical standards

Yes

Conflict of interests

No commercial or financial relationships that could be construed as a potential conflict of interest.

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Short Communication

Rhyzopertha dominica (Coleoptera: Bostrychidae): Studies on screening techniques of wheat genotypes/varieties for resistance

Syed Mohamed Ibrahim S[*], Chaudhary F K[1], Prithiv Raj V[2] and Rajasehwaran B[3]

[*1,2]*Department of Agricultural Entomology, Sardarkrushinagar Dantiwada Agricultural University, Gujarat-385506*
[3]*Department of Agricultural Entomology, Anand Agricultural University, Anand, Gujarat-388110*

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Corresponding author: *E-mail: syedali.s1966@gmail.com*

Cereals are cheap to produce, easy to store and transport and do not deteriorate readily if kept dry. Among the cereals, wheat (*Triticum aestivum* L. em Thell.) is the strategic and most important cereal crop for the majority of the world's population about two billion people (36 % of the world population). The annual production and an area of wheat in India was recorded as 109.52 tonnes and 30.55 million hectare with an average productivity of 3464 Kg/ha, respectively (Anonymous, 2021). It was attacked by both field and also storage conditions by many insect pests. Among the pests, it is a very dangerous and harmful primary pest that can able to infest all types of cereals (Perisic *et al.*, 2020). The insect readily infests storage grains and can cause economic losses throughout much of the world due to its high potential viability and adaptability (Scheff *et al.*, 2022). After attaining the adult stage, the large exit holes were bored by mature insect inside the grains, so the control of insect with insecticides and grain protectants is very difficult compared to other pests in stored wheat (Vardeman *et al.*, 2007). Due to its internal feedings, the weight loss caused by adult feeding was varied from 6.5 to 19.4 % during 1st to 4th weeks, respectively after adult emergence (Tiwari and Sharma, 2002). To overcome this problem, farmers are using different synthetic insecticides which have inauspicious effects on the environment and non-target organisms and also create resistance to insects, so the small effective work was done to graded the wheat genotypes/varieties and find out the resistant genotype/variety against *R. dominica* which cause significant damage during storage period (Kumawat and Verma, 2017). Once if the resistant variety was explored, it provides an economically and environmentally safe storage protection at free of cost.

The screening experiment of twenty five wheat genotype/variety for their susceptibility against *R. dominica* carried out under laboratory condition during 2020-2021. The twenty-five genotypes/varieties were procured from Wheat Research Station, Vijapur for screening process. Collected samples were cleaned and examined critically to separate the damaged seeds and avoid contamination. Initially the seeds were dried in sunlight (Solomon, 1951).

The culture of *Rhyzopertha dominica* was collected from Wheat Research Station, Vijapur and the same were multiplied on the regional wheat variety GW 451 for conducting the further study. The culture was kept in the glass jar (1 Kg capacity) containing wheat variety GW 451 and placed inside the rearing cage in department laboratory. The mouth of the jar containing insect culture was covered properly with white muslin cloth and held tightly with rubber band. After a week, parent insects were removed from the jar by sieving and seeds with eggs were kept undisturbed under the laboratory condition at an average temperature of 27 ± 2 ºC temperature and 75 ± 5 % relative humidity for rearing. For ensuring the continuous availability of insects, sub culturing was done periodically.

Lesser grain borer, *R. dominica* is almost sedentary in nature but also fly occasionally. The newly emerged adult beetles were collected and transferred from initial culture jar to another jar having wheat seeds by using the forceps and camel hair brush for sub culturing. Those sub cultured insects were used as parent culture for further investigation. Sex differentiation in *R. dominica* on morphological characters are very difficult, so the male and female were distinguished during mating (copulation). During the mating process the female adult remains beneath the male and thus both sexes could easily separated in different Petri plates marked with male and female (Deshwal *et al.*, 2018). Based on size and flying capacity the male and female can also be distinguished. Male is smaller than female and usually more active and better flier than the female adult.

To study adult oriental preference, free choice and force choice tests were carried out and the damage potential of lesser grain borer, *R. dominica* was tested. The study was conducted by using circular galvanized tray (35 cm × 11 cm) by fixing white cardboard sheets in a radial manner and twenty five equal compartments were made on the bottom of the cage. 100 seeds of each genotype/variety were weighted and kept in each compartment at equal distance from the centre. Twenty-five pairs of newly emerged adults (male and female) of lesser grain borer were released into the Petri dish (1.5 cm × 9 cm) placed in centre of the circular galvanized cage. After releasing the adults the cage was covered with two fold muslin cloth and tied with the help of thick thread. Orientation of the adults towards each genotype/variety was observed after 12, 24, 36, 48, 60 and 72 hours of release. After completion of the migration of all adults of *R. dominica,* the seeds along with attracted adults were transferred into the separate plastic jar and the number of adult attracted toward each genotype/variety were counted separately and also per cent weight loss and grain damage were calculated after 60 days (Mehta, 2020).

The wheat genotypes/varieties were classified into four category *viz.,* high preference, moderately preference, less preference and no preference by using the arbitrary categorization method on the basis of adult orientation preference (Arya, 2018). The test was conducted providing force choice environment to the adults of *R. dominica* against wheat genotypes/varieties which the samples were restricted for an adults as described by Jha *et al.* (1999). For further confirmation of resistance through force choice test, the low susceptibility index genotype/variety was selected initially. For that purpose, 100 pre-weighted seeds of wheat genotypes/varieties were taken in a plastic sample container (7.0 cm × 5.5 cm) and two pairs of adults (1-2 days old) of lesser grain borer were forcibly released into the each sample containers having separate genotype/variety which make equal preference for all genotypes/varieties. The mouth of the sample container was covered with double folded muslin cloth and held tightly with rubber band. Adults were allowed for oviposition for a period of one week. After a week, the adults were separated from the seed of each genotype/variety. Later, the sample containers were kept undisturbed to document the per cent weight loss, mean development period, and susceptibility index. Based on per cent weight loss, the genotypes/varieties were graded by arbitary categorization as resistant (<6.70) moderately resistant (6.71-10.80), less susceptible (10.81-14.90), moderately susceptible (14.91-19) and highly susceptible (>19). After excluding the frass from the infested seeds, the final weight of sample was taken with single pan electronic balance separately for each treatment. The weight loss (%) was calculated by using the following formula.

