Journal of Tropical Crop Science Vol. 11 No. 1, February 2024
www.j-tropical-crops.com

Received 15/08/2023; Revised 17/11/2023; Accepted 26/01/2024
https://doi.org/10.29244/jtcs.11.01.9-18

Performance of Convergent Breeding Wheat (*Triticum aestivum* L.) Lines in the Lowlands

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Abstract

The development of tropical wheat in Indonesia is currently confined to the availability of wheat's optimal environments in the highlands. Wheat competes with major highland crops, such as vegetables, which also have high economic values. Despite this, the demand for wheat in Indonesia remains high, whether in the form of wheat flour, wheat meal, or oats. Wheat breeders are actively working to create various crossbreeds so that wheat can adapt and perform effectively in lowland areas. The convergent breeding method is one of the strategies employed to produce genotypes with superior performance. Convergent breeding enhances genetic diversity by incorporating superior traits from all parent plants. The breeding results expedite the emergence of genetic combinations between selected parents. This method involves combining several parent varieties with various traits, with the hope that their offspring will inherit all the characteristics of the crossed parents. Our study with wheat convergent breeding has reached the F6 generation, and in this current study we evaluated the performance of each observed trait in different environments, with the goal of determining the levels of homogeneity and homozygosity. The study utilized a randomized complete block design with three replications, and the crops were planted in various locations. The planting locations selected were those that are >1000 m above sea level (asl), and at a lowland of ± 250 m asl. Wheat performance based on stomatal characteristics showed a reduction in the lowland, which indicates a response to climatic conditions in a particular environment. The higher the environmental temperatures, the smaller the stomatal size, which reduces plant water loss. Noteworthy findings include the tallest plant in CBF-6.CAMN23(265), the highest number of tillers in CBF-6.CAMN233 and CBF-6.CAMN8(4), the largest flag leaf area in CBF-7.CAMN60, and the highest 100-seed weight, as well as overall yield in CBF-7.CAMN119. An analysis of the lowland sensitivity index identified ten moderate genotypes that could potentially adapt well and achieve optimal yields.

Keywords: tropical wheat, good performance and lowland sensitivity index.

Introduction

Wheat productivity in Indonesia remains relatively low, necessitating ongoing research and development efforts to fulfill domestic demand and reduce import dependence. According to 2022 FAO data, Indonesia's wheat imports have reached 13 million tons, and estimates suggest a yearly increasing trend. Common wheat (*Triticum aestivum*), also known as bread wheat, is a cultivated wheat species suitable for cultivation in summer within subtropical regions (Salim, 2016). *Triticum aestivum* has been developed in Indonesia, resulting in several adaptable varieties well-suited for tropical regions. Tropical wheat varieties in Indonesia thrive at elevations above 250 meters above sea level (m asl), with optimal performance occurring at 1000 m asl. The wheat exhibits resilience within a minimum temperature range of 2-4 °C, an optimum temperature range of 20-25 °C, and a maximum temperature of 37 °C. The ideal rainfall range for wheat cultivation is between 350-1250 mm, with an annual adequacy of 825 mm. Alongside these climatic conditions, suitable soil conditions for growth include a pH range of 6.8-7.5 and near-field capacity humidity (Sembiring, 2016). Despite meeting these climate and soil conditions, limited wheat development in highland areas still requires attention to meet the demands (Ministry of Trade of the Republic of Indonesia, 2022).

Received 15/08/2023; Revised 17/11/2023; Accepted 26/01/2024
https://doi.org/10.29244/jtcs.11.01.9-18

Several varieties introduced from Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) and other countries have been successfully adapted in Indonesia and released as superior national varieties. Notable examples include Selayar, Dewata, Nias, Timor, Ganesha, Guri (1,2), and Guri (3,4,5,6 wax) (Agricultural Instrumentation Standardization Agency, 2023). Some of these varieties have played pivotal roles as parents in enhancing wheat productivity in Indonesia through convergent breeding programs. These programs combine various parent wheat lines to boost genetic diversity (Hamam and Negim, 2014; Nur et al., 2015). The incorporation of broad genetic diversity in these breeding programs facilitates selection efforts, including the identification of lines that are tolerant or resistant to environmental stress (Said, 2014).

Convergent breeding involves the double crossing of plants to capture desired traits from elite parents with essential characteristics. Numerous crosses of self-pollinating plants have been conducted, leading to the acquisition of several superior rice varieties (Siddiq et al., 2012). In the realm of wheat, convergent crosses are executed by employing various parents with distinct genetic characteristics to obtain desired traits. The convergent crossing method is akin to Magic (Multiple Advanced Generation Intercross). In this approach, parents contribute a variety of traits with the anticipation that these traits can be linked to offspring with the potential for high yields in sub-optimal environments.

The genetic material utilized in this research comprises advanced generation F6 lines that have undergone selection across multiple generations and diverse environments. The selected trait for the parents is resistance to abiotic stress, specifically high temperatures, coupled with high productivity results. These traits represent the primary characteristics obtained through the convergent breeding process. The study aimed to develop lines that can adapt effectively to intermediate and lowland areas while demonstrating high resilience to environmental stress. The primary focus of this study was to examine the responses of convergent breeding lines to abiotic environmental stress factors, particularly heat stress, in lowland regions. Cipanas, situated in a highland area, and Tajur, located in a lowland area, served as contrasting environments for the study. Lowlands are a crucial destination for wheat cultivation research in Indonesia. The observed characteristics in the research highlight performance differences in optimal and suboptimal areas with various stresses in the lowlands. The outcomes of this research are anticipated to provide valuable insights for developing genotypes that perform well under abiotic stress conditions in lowland areas.

Material and Methods

This research was conducted at two locations, at the highlands Cipanas, Cianjur, West Java with elevation of 1080 meters above sea level, from August to December 2022, and the lowland Tajur, Bogor, with an elevation of approximately 250 meters above sea level, from January to May 2023. The genetic materials used in this study consisted of 26 advanced wheat lines resulting from convergent breeding crosses between Selayar, Oasis, Rabe, HP1774, Dewata, and Alibey, as well as 4 reference varieties, namely Dewata, Guri-5, Guri-6 (wax), and Selayar. This lines resulting from convergent breeding was created by breeders from BSIP in 2013. The lines used were in the F6 generation, which had been initiated for preliminary yield testing. The research was arranged in a randomized complete block design consisting of 26 lines and 4 reference varieties as controls, replicated three times, resulting in a total of 90 plots at each location. The plot size utilized was 1.5 x 5 meters with a planting distance of 25 cm between rows, and seeds were sown in rows. Wheat cultivation guidelines provided by the Indonesian Ministry of Agriculture (Sembiring, 2016) were used as a reference.

Observations and measurements were carried out on 10 sample plants in each plot. The outer rows of plants were not used for observations; only the middle 4 rows were selected as samples, taken randomly from within a 1 m x 1 m (1 m²) area. In the sample plot, ten plants were selected. The plants selected are random in each array. One plant was repeated for three biological replicates for all observed characters. The measured agronomic traits were as follows: (1) Stomatal characteristics that were observed are from the abaxial leaf collected during the vegetative phase. The microscope used was an Olympus binocular microscope with 40x magnification. Observation and measurements were made on quantity, size, stomatal density (SD), and stomatal index (SI), with the following formula:

$$\mathrm{SD} = \frac{\sum \mathrm{stomata}}{\mathrm{object\ area}}$$

$$\mathrm{SI} = \frac{\sum \mathrm{stomata}}{\sum \mathrm{stomata} + \sum \mathrm{epidermis}} \mathrm{x100}$$

(2) Plant height was measured using a 1-cm scale measuring instrument. (3) Tillering number: The number of tillers was counted within a row. (4) Flag Leaf Area: The area of the flag leaf was measured using ImageJ software. Plant height, number of tillers and flag leaf area were measured at the final vegetative phase. (5) 100-seed-weight (6) Yield:

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the fresh weight of the harvested yield (7) Lowland stress sensitivity index (SSI), where genotypes were grouped into categories of tolerant, moderately tolerant, and sensitive based on their sensitivity index values. The index of sensitivity to high temperature was calculated using the equation proposed by Fischer and Maurer (1978):

$$SSI = (1 - Ys/Yp) / SI$$

Where:

SSI = sensitivity index of a specific genotype

SI = $(1-\overline{Xs}/\overline{Xp})$

Ys = mean trait value of genotype -i in the stressed environment

Yp = mean trait value of genotype -i in the optimal environment

$\overline{Xs}$ = mean trait value of the population in the stressed environment

$\overline{Xp}$ = mean trait value of the population in the optimal environment

According to the equation, wheat genotypes were classified as tolerant if they had $S < 0.5$, moderate if $0.5 < S < 1$, and sensitive if $S > 1$ (Fischer and Maurer 1978)

The data analysis encompassed the within-environment analysis of variance and the combined analysis of the two locations. Mean value tests were performed using the Tukey test to identify differences among genotype or location for significantly different traits. The data analysis and mean value tests were conducted using the R programming language with the Agricola library. Analysis of variance was employed to estimate the broad-sense heritability (h^2_{bs}) value according to Stansfield (1983). Heritability estimation followed the method proposed by Hallauer and Miranda (1998) The model equation used for h^2_{bs} is:

$$h^2_{bs} = (\sigma^2_g) (\sigma^2_p) \times 100\%;$$

Where:
- σ^2_g = genetic variance
- σ^2_p = phenotypic variance

Heritability is categorized as low if the value is less than 20%, moderate if it falls within the 20-50% range, and high if it surpasses 50% (Sobir and Syukur 2015). A high heritability value indicates the effectiveness of selection efforts (Wulandari et al. 2016).

Result and Discussion

Figures 1 show that air temperature and relative humidity in the highland Cipanas exhibit an inverse relationship based on the planting month. The temperature in the Cipanas decreases over the months of planting, while in the lowland Tajur, it increases with each planting month. Elevation can significantly influence most climatic conditions due to its impact on air pressure. Lowland areas experience higher air pressure, causing an increase in air mass and volume at higher elevations. This results in the accumulation of substantial heat, which can lead to heat stress affecting plants. Conversely, the trend for relative humidity is the opposite. However, wind speed and precipitation in the Cipanas region are lower compared to the Tajur location. This demonstrates that elevation significantly influences the climate of a region. Tropical wheat varieties in Indonesia can grow at > 250 meters above sea level (m asl) but performing well at 1000 m asl where the minimum temperature of 2 to 4°C, the average temperatures of 20 to 25°C, and the maximum temperature of 37°C. The optimal rainfall range for wheat cultivation

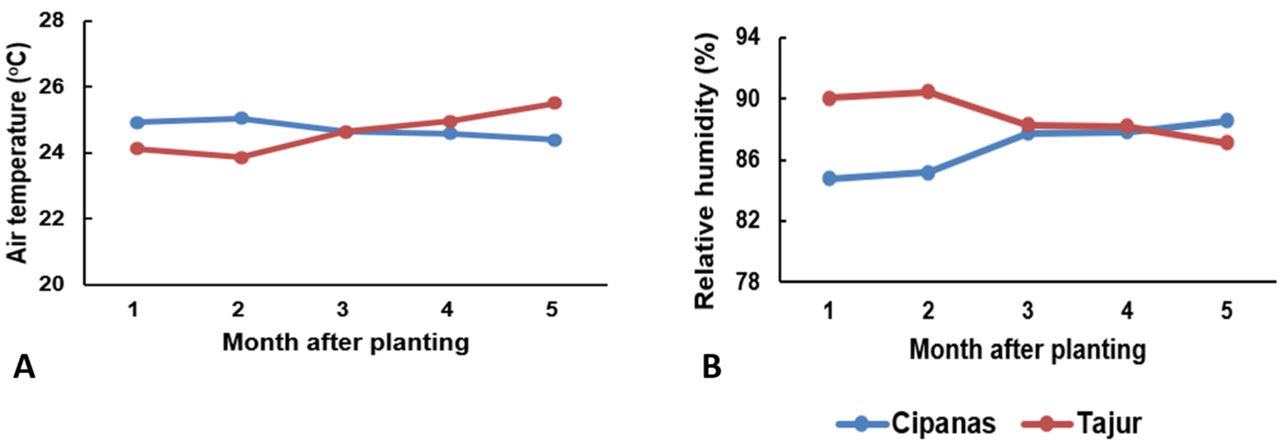

Figure 1. Air temperatures (A) and relative humidities (B) during the five months study in the highland Cipanas (August – December 2022) and the lowland Tajur (January – May 2023)

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https://doi.org/10.29244/jtcs.11.01.9-18

is between 350 to 1250 mm, with an adequate rainfall of 825 mm annually (Sembiring, 2016)

In Table 1, it was seems from the mean value that stomatal length, stomatal density and stomatal index were slightly reduce at lowland, i.e stomatal length from 27.74 to 27.07, stomatal density from 10.79 to 10.53, and stomatal index from 27.52 to 25.90. Elevated air temperature can raise the temperature around plant organs and cells, triggering the closure of stomatal pores with lower density. Figure 1A shows that the temperature in Tajur is higher than Cipanas, resulting in an increased transpiration rate. Consequently, wheat plants adapt by reducing the number of stomata to minimize water loss (hydration), as reported in Céccoli et al. (2022).

The stomatal index is the stomata ratio to the number of stomata and epidermