06.30.2025

JOURNAL OF

Health, Metabolism & Nutrition Studies (JHMNS) Vol. 8 No. 3

INHERITANCE OF HEAT TOLERANCE IN BREAD WHEAT (*TRITICUM AESTIVUM* L.)

[1]I. M. ABDULLAHI; [2]A. USMAN; [3]E. N. HENREITTA; & [3]L. A. OBONYILO

[1]Cereal Research Department, Lake Chad Research Institute Maiduguri. [2]Department of Agronomy, Faculty of Agriculture, Federal University of Lafia. [3]Department of Plant Science, Faculty of Agriculture, Ahmadu Bello University, Zaria.

DOI Link: https://doi.org/10.70382/bejhmns.v8i3.024

Abstract

Heat is a serious production challenge to wheat such that more than 50% of the cultivated area experiences a high temperature (HT) stress leading to a dramatic loss in yield every year Mitigating this constraint requires development of heat tolerant wheat genotypes. The objective of this study was determining the mode of gene action governing the inheritance heat tolerance in wheat. Six genotypes comprising of three heat tolerant and three heat susceptible were crossed to generate three sets of crosses: 29872 x 30119 (cross I), Tesfa x 29642 (cross II) and 30098 x 29988 (cross III). The F_1 progenies of each cross were advanced to F_2. The parents, F_1 and F_2 of each cross were evaluated under heat stress condition (27-37^{0}C) at Research Farm, Federal University of Lafia in randomized complete block design with two replications. Crop management followed the recommended agronomic practices

Introduction

Wheat (*Triticum aestivum* L.) is one of the world's most important crops, providing a significant source of calories and protein for the human population worldwide (Mishra *et al.,* 2021). Wheat grain consists of three distinct parts: bran (13-17%), germ (23%), endosperm (80-85%), and contains all essential nutrients. Generally, wheat contains 70% carbohydrates, 12% water, 2% fat, 12% protein, 1.8% minerals, and 2.2% crude fiber in the grain. Wheat is used for the production of bio-ethanol, succinic acid, bread, cake, crackers, cookies, pastries,

E-ISSN 3026-8664 P-ISSN3027-2238

for wheat production. Data were collected on days to heading, days to maturity, length of spike (cm), number of spikelets per spike, grain yield (g), 1000 grains weight (g), biomass (g), relative chlorophyll content, canopy temperature (^{0}C), membrane thermal stability (%) and relative cell injury (%). The results of analysis of variance revealed significant (p≤0.05) differences among the generations for all traits studied except canopy temperature (Zadok 77) and length of spike in cross indicating variation among generations for the traits providing adequate scope for selection. The results of C scaling test were significant (p≤0.05) for heat and other agronomic traits suggesting inadequacy of the additive-dominant model. This may imply the use of generation mean analysis to fully understand the mode of inheritance for heat tolerance in wheat.

Keywords: Heat, wheat, membrane thermal stability, additive-dominant model.

Spaghetti, macaroni, cosmetics, malt, alcohol, dextrose, gluten, and pharmaceutical products, animal feed and for many more others (Yemsrach *et al.,* 2015). Global wheat production stands at 808.2 million metric tons (FAOSTAT, 2023). In Africa, wheat production stands at 27.34 million metric tons in the same year. Despite the global economic importance of wheat, productivity in Nigeria is constrained by several biotic and abiotic factors. The most important abiotic stresses are high temperature, drought, flood and other natural disasters.

Based on field and weather data, detrimental effect of high temperature on wheat productivity were quantified, a 1^{0}C temperature increase was estimated to reduced yield by 3 - 17% in south Asia (Tiwari *et al.,* 2013), 3-10% in China (You *et al.,* 2009) and 21% in USA (Barkley *et al.,* 2013). Wheat yield could be reduced up to 50% when the seasonal temperature was 2^{0}C higher than average (Asseng *et al.,* 2011). Thus, negative effect of high temperature on productivity of wheat becomes more detrimental as climate change progresses. Globally, wheat grain yield was estimated to be reduced by 6% for each degree Celsius temperature increased. Thus, high temperature accompanied by heat stress is the major cause of low wheat productivity in Nigeria.