$$\text{Weight loss (\%)} = \frac{\text{Initial weight of seed} - \text{Final weight of seed}}{\text{Initial weight of seed}} \times 100$$

The average development time (T) is the time needed for the emergence of 50% of adults and was calculated as (Howe, 1971).

$$\text{Mean development period (day)} = \frac{\text{D1A1} + \text{D2A2} + \text{D3A3} + \ldots\ldots \text{DnAn}}{\text{Total number of adults emerged}}$$

Where,

D1 = Day on which adults started emerging

A1 = Number of adults emerged on D1^{th} day

The number of F_1 adults emerged was counted and removed regularly in the each genotype/variety at 25 after days of release. Based on above observation, the susceptibility index was calculated by using the formula suggested by Dobie (1974).

$$\text{Susceptibility index} = \frac{\text{Log F}}{\text{D}} \times 100$$

Where,

F = Total number of adults emerged

D = Mean development period (day)

The data were collected statistically by using the CRD (Completely randomized design) or one way analysis of (ANOVA). Data were analyzed by using the SPSS computer program (IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.), the square root and arc sinc transformation were done in required parameters. Significance of difference between the treatments means were compared by Duncan's multiple range test.

The wheat genotypes/varieties *viz*, were screened under free choice and force choice test for their resistance against *R. dominica.* Under free choice test, twenty five wheat genotypes/varieties were screened for their susceptibility and assessed the damage potential of lesser grain borer based on the number of adults migrated at an interval of 12 hours for three days, Per cent weight loss, number of adult emerged and per cent grain damage to the wheat genotypes/varieties which were data recorded and presented in Table 1 & 2.

Table 1. Adult orientation of *R. dominica* to different wheat genotypes/variety

Genotypes/ Varieties	Number of adults oriented after release				
	12 hrs	24 hrs	36 hrs	48 hrs	Mean
GW 11	1.71^{bcdef} (2.00)	1.62^{def} (1.67)	1.82^{cde} (2.33)	1.82^{bcd} (2.33)	1.75^{de} (2.08)
GW 173	1.91^{bcd} (2.67)	2.06^{bc} (3.33)	2.07^{bc} (3.33)	2.07^{bc} (3.33)	2.04^{c} (3.17)
GW 190	1.52^{defg} (1.33)	1.80^{bcde} (2.33)	1.52^{def} (1.33)	1.52^{defg} (1.33)	1.60^{ef} (1.58)
GW 273	1.71^{bcdef} (2.00)	1.72^{cdef} (2.00)	1.82^{cde} (2.33)	1.82^{bcd} (2.33)	1.78^{de} (2.17)
GW 322	1.80^{bcde} (2.33)	1.82^{bcde} (2.33)	1.73^{cde} (2.00)	1.73^{cdef} (2.00)	1.78^{de} (2.17)
GW 366	1.27^{fg} (0.67)	1.28^{f} (0.67)	1.13^{f} (0.33)	1.13^{g} (0.33)	1.22^{h} (0.50)
GW 451	1.27^{fg} (0.67)	1.52^{ef} (1.33)	1.41^{df} (1.00)	1.52^{defg} (1.33)	1.44^{fgh} (1.08)
GW 496	1.13^{g} (0.33)	1.28^{f} (0.67)	1.13^{f} (0.33)	1.27^{g} (0.67)	1.22^{h} (0.50)
GW 499	3.15^{a} (9.00)	3.10^{a} (8.67)	3.26^{a} (9.67)	3.26^{a} (9.67)	3.20^{a} (9.25)
GW 503	1.33^{defg} (1.52)	1.41^{ef} (1.00)	1.27^{f} (0.67)	1.27^{g} (0.67)	1.38^{fgh} (0.92)
GW 1339	1.62^{cdef} (1.67)	1.52^{ef} (1.33)	1.52^{def} (1.33)	1.52^{defg} (1.33)	1.55^{efg} (1.42)
GDW 1255	1.82^{bcde} (2.33)	1.73^{cdef} (2.00)	1.71^{cde} (2.00)	1.71^{cdef} (2.00)	1.76^{de} (2.08)
VD 18-07	1.62^{cdef} (1.67)	1.82^{bcde} (2.33)	1.24^{f} (0.67)	1.38^{fg} (1.00)	1.54^{ef} (1.42)
VD 18-09	1.80^{bcde} (2.33)	2.08^{bc} (3.33)	2.30^{bc} (4.33)	2.15^{b} (3.67)	2.09^{bc} (3.42)
VD 18-12	1.82^{bcde} (2.33)	1.99^{bcd} (3.00)	1.91^{cd} (2.67)	1.91^{bcd} (2.67)	1.91^{cd} (2.67)
VD 18-13	2.07^{bc} (3.33)	1.80^{bcde} (2.33)	2.06^{f} (3.33)	2.15^{b} (3.67)	2.04^{c} (3.17)
VD 18-14	1.62^{cdef} (1.67)	1.28^{f} (0.67)	1.27^{f} (0.67)	1.27^{g} (0.67)	1.38^{fgh} (0.92)
VD 18-16	2.15^{b} (3.67)	2.16^{b} (3.67)	2.30^{b} (4.33)	2.15^{b} (3.67)	2.20^{b} (3.83)
VD 19-05	1.27^{fg} (0.67)	1.28^{f} (0.67)	1.27^{f} (0.67)	1.27^{g} (0.67)	1.29^{c} (0.67)
VD 19-06	1.27^{fg} (0.67)	1.41^{ef} (1.00)	1.41^{df} (1.00)	1.41^{efg} (1.00)	1.38^{fgh} (0.92)
VD 19-09	1.38^{efg} (1.00)	1.38^{ef} (1.00)	1.27^{f} (0.67)	1.27^{g} (0.67)	1.35^{fgh} (0.83)
HI 8498	1.52^{defg} (1.33)	1.28^{f} (0.67)	1.27^{f} (0.67)	1.27^{g} (0.67)	1.35^{fgh} (0.83)
HI 8737	1.71^{bcdef} (2.00)	1.72^{cdef} (2.00)	1.80^{cde} (2.33)	1.80^{bcde} (2.33)	1.78^{de} (2.17)
HD 2932	1.62^{cdef} (1.67)	1.52^{ef} (1.33)	1.52^{def} (1.33)	1.52^{defg} (1.33)	1.55^{efg} (1.42)
LOK 1	1.52^{defg} (1.33)	1.28^{f} (0.67)	1.27^{f} (0.67)	1.27^{g} (0.67)	1.35^{fgh} (0.83)
S. Em. ±	0.14	0.13	0.13	0.12	0.15
C. D. at 5%	0.40	0.39	0.37	0.36	0.46

Notes : Figures in parentheses are retransformed values of $\sqrt{X+1}$ trransformation; Treatment mean with common superscript letter (s) are not significant by DMRT at 5% level of significance.

Table 2. Reaction of wheat genotypes/varieties to *Rhyzopertha dominica* under free choice test

Genotypes /Varieties	*Mean No. Of adults attracted	Initial Weight	Final Weight	Weight loss (%)	No. Of adult emergence	% Grain damage
GW-11	1.75^{de} (2.08)	3.62^{l}	3.28^{m}	12.57^{d} (4.77)	1.33^{hi}	7.17^{fgh} (2.33)
GW-173	2.04^{c} (3.17)	4.03^{ij}	3.72^{l}	16.01^{b} (7.62)	3.00^{fg}	17.78^{bcdef} (9.33)
GW-190	1.60^{ef} (1.58)	3.66^{kl}	3.59^{l}	7.72^{hij} (1.82)	9.00^{c}	23.05^{ab} (15.33)
GW-273	1.78^{de} (2.17)	3.77^{kl}	3.66^{l}	9.93^{fg} (3.02)	0.67^{hi}	7.94^{gh} (2.00)
GW-322	1.78^{de} (2.17)	3.69^{kl}	3.62^{l}	8.10^{hi} (1.99)	2.00^{gf}	15.92^{cdefgh} (7.67)
GW-366	1.22^{h} (0.50)	5.49^{c}	5.49^{cd}	5.98^{ijklm} (1.09)	0.33^{i}	4.62^{h} (1.00)
GW-451	1.44^{fgh} (1.08)	4.45^{f}	4.43^{hijk}	4.54^{klm} (0.68)	5.33^{e}	11.01^{efgh} (3.67)
GW-496	1.22^{h} (0.50)	4.57^{f}	4.55^{ghi}	3.43^{m} (0.37)	0.67^{hi}	5.73^{h} (1.00)
GW-499	3.20^{a} (9.25)	4.94^{e}	4.45^{ghijk}	18.23^{a} (9.79)	5.33^{e}	18.01^{bcdef} (9.67)
GW-503	1.38^{fgh} (0.92)	3.70^{kl}	3.67^{l}	5.38^{jklm} (0.90)	0.67^{hi}	5.42^{h} (1.33)
GW-1339	1.55^{efg} (1.42)	4.62^{f}	4.35^{ijk}	14.06^{c} (5.92)	5.00^{e}	20.49^{bcd} (12.33)
GDW1255	1.76^{de} (2.08)	5.20^{d}	4.96^{fg}	12.38^{d} (4.62)	7.00^{d}	20.34^{bcd} (12.33)
VD18-07	1.54^{ef} (1.42)	5.05^{de}	5.00^{f}	5.89^{ijklm} (1.06)	1.67^{hi}	9.97^{efgh} (3.00)
VD18-09	2.09^{bc} (3.42)	4.42^{fg}	4.22^{jk}	12.25^{d} (4.53)	10.67^{b}	26.64a (20.67)
VD18-12	1.91^{cd} (2.67)	4.99^{e}	4.75^{fgh}	12.58^{d} (4.75)	2.00g^{h}	18.10^{bcde} (10.33)
VD18-13	2.04^{c} (3.17)	6.12^{ab}	5.91^{ab}	10.42^{efg} (3.38)	1.33^{hi}	12.11^{defgh} (5.00)
VD18-14	1.38^{fgh} (0.92)	5.98^{b}	5.68^{bc}	12.70^{d} (4.85)	3.33^{f}	10.87^{defgh} (5.33)
VD18-16	2.20^{b} (3.83)	5.48^{c}	5.31^{e}	10.13^{efg} (3.10)	8.33^{c}	20.68^{bc} (13.00)
VD19-05	1.29^{c} (0.67)	6.21^{a}	6.06a	8.99^{gh} (2.47)	1.00^{hi}	7.15^{h} (1.67)
VD19-06	1.38^{fgh} (0.92)	4.86^{e}	4.68^{gf}	11.29^{def} (3.85)	1.00^{hi}	7.15^{h} (1.67)
VD19-09	1.35^{fgh} (0.83)	4.17^{hi}	4.17^{k}	11.68^{de} (4.10)	0.67^{hi}	6.22^{gh} (2.00)
HI8498	1.35^{fgh} (0.83)	4.60^{f}	4.52^{ghij}	7.54^{hijk} (1.73)	0.33^{i}	1.91^{h} (0.33)
HI8737	1.78^{de} (2.17)	4.53^{f}	4.15^{k}	16.67^{b} (8.24)	13.00^{a}	23.05^{ab} (16.00)
HD2932	1.55^{efg} (1.42)	4.24^{g}	4.19k	6.89^{hijkl} (1.45)	3.00^{fg}	9.78^{efgh} (4.33)
LOK1	1.35^{fgh} (0.83)	3.87^{jk}	3.85^{l}	3.72^{lm} (0.43)	3.67^{f}	10.20^{efgh} (4.67)
S.Em	0.05	0.15	0.10	0.56	0.4	2.90
C.D at 5%	0.14	0.46	0.29	1.65	1.18	8.53

Notes: *Figures in parentheses are retransformed values of $\sqrt{X+1}$ transformation; Values in parentheses are retransformed values of Arc sin transformation; Treatment mean with common superscript letter (s) are not significant by DNMRT at 5% level of significance.

The tabulated result revealed that the wheat genotypes/varieties differed significantly with respect to the adult oriented toward them at an interval of 12, 24, 36, 48, 60 and 72 hrs after release. The adult orientation among genotypes/varieties varied from 0.33 to 9.00 and 0.67 to 8.67 at 12 and 24 hrs, respectively and 0.33 to 9.67 at 36 and 48 hrs. At 60 and 72 hrs after release, there was no adult orientation observed and same number of adults attracted toward each genotypes/varieties which started feeding the seeds. After 12, 24, 36 and 48 hrs, the orientation of adult *R. dominica* was significantly differed. Mean number of adults orientation to wheat variety ranging between 9.27 and 3.83 adults per 100 grains (Table 1). The variety GW 499 attracted highest adults (9.27 adults), while GW 496 and GW 366 displayed least (0.50 adults) mean number of adults. The rest of the genotypes/varieties invited the adults ranged between 0.83 and 3.42 adults per 100 grain. The initial weight of 100 grains of each genotypes/varieties were recorded before the adult introduction and after the infestation, as per choice of insect and their emergence, the adults were removed to observed the final weight and per cent weight loss. The least per cent weight loss displayed in the genotype GW 496 (0.37) as par with LOK 1 (0.43) and the genotype GW 499 was displayed as maximum weight loss (9.79) followed by variety HI 8737 (8.24), respectively. The rest of genotypes/varieties were value ranging 0.68 and 7.62 %. Similarly, as per the results the minimum per cent grain damage was noted in the variety HI 8498 (0.33) as par with GW 496 (1.00) and the variety VD 18-09 (20.67) had recorded the maximum per cent grain damage among all (Table 2).

The insects might infest the host of their choice in the free choice test. This method is usually used to measure a cultivar's ability to repel insects (Giga 1995). In past, Sharma *et al.* (2001) found the minimum adult of *R. dominica* oriented in wheat genotypes *viz.,* HD 2705, GW 173 and RAJ 1399 after 48 hrs of release. Korawar (2018) observed the highest number of orientation of adults of *R. dominica* towards genotype NIAW 3581 while lowest toward the genotype MACS 6222 after 24 and 48 hrs of release. Followed by Mehta (2020) revealed highest adult orientation to wheat variety HPW 155 which was followed by HPW 236 and minimum adult orientation was found in HPW 349. They measured grain weight loss and noted fluctuations by using the choice approach. As per results in Table 4, genotype GW 496 and LOK 1 were very less preferred by adult insect on basis of adult movement and grain damage.

Table 3. Classification of wheat genotypes/varieties on basis of adult orientation preference

Category	Number of adults oriented	Genotypes/varieties
Less preference	< 2.69	GW 366, GW 496, VD 19-05, LOK 1, HI 8498, VD 19-09, GW 503, VD 18-14, VD 19-06,GW 451, VD 18-07, GW 11, GW 1339, HD 2932,GW 190, HI 8737, GDW 1255, GW 322,GW 273, VD 18-12
Moderately preference	2.69 – 4.88	VD 18-16, VD 18- 13, VD 18-09, GW 173
High preference	4.89 – 7.06	---
Very High preference	> 7.06	GW 499

The result on evaluation of different wheat genotypes/varieties against the adults of *Rhyzopertha dominica* on the basis of initial weight (g), final weight (g), weight loss (%), mean developmental period (day), F1 adult emergence (number) and susceptibility index are presented in Table 4. The data of all the parameters of various wheat genotypes/varieties in the test were showed significant difference among various wheat genotypes/varieties, respectively. The wheat variety GW 190 displayed the maximum significant (23.10 %) weight loss followed by GW 503 (20.69 %) but they were statistically at par. Whereas, the LOK 1 displayed least seed weight loss (2.60 %) but it was at par with genotype GW 366 (3.35 %) followed by VD18-14 (3.79 %) which indicated poor preference of *R. dominica* toward wheat varieties. Saad *et al.* (2018) recorded minimum weight loss in wheat variety, Romanian at 10, 15 and 20 unsexed adult infestation level of *R. dominica*, while maximum weight loss was recorded in American variety, Summer Red wheat at same level of adult infestation. We noticed the sustainable variation of mean developmental period of *R. dominica* on various wheat genotypes/varieties (Table 4). The *R. dominica* reared on wheat variety GW 11 demonstrated longest mean developmental period *i.e.* 51.22 days. It was followed by wheat varieties/ genotypes LOK 1(50.63 days), GW 499 (49.73 days) and VD 18-12 (49.58 days), but they were statistically at par. *R. dominica* took shortest mean developmental period on variety GW 366 (35.06 days) followed by wheat variety GW 173 (39.80 days). Based on results, susceptible genotypes showed the rapid and early adult emergence, while the resistant genotypes revealed delayed and slow adult emergence. The results of present study are in similar with the findings of Kumawat and Verma (2017) who reported that the mean duration of life period of *R. dominica* varied from 35.00 to 51.33 days on various wheat variety. Similarly Mehta (2020) reported the maximum and minimum mean developmental period on the wheat varieties HPW 249 and HPW 155, respectively. The number of F_1 adults emergence varied from 10.33-43.33 adults per 100 seeds (Table-4). The highest number of F_1 adult emerged (43.33 adults) in wheat variety GW 190 and genotype VD 18-14 recorded lowest number of F1 adult (10.33 adults). Rest of the genotypes/varieties were recorded the F_1 adult emergence was ranged from12.00 to 41.33 adults. Kakade *et al.* (2014) recorded that the highest and lowest F_1 adult emergence in wheat variety Raj 3765 and Raj 1482, respectively 60 days after release of adults in 100 seeds. The susceptibility index was calculated on the basis of growth parameters in different genotypes/varieties. Despites the weight loss and growth parameters, there were a significant difference among the susceptibility index of 25 wheat genotypes/varieties which values ranging 2.03 to 3.52 (Table-4). The wheat genotype HD 2932 displayed highest susceptibility index

(3.52). Rest of the genotypes/varieties were values ranging between 2.58 and 3.47.The wheat variety LOK 1 recorded lowest susceptibility index (2.03) followed by genotypes VD 18-12 (2.15). Similarly, Bhanderi *et al.* (2015) reported that higher susceptibility index in wheat variety samurai 2 and were lower in wheat variety Suri 3. These results are in conformity with the findings of present study. As per tabulated results in Table 6, GW 503 and GW 190 were severely damaged and cause heavy weight loss by adult insects.

Table 4. Evaluation of wheat genotypes/varieties against lesser grain borer under force choice test

Genotypes/ varieties	Parameters					
	Initial Weight (g)	**Final Weight (g)**	**Weight loss (%)**	**Mean developmental period (day)**	**F_1 adult emerged (Number)**	**S I**
GW 11	3.67^{op}	3.27^{j}	19.19^{f} (10.81)	51.22^{a}	21.00^{gh}	2.58^{m}
GW 173	4.00^{mno}	3.81^{ghi}	11.32^{ij} (3.87)	39.80^{j}	12.67^{ijk}	2.77^{kl}
GW 190	3.59^{p}	2.76^{k}	28.72^{a} (23.10)	47.18^{hi}	43.33^{a}	3.47^{a}
GW 273	3.59^{p}	2.93^{jk}	25.46^{c} (18.49)	48.87^{def}	31.33^{de}	3.06^{fgh}
GW 322	4.07^{lmn}	3.75^{ghi}	18.74^{f} (10.32)	48.32^{bcde}	24.33^{f}	2.87^{ijk}
GW 366	5.62^{cde}	5.45^{b}	10.52^{jk} (3.35)	35.06^{k}	12.00^{jk}	3.08e^{fgh}
GW 451	4.39^{kl}	3.67^{hi}	25.71^{c} (18.84)	48.82^{efgh}	41.33^{ab}	3.31^{bc}
GW 496	4.95^{hij}	4.43^{ef}	18.81^{f} (10.40)	46.31^{hi}	29.67^{e}	3.18^{cdef}
GW 499	4.63^{jk}	3.98^{ghi}	25.30^{c} (18.28)	49.73^{def}	36.00^{c}	3.13^{defg}
GW 503	3.85^{nop}	3.04^{jk}	27.05^{b} (20.69)	47.29^{fgHI}	34.00^{cd}	3.24^{cde}
GW 1339	4.45^{k}	3.83^{gHI}	21.18^{de} (13.06)	46.83^{ghI}	39.33^{b}	3.41^{ab}
GDW 1255	5.10^{fgh}	4.56^{de}	18.48^{f} (10.05)	47.11^{cde}	26.00^{f}	3.00^{ghI}
VD 18-07	5.93^{bc}	5.42^{b}	16.95^{g} (8.50)	44.80^{cde}	29.00^{e}	3.26^{bcd}
VD 18-09	4.55^{k}	3.91^{ghI}	21.54^{d} (13.49)	48.74^{efgh}	30.67^{e}	3.05^{fgh}
VD 18-12	5.03^{ghi}	4.91^{cd}	12.36^{ij} (4.60)	49.58^{abcd}	11.67^{jk}	2.15^{o}
VD 18-13	6.34^{a}	6.11^{a}	11.93^{ij} (4.29)	43.46^{cde}	14.00^{ij}	2.64^{lm}
VD 18-14	5.77^{bcd}	5.55^{b}	11.22^{ij} (3.79)	42.34^{cde}	10.33^{k}	2.40^{n}
VD 18-16	5.46^{def}	5.19^{bc}	12.74^{hI} (4.87)	45.98^{abc}	23.00^{fg}	2.96^{hij}
VD 19-05	6.08^{ab}	5.43^{b}	18.08^{f} (9.63)	49.44^{cde}	24.67^{f}	2.81^{jk}
VD 19-06	4.94^{hij}	4.44^{ef}	14.12^{h} (5.96)	47.30^{cde}	19.00^{h}	2.70^{klm}
VD 19-09	4.04^{lmno}	3.64^{i}	18.62^{f} (10.20)	46.40^{efg}	18.33^{h}	2.72^{klm}
HI 8498	4.70^{ijk}	4.06^{gh}	20.37^{ij} (12.13)	41.75^{ij}	15.33^{i}	2.84^{jk}
HI 8737	5.35^{efg}	4.56^{de}	21.98^{d} (14.01)	47.64^{cde}	34.67^{c}	3.23^{cde}
HD 2932	4.33^{klm}	4.11^{fg}	11.98^{ij} (4.30)	45.31^{bcde}	39.33^{b}	3.52^{a}
LOK 1	3.75^{nop}	3.65^{i}	9.26^{k} (2.60)	50.63^{ab}	10.67^{k}	2.03^{o}
S. Em. ±	0.12	0.12	0.39	0.84	0.97	0.05
C. D. at 5%	0.35	0.35	1.06	2.47	2.87	0.15
C. V. %	4.39	4.80	3.58	3.14	6.69	3.08

Notes: Figures in parentheses are retransformed values of Arc sin transformation; Treatment mean with common superscript letter (s) are not significant by DNMRT at 5% level of significance.

The results of correlation analysis of different growth parameters of *R. dominica* on wheat genotypes/varieties are presented in Table-5. It revealed that initial weight had highly significant positive correlation with final weight (r = 0.97**), but it was significant negative correlation with per cent weight loss (r = -0.45*). Mean developmental period (r = -0.37), F1 adult emerged (r = -0.29) and susceptibility index (r = -0.22) were negatively correlated with the initial weight. Similarly, the final weight had highly significant negative correlation with per cent weight loss (r = -0.65**), but it was negatively correlated with mean developmental period (r = -0.42) and had significant negative correlation with F_1 adult emergence (r = -0.46*) and susceptibility index (r = -0.39*). Weight loss (%)

exhibited highly significant positive correlation with F_1 adult emergence (0.76**) and susceptibility index (0.69**), while established significant positive correlation with mean developmental period (0.41*). Mean developmental period formed significant positive correlation with F_1 adult emergence (0.39*), while it showed positive correlation with susceptibility index (0.01). F_1 adult emergence established highly significant positive correlation with susceptibility index (0.88**). From ongoing discussion, indicated that increase in developmental period, F_1 adult emergence and susceptibility index increased the weight loss in all the wheat genotypes/varieties. The more number of F1 adult emerged also indicated the susceptibility of wheat genotypes/varieties against *R. dominica*. Earlier, Syed *et al.* (2006), observed positive significant correlation between weight loss (%) and progeny development and moisture (%) of seed. Similarly, the positive correlation between per cent weight loss and mean developmental period, susceptibility index and F_1 adult emergence were reported by Arya (2018) which were close conformity to present study.

Table 5. Classification of wheat genotypes/varieties on basis of force choice weight loss (%)

Category	% weight loss	Wheat genotypes/varieties
Resistant	< 6.70	GW 366, LOK 1,VD 18-14, GW 173, VD 18-13, HD 2932, VD 18-12, VD 18-16,VD 19-06
Moderately resistant	6.70 – 10.80	VD 18-07, VD 19-05, GDW 1255, VD 19-09, GW 322, GW 496
Less susceptible	10.81 – 14.90	GW 11, HI 8498, GW 1339, VD 18-09, HI 8737
Moderately susceptible	14.91 – 19.0	GW 499, GW 273,GW 451
Susceptible	> 19.0	GW 503, GW 190

Table 6. Correlation between the growth parameters of *R. dominica* on various wheat genotypes/varieties

Parameters	Initial weight	Final weight	Weight loss	Mean developmental period	F_1 adult emergence	SI
Initial weight	1.00	0.97**	-0.45*	-0.37	-0.29	-0.22
Final weight		1.00	-0.65**	-0.42	-0.46*	-0.39*
Weight loss			1.00	0.41*	0.76**	0.69**
Mean developmental period				1.00	0.39*	0.01
F1 adult emergence					1.00	0.88**
Susceptibility index						1.00

* Significant at 5 per cent level of significance (r = 0.396); **Significant at 1 per cent level of significance (r = 0.505)

Twenty five wheat genotypes/varieties were screened, since the cultivar LOK 1 had least per cent weight loss, F1 adult emergence and susceptibility index which have an immune potential and ability to resist against *R. dominica*. These germplasm can be used as resistance lines donor in future breeding programmes. Although the biochemical parameters of the varieties used in this study were not examined, the reasons for differences in susceptibility/preference to *R. dominica* can be discovered by examining biochemical parameters of different varieties and determining their relationship to the borer's biological parameters.

Author contributions

All the authors contributed to the article and approved the submitted version.

Compliance with ethical standards

Yes

Conflict of interests

No commercial or financial relationships that could be construed as a potential conflict of interest.

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Short Communication

Canopy temperature in Sorghum under drought stress: Influence of gas-exchange parameters

Brahmesh Reddy BR[1], Kiran BO[2], Somanagouda B Patil[3] and Ashvathama VH[1]

[1]*Department of Plant Physiology, University of Agricultural Sciences, Dharwad*
[2]*All India Coordinated Sorghum Improvement Project, RARS, Vijayapur*
[3]*All India Coordinated Research Project on Dryland Agriculture, RARS, Vijayapur*

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Corresponding author: *E-mail: brahmeshcph@yahoo.com*

Drought resistance is often regarded as a complex trait, arising from different underlying constitutive or adaptive traits, each of which is potentially under complex genetic and environmental control. The assessment of leaf or canopy temperature (CT) has been proposed as a low-cost indirect selection criterion for drought and heat stress resistance Canopy temperature is indirectly related to stomatal conductance and carbon exchange (Anderegg *et al.*, 2021). The photosynthesis gets affected by elevated leaf temperature in response to high ambient temperature only or in combination with drought due to reduced stomatal conductance (Pradhan *et al.*, 2022). Under unfavourable soil-water conditions, greater CTD and yield have been attributed to increased stomatal conductance and crop water use (Balota *et al.*, 2008). Hence, the present study was mainly focused on understanding the effects of drought stress on canopy temperature and to test the hypothesis that cooler canopy is more critical for better performance under drought stress in sorghum genotypes.

The experiment was conducted under the AICRP - Sorghum at the Regional Agricultural Research Station, Vijayapura. Eighteen genotypes were studied which varied with phenological characteristics in both irrigated and stressed conditions. The irrigated regime was provided with water periodically until the physiological maturity stage while drought stress was induced by withholding the irrigation post 40 days after emergence uniformly. The gas exchange parameters were determined with LI - 6800 portable closed chamber infrared gas analyser (LI-COR Biosciences, Lincoln, NE, USA). An infrared thermocouple was used to record the canopy temperatures. The infrared thermocouple was placed at one meter height from the top most leaf of that particular genotype. The data for each genotype were the mean of four readings (Jokar *et al.* 2018; Karimizadheh *et al.*, 2011). The canopy temperature depression was obtained as a difference of the canopy temperature from the ambient air temperature. The analysis of variance (ANOVA) was done as suggested by Gomez and Gomez. The correlation and relationship studies were performed in the RStudio (B Corporation, Boston, MA) using “Corrplot”, “tidyverse” and “ggplot2” packages.

The difference in assimilation rate was 37%, transpiration rate was 32% and that of stomatal conductance was 36% between the irrigated and stressed regime. The best performance was recorded by Phule Anuradha and RSV 1876 under the stressed regime. They maintained photosynthetic rate at 16.30 μmol/m^2/s and 16.22 μmol/

m^2/s respectively as depicted in Table 1. The lines showing higher photosynthetic activity under the drought stress are considered to be drought tolerant (Getnet *et al.*, 2015). In view of this conclusion, the genotypes RSV 1876 and Phule Anuradha in the current study can be considered as drought tolerant. A concurrent performance was observed with the transpiration rate and the stomatal conductance. Phule Anuradha and RSV 18 were able to maintain transpiration rate of 4.48 mmol/m^2/s and 4.1 mmol/m^2/s respectively while stomatal conductance stood at 0.144 mol/m^2/s and 0.138 mol/m^2/s, respectively (Fig. 1). Rajarajan *et al.* (2021) expressed that the higher yields of sorghum are associated with higher transpiration rate under the water stress. In accordance with this statement, it was observed in the current study that the genotypes RSV 1876, Phule Anuradha and other genotypes when subjected to stress having higher transpiration rate also achieved higher grain yield and biomass accumulation as observed from the Table 1. There was a decline in the stomatal conductance when the genotypes were subjected to drought stress similar to what was observed by Goche *et al.* (2020).

Ambient air temperature while recording the observations was 36.2°C. The lowest canopy temperature was maintained by CRS 99 (34°C) followed by RNTN-13-39 (34.1°C) in the irrigated regime, but in the stressed regime the lowest canopy temperature was recorded in the RSV 1876 (34.5 °C) followed by Phule Anuradha (34.6°C) as can be observed from the Table 1. The genotype depicting highest deviation from the ambient air temperature will be having the highest canopy temperature depression and *vice-versa.* In the stressed regime, genotype RSV 1876 had lowest canopy temperature that resulted in highest canopy temperature depression of 1.7°C followed by Phule Anuradha with 1.6°C depression (Table 1). Drought-susceptible genotypes would be impaired in growth, produce lower biomass and exhibit higher CT already at the beginning of the measurement period (Anderegg *et al.*, 2021). Ndiso *et al.* (2016) reported lower canopy temperature in drought tolerant genotypes.

The higher yields of sorghum are associated with a higher transpiration rate under the water stress. Higher transpirational rate and lower stomatal conductance contribute in higher canopy temperature depression owing to lower canopy temperatures (Rajarajan *et al.,* 2021). The drought tolerant genotypes RSV 1876 and Phule Anuradha had tighter control over the stomata when compared with the drought susceptible counterpart. The drought-sensitive genotype was less effective than the drought-tolerant counterpart in controlling stomatal responses as indicated by the prolonged delay in the reduction of stomatal conductance or the rise in leaf surface temperature, parameters which reflect stomatal closure/opening (Goche *et al.*, 2020). Canopy temperatures under stress were also negatively correlated across genotypes with absolute grain yields ($r= -0.67$, $P < 0.05$) under stress (Fig. 2). Absolute grain-yield under drought-stress was correlated with canopy temperatures (Blum *et al.*, 1989). The plants with cooler canopies are better able to regulate stomatal conductance leading to cooler leaves (canopy) compared to ambient conditions (Ginkel *et al.*, 2006). Cooler canopy temperature at heading and grain filling stages led to increase in yield for each condition. They observed that the 1°C change in the CTD altered the yield broadly by 150-270 Kg/ha. Selection of cooler canopy temperature under conditions of soil-water depletion could favor the development of lines with high yield potential (Kepekhov, 2022). Canopy temperature (CT) has been confirmed to be related to stomatal conductance and can be an indirect indicator of plant water uptake capability under drought (Mahmood, 2020).

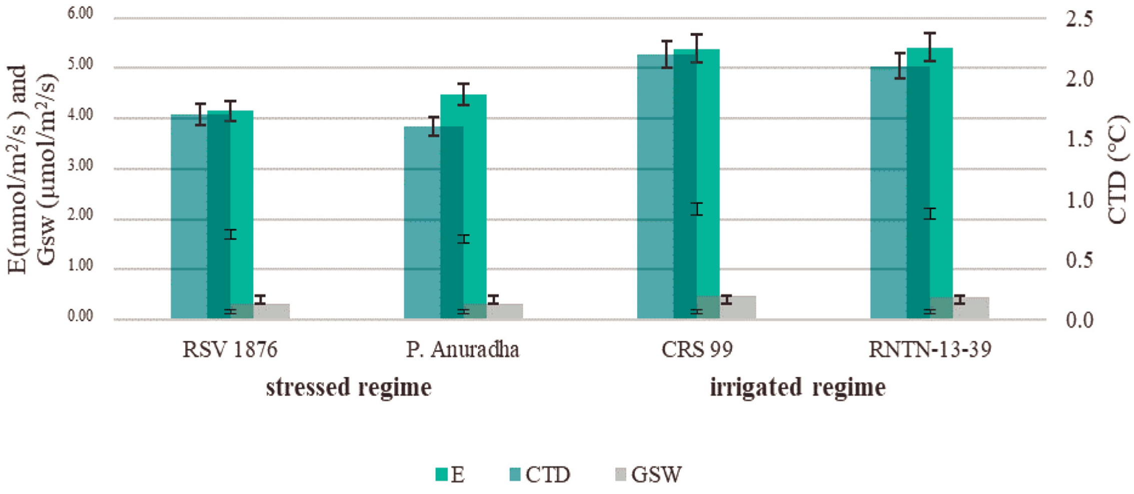

Fig 1: Canopy temperature in irrigated and stressed regime

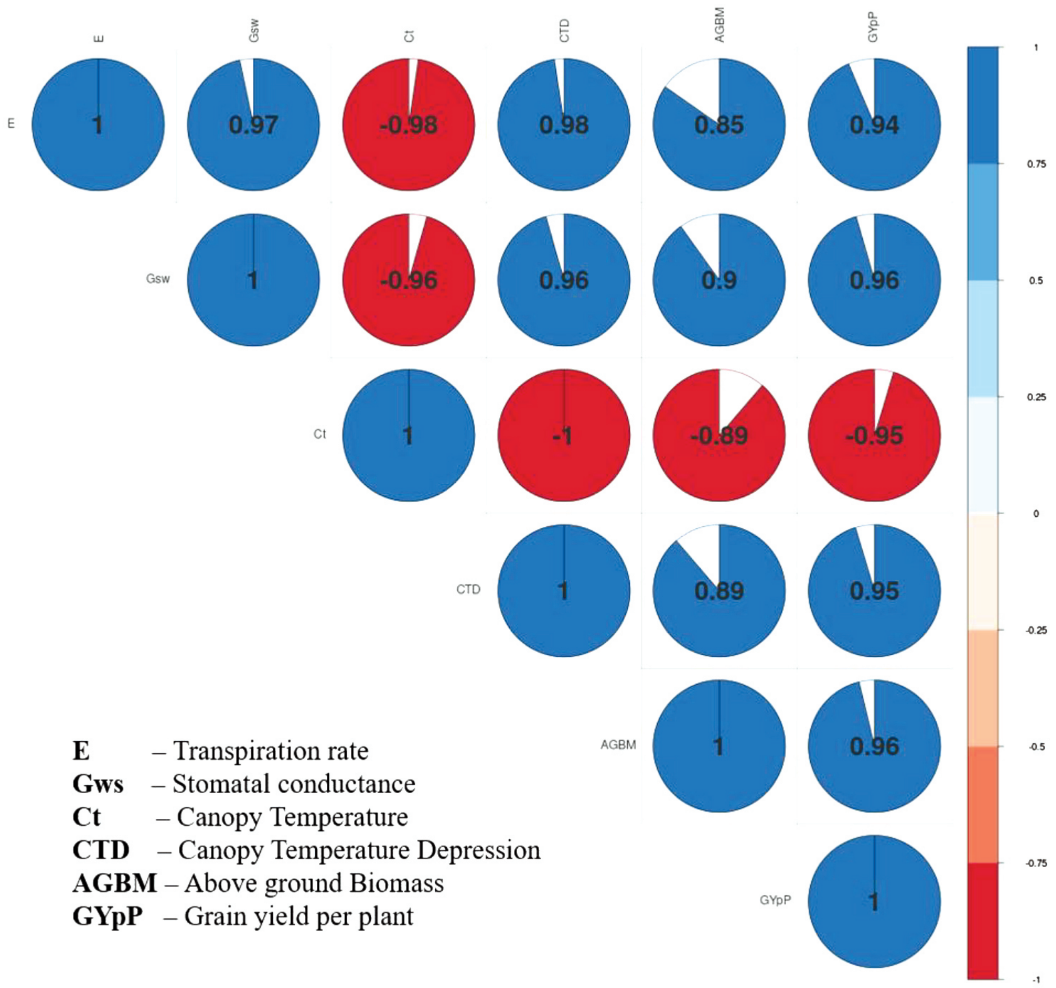

Fig 2: Correlogram of various attributes in sorghum genotypes

Table 1. Performance of genotypes under different moisture regimes as evaluated by various parameters

Genotype	Photosynthetic rate (µmol/m²/s)		Transpiration rate (mmol/m²/s)		Stomatal conductance (µmol/m²/s)		Canopy Temperature (°C)		Canopy temperature depression (°C)		Grain yield per plant (g)		Above ground biomass (g)	
	Irrigated	Stressed	Irrigated	Stressed	Irrigated	Stressed	Irrigated	Stressed	Irrigated	Stressed	Irrigated	Stressed	Irrigated	Stressed
RSV 1850	5.12	3.64	1.08	0.77	0.055	0.039	36.0	36.4	0.9	0.5	38.06	29.55	185.6	105.6
RSV 1876	19.64	17.27	4.22	3.71	0.155	0.136	35.1	35.2	1.8	1.7	60.09	53.65	228.9	202.5
RSV 1945	18.45	12.84	3.81	2.64	0.141	0.097	35.2	35.6	1.7	1.3	59.01	45.28	225.0	172.2
RSV 2371	16.76	11.60	3.30	2.28	0.126	0.087	35.3	35.6	1.6	1.3	57.75	44.18	224.5	170.4
CRS 89	14.24	8.88	3.05	1.90	0.122	0.076	35.4	35.7	1.5	1.2	56.17	40.83	221.1	155.4
CRS 93	12.87	8.24	2.96	1.89	0.114	0.072	35.5	35.8	1.4	1.1	54.50	40.10	218.2	151.4
CRS 95	12.61	8.64	2.76	1.89	0.111	0.075	35.5	35.7	1.4	1.2	54.05	41.11	216.5	153.8
CRS 98	12.05	5.82	2.68	1.28	0.108	0.051	35.5	36.0	1.4	0.9	53.66	35.40	216.1	141.4
CRS 99	26.88	13.33	5.40	2.67	0.205	0.101	34.7	35.6	2.2	1.3	65.25	43.38	242.2	174.3
VJP 2704	21.95	11.83	4.33	2.32	0.170	0.090	35.0	35.7	1.9	1.2	61.38	42.04	233.9	167.0
VJP 2705	13.99	10.24	3.16	2.31	0.116	0.084	35.4	35.6	1.5	1.3	55.58	43.86	220.7	165.2
RNTN-13-39	25.46	13.64	4.93	2.64	0.192	0.102	34.8	35.6	2.1	1.3	64.47	44.04	239.0	174.5
RNTN-14-1	14.36	6.49	2.80	1.26	0.113	0.050	35.4	36.1	1.5	0.8	55.73	36.03	220.6	140.6
RNTN-14-2	8.11	5.01	1.56	0.95	0.066	0.040	35.8	36.3	1.1	0.6	43.50	31.51	194.3	110.5
RNTN-14-3	8.41	6.69	1.79	1.42	0.075	0.060	35.8	36.0	1.1	0.9	44.75	37.16	195.6	129.6
M-35-1	14.00	8.97	2.76	1.76	0.109	0.069	35.4	35.7	1.5	1.2	55.60	40.93	218.6	152.1
P. Suchitra	18.10	10.44	3.72	2.15	0.142	0.081	35.2	35.7	1.7	1.2	58.69	41.24	227.0	160.3
P. Anuradha	21.86	17.65	4.65	3.76	0.173	0.139	35.0	35.3	1.9	1.6	62.12	52.09	234.3	201.1
Mean	15.82	10.07	3.28	2.09	0.127	0.080	35.3	35.8	1.6	1.2	55.57	41.24	220.1	157.1
	Sem(±)	CD @ 5%	Sem(±)	CD @ 5%	Sem	CD	Sem	CD	Sem	CD	S.Em	LSD @5%	S.Em	LSD @5%
Main plot	0.168	2.13	0.157	1.99	0.01	0.08	0.01	0.11	0.00	0.03	0.02	0.26	0.11	1.51
Sub plot	0.146	0.46	0.03	0.09	0.00	0.00	0.01	0.02	0.00	0.01	2.91	9.27	2.07	6.61

This study confirms the dependability of canopy temperature on the gas-exchange parameters in sorghum. The cooler canopy is essential for the regular metabolic activity on the plant which is more evident in the drought tolerant genotypes. The positive association of that with canopy temperature depression in a genotype is of profound importance. Another observation is that the canopy temperature is not an independent attribute but, it is dependent on the gas exchange parameters transpiration rate and stomatal conductance properties unique to that genotype.

Conflict of interest

The authors declare no conflict of interest

Consent for publication

All the authors provided consent and approved the submission of the manuscript to the journal of cereal research

Compliance with ethical standards:

NA

Authors contribution

All authors provided critical input and helped to shape the research, analysis and manuscript.

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