The negative effects of high temperatures on the productivity of wheat and other crops will become more detrimental (Lobell *et al.,* 2011). In this context, a sustainable way of mitigating economic consequences and heat stress damage is to develop heat tolerant varieties. Several approaches such as mutagenensis, synthetics and transgenics have been used in an attempt to develop heat tolerant varieties. Although resistance to high temperature involves several complex tolerance and avoidance mechanisms, thermal stability in wheat is a critical concern, especially in the context of rising temperatures due to climate change. Membrane thermal stability is moderately heritable (Yildirim *et al.,* 2009) and showed high genetic correlation with yield indicates its potential application in breeding. The objective of this study was determining the mode of gene action governing the inheritance heat tolerance in wheat.

Materials and Methods

The research was conducted in two locations, the National Root Crops Research Institute, Vom station in Jos, Plateau State and the Teaching and Research Farm Faculty of Agriculture, Federal University of Lafia, Nasarawa State. The National Root Crops Research Institute, Vom lies on Latitude 9^0 44^0N and Longitude 9^0 47^0 E with an altitude of 400 m above sea level in Guinea Savannah agro-ecological zone of Nigeria (NCRI, 2020). The weather condition of Vom at the time of population development showed temperature and relative humidity ranges from 18^0C - 34^0C and 18% - 22% from December 2021 to March 2022. Rainfall ranges between 188.4 - 366.8 mm between July and September. Hybridization and generation advancement of F_1 to F_2 was conducted in Vom. Federal University of Lafia is located on Latitude 8°28'15.2"N 8°35'14.9"E (FU Lafia, 2020). The temperature of the experimental site at the time of evaluation was within the range of 24^0C – 44^0C between December 2022 and March 2023. The hybridization exercise was conducted during 2021/2022 between 29872 (Susceptible female) x 30119 (Tolerant male), Tesfa (susceptible female) x 29642 (tolerant male) and 30098 (susceptible female) x 29988 (tolerant maleThe evaluation of P_1, P_2, F_1 and F_2 for each cross were evaluated under heat conditions (27^0C – 37^0C) at Lafia. Temperature status of the experimental sites is presented in Table 1

Vol. 8, No. 3

Journal of Health, Metabolism and Nutrition Studies

Table 1. Lafia temperatures during evaluation between December 2022 and March 2023

Temperature (^0C)	Jos					Lafia				
	Dec	Jan	Feb	March	April	Dec	Jan	Feb	March	April
Minimum	18	20	22	24	22	28	26	28	28	24
Average	24	27	28	29	28	34	32	34	36	34
Maximum	30	34	34	34	34	40	38	40	44	44

Genetic materials

The genetic materials consist of six genotypes of three heats tolerant and three heats susceptible obtained from Germplasm unit of Lake Chad Research Institute Maiduguri based on heat tolerance and susceptibility status. Description of the genotypes used for the experiment is presented in Table 3.2

Table 2: Description of Genotypes used for the crosses of Wheat genotypes

Code	Pedigree	DHH	CHL	DMT	YLDha^{-1}	Origin	Status
29872 (P_1)	ATTILA1/NS732/HER//PARUS/PASTOR/3/TEMPORALERAM 87*2/KONK SERI*3//RL6010/4*YR/3/PASTOR/4/BAV92/5/	60.67	8.02	99.3	1.76	LCRI	Susceptible
30119 (P_2)		60.33	9.99	93	3.81	LCRI	Tolerance
Tesfa (P_1)	Tesfa	72.33	8.04	93.33	3.81	LCRI	Susceptible
29642 (P_2)	HUBARA1/5/KAUZ/3/MYNA/VUL//BUC/FLK/4/ MILAN	57	9.14	91.67	4.77	LCRI	Tolerance
30098 (P_1)	RABIH-10/ETBW 4922//KAUZ'S'/FLORKWA-1 SERI*3//RL6010/4*YR/3/PASTOR/4/BAV92/5/.....	67	8.17	100	3.07	LCRI	Susceptible
29988 (P_2)		52	11.62	93.1	3.78	LCRI	Tolerance

Key: DHH=Days to heading,RCHL=Relative chloropyll content, DMT= Days to maturity, YLDha^{-1}=Grain yield per hectare

Experimental Design and Evaluation

The experiment was laid out in Randomized Complete Block Design with two replications. For non-segregating populations (Parents and F_1), each plot measured 2 x 2m, while for the segregating population (F_2), the plots measured 2 x 4m, with intra- and inter-row spacing of 30 x 20cm, respectively. Sowing was carried out on

15 December 2022 by dibbling method. Each replicate consisted of 60 plants for the parents and the F_1s, 120 plants for the F_2 population. Irrigation was carried out after sowing by flooding method.

Fertilizers were applied at recommended rate of NPK (120 kg N, 60 kg P_2O5 and 60 kg K_2O ha^{-1}) at sowing; half of the N and all of P and K were applied at sowing using NPK 15:15:15. The remaining half N was applied four weeks after sowing (WAS) using urea (46%) as source of N. Surface irrigation was used by conveying water through the primary canals and delivered into the basins using syphon tubes. Weeding was done manually by using hoe at 5 WAS, followed by handpicking at 8 WAS. An insecticide Emamectin Benzoate + Acetamiprid was applied at recommended rate (250 ml ha^{-1}) twice at grain filling to control stem borer. Harvesting was done manually with a sickle when the crop had reached maturity (LCRI, 2017).

Data were collected on Tiller count, Plant height (cm), Days to heading, Length of spike (cm), Number of spikelet per spike, Days to Maturity, Grain yield per plant (g), Biomass per plant (g), Canopy Temperature (^{0}C), Relative Chlorophyll content and Membrane thermal stability and Relative cell injury

Procedure for Cell Membrane Thermal Stability Test

Cell membrane thermal stability (MTS): Expended leaves were cut from plants in each replication. The leaves were thoroughly washed with de-ionized water, and each leaf was divided into two parts to be used as control and heat treatment. One gram sample of these leaves was placed into two different test tubes containing 20 ml of de-ionized water. One of the test tubes was kept at 25 ^{0}C and the other at 46^{0}C for one hour in water bath to stabilize the content of the liquid compounds after treatment; the test tubes were kept at room temperature. Conductivity readings were recorded at 25^{0}C using an electrical conductivity meter for control (C_1) and heat treated (T_1) tubes. Both the test tubes were further autoclaved at 120^{0}C for 20 minutes. The second conductivity reading of the aqueous phase (C_2 and T_2) was taken after the samples were cooled to room temperature. The MTS values were estimated using the following equation as suggested by Blum and Ebercon (1981).

$$MTS = (1 - \frac{T_1}{T_2}) \times 100$$

Where T_1 and T_2 are conductivity readings before and after autoclaving, respectively.

RCI% $1-\left(1-\frac{T_1}{T_2}\right)/1-\left(\frac{C_1}{C_2}\right)\times 100$

Where:

C_1 and C_2 are control conductivity readings before and after autoclaving, respectively.

Data Analysis

The data collected were subjected to analysis of variance (ANOVA) using General Linear Model procedure of Statistical Analysis System (SAS) package. Where significant differences exist, Fisher's protected least significant difference (LSD) test was used to make comparisons between treatment means (Gomez and Gomez, 1984).

Linear model used for RCBD analysis:

Where: Observed effect for i^{th} replication j^{th} genotype and k^{th} block. Grand mean of the experiment, Effect due to i^{th} replication, Effect due to j^{th} genotype Effects due to the residual or random error of the experiment

Inheritance

Scaling test C was computed following the methods explained by Mather (1949) and Hayman & Mather (1955) to test the adequacy of additive-dominance model. Using $C = 4\overline{F}_2 - 2\overline{F}_1 - \overline{P}_1 - \overline{P}_2$ Where $\overline{F}_2, \overline{F}_1, \overline{P}_1,$ and $\overline{P}_2$ are means effects of F_2, F_1, P_1 and P_2.

Results and Discussion

The results of analysis of variance (ANOVA) for the agronomic and heat tolerant traits of bread wheat evaluated during heat condition at Lafia during 2022/2023 dry season are presented in Table 3. The results revealed significant ($p \leq 0.05$) differences among generations for all traits studied except canopy temperature (Zadok 77) and length of spike per plant in cross I. Canopy temperature (Zadok 77), days to maturity and biomass in cross II. However, in cross III, results indicated significant ($p \leq 0.05$) variation for all traits, except canopy temperature (Zadok 72), days to maturity and number of spikelets per spike. The observed significant variations for tiller count, days to heading, Relative chlropyll content, membrane thermal stability, relative cell injury, number of spikelets per spike, grain yield per plant and biomass in cross I. Tiller count, membrane thermal stability, relative cell injury, length of spike per plant and grain yield per plant in cross II. Tiller count, days to heading, plant height, membrane thermal stability, relative cell injury, length of spike, grain yield per plant in cross III, may suggest scope for improvement of the genotypes for heat tolerance. This is in line with the findings of Sareen *et al.,* (2018) who reported significant variations for all crosses and traits under heat stress conditions, suggesting opportunity to improve wheat for heat tolerance.

Table 3: Analysis of variance for traits of bread wheat (*Triticum aestivum* L.) Lafia

SOV	df	TLC	DDH	RCHL	MTS	RCI	CT 72	CT77	PHT	LSP	DMT	NSP	YLD	BMA
29872 x 30119														
Rep	1	0.15	2.04	0.01	0.15	0.15	2.71	1.47	0.26	0.11	0.15	0.09	0.47	5.79
Gen	3	**4.59****	**43.03****	**4.64***	**800.82****	**800.82****	**0.07***	**0.51**	**54.18****	**1.18**	**4.01****	**5.63****	**4.50***	**85.42****
Error	3	0.05	0.89	0.35	0.45	0.45	1.01	0.53	0.06	0.11	0.04	0.21	0.35	1.83
Tesfa x 29642														
Rep	1	0.55	0.04	0.16	0.13	0.13	0.04	1.60	0.50	0.36	2.39	0.01	23.03	1.58
Gen	3	**0.98****	**15.78****	**7.07****	**414.40****	**414.40****	**1.43***	**1.27**	**1.31***	**2.30***	**0.53**	**2.90***	**80.16***	**63.92**
Error	3	0.02	0.07	0.43	0.13	0.55	0.14	0.59	0.09	0.51	0.11	0.11	13.87	0.04
30098 x 29988														
Rep	1	0.03	0.09	0.02	0.12	0.12	0.08	0.01	0.09	0.09	0.39	0.53	1.79	0.43
Gen	3	**4.74****	**1.79***	**4.62***	**692.14****	**692.14****	**3.53**	**0.39***	**1.29***	**2.88***	**1.21**	**6.04**	**36.28****	**35.31****
Error	3	0.01	0.22	0.89	0.04	0.04	0.45	0.42	0.14	0.24	0.22	2.11	0.61	1.63

Key: SOV=Source of Variation, df=degrees of freedom, Rep=Replication, Gen=Generation**, *=** significant difference at (P≤0.05) probability level, TLC= Tiller count, DDH= Days to heading, RCHL= Relative chloropyll content, MTS=Membrane thermal stability, RCI= Cell membrane relative injury, SL=Length of spike, CT 72 and 77=Canopy temperature, PHT=Plant height, DMT=Days to maturity, NSP= Number of spikelets per spike, YLD=Yield per plant, BMA=Biomass

Scaling test and gene effects of additive-dominance model for four (P_1, P_2, F_1 and F_2) generations for yield and yield contributing traits of the crosses 29872 x 30119, Tesfa x 29642 and 30098 x 29988 are presented in Table 4.9. The results revealed significant (p≤0.05) variation for all the studied traits, except for relative chlorophyll content, canopy temperature and days to maturity in Cross I. In cross II, significant (p≤0.05) variation was observed for all the studied traits except relative cell injury.

However, in cross III, significant (p≤0.05) variation was observed for all traits investigated except number of tillers. The significance C scaling tests observed for DHH, MTS, RCI, CT (Zadok 77), PHT, LSP, NSP, YLD and BMA, indicates the inadequacy of the additive-dominance model to explain variation of these traits which suggest the presence of non-allelic interaction (epistasis) as digenic model to adequately explain the inheritance of the traits in the crosses. This is in line with the findings of El-Hawary (2016) and Kumar *et al.*, (2017), all reported the significance of any of these tests in the two crosses under both environments, except for number of spikes/plant in cross I at late sowing conditions.

Table 5: C Scaling test of additive-dominance model of bread Wheat crosses evaluated in Lafia during 2022/2023 dry season

Trait	C scaling test of additive dominance model		
	29872 x 30119	Tesfa x 29642	30998 x 29988
Tiller count	-6.88±0.72*	-3.63±0.24*	26.79±0.85
Days to heading	-12.64±4.99*	2.83±2.04*	-1.27.79±1.53*
Relative chloropyll content	-2.65±1.65	-7.55±0.72*	-1.14±2.21*
Membrane therma stability	-8.17±1.43*	-98.69±0.54*	5.41±2.24**
Relative cell injury	6.21±2.28*	18.00±3.03	-4.51±2.44*
Canopy temperature 72	8.77±3.66	2.38±0.07*	-0.31±1.31*
Canopy temperature 77	0.07±3.82*	-3.50±1.72*	1.31±1.43*
Plant height (cm)	-11.62±5.02*	-6.93±0.79*	-1.19±0.61*
Length of spike per plant (cm)	-4.06±2.12*	-5.65±0.32*	-1.16±1.01*
Days to maturity	16.27±6.33	-2.46±0.64*	-8.14±3.16*
Number of spikelets per spike	-7.88±2.82*	-18.20±0.49*	-6.01±1.48*
Yield per plant (g)	-18.37±2.82*	-13.07±0.65*	-9.31±2.31*
Biomass per plant (g)	-24.95±3.09*	-32.93±0.72*	-6.45±2.23*

*, **: significant and highly significant difference at (P≤0.05) and (P≤0.01) probability level respectively

Conclusions

The study revealed significant (p= ≤0.05) variations for heat tolerant and agronomic traits and the variations are heritable with broad-sense heritability estimates (> 60%). The study revealed that additive-dominance model was not adequate to explain the inheritance of the traits, as indicated by the significance (p= ≤0.05) of C scaling test. The inadequacy of the additive-dominance model suggests the use of generation mean analysis to understand the mode of inheritance for heat tolerance in wheat.

References

Asseng, S., Foster, I.A. and Turner, N.C. (2011). The impact of temperature variability on wheat yields. *Global Change Biology*. Vol. 17:997-1012.

Barkley, A. Track, J. Nalley, L. Bergtold, J. Bowden, R. and Fritz, A. (2013). Weather, disease, and Wheat breeding effects on Kansas wheat varietal yields, 1985-2011. *Agronomy Journal.* 227-35.

El-Hawary, M.N.A. (2016). Estimation of some genetic parameters using the six population mean analysis in four bread wheat crosses. Proceeding of the 6th field crops conference, 2016

FAOSTAT(Food and Agriculture Organization of the United Nations) (2023) Statistical databases and datasets Of Food and Agriculture Organization of the United Nations.

Federal University of Lafia (2022). *Fulafia. Edu.ng.* Retrieved 2022-12-30.

Gomez, K. and Gomez, A. (1984). Statistical Procedures for Agricultural Research 2nd ed. A Wiley Inter science Publication.John Wiley and Sons. New York. Chichester.Brisbane Toronto Singapore, pp 680.

Kumar, R.R. Goswami, S. Shamim, M. Dubey, K. Singh, K. and Singh, S. (2017). Exploring the heat-responsive chaperones and microsatellite markers associated with terminal heat stress tolerance in developing wheat Function Integration Genomics 17, 621–640.doi: 10.1007/s10142-017-0560-1.

Lake Chad Research Institute (2015) Extension Guide on the Production of Wheat.Pp 1-5

Lobell, D. B. Schlenker, W. and Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science* 333, 616–620. doi: 10.1126/science.1204531.

Mather, K. (1949) "Biometrical Genetics". 1st ed., p. 162. Metheum and Co., London.

Mishra, D., Shekhar, C. and Chakraborty, N. (2021). High temperature stress responses and wheat: Impacts and alleviation strategies. Environmentl and experimental botany Vol190, October 2021, 104589.

National Root Crops Research Institute, Vom (2020).Average temperature, rainfall and relative humidity for Kuru sub-station, 2019 and 2020.

Sareen, S., Bhusal, N., Singh, G. and Tyagi, B. (2018). Genetic of grain yield and its components in wheat under heat stress. *Cereals Research Communications* 46(3):1-12. DOI: 10.1556/0806.46.2018.024

Tiwari, C. Wallwork, H. Kumar, H. Dhari, U. Mishra, V.K Reynolds, M.P. and Joshi, A. (2013). Molecular mapping of high temperature tolerance in bread whaet adapted to Eastern Gangetic plain region of India. *Field crop Research* 154. Pp 201-210.

Yemsrach, Y. Tsadik, G. and Shimelis, A.E. (2015). Development of Value Added Products from Byproducts of Ethiopian Wheat Milling Industries. *Journal of Food Processing Technology* 2015, 6:8 DOI: 10.4172/2157-7110.1000474.

Yildirim, M., Bahar, B., Koc, M.and Barutcular, C. (2009). Membrane Thermal Stability at different Developmental Stages of Spring Wheat Genotypes and Their Diallel Cross Populations. *Tarim Bilimleri Dergisi* 2009, 15(4)293-300 ANKARA ÜNİVERSİTESİ ZİRAAT FAKÜLTESİ. DOI: 10.1501/Tarimbil_0000001103

You, L. Rosegrant, M. W. Wood, S. and Sun, D. (2009). Impact of growing season Temperature on wheat productivity in China. *Agricultural Journal for Meteorology*. 149, pp. 1009–1014. doi: 10.1016/j.agrformet.2008.12.004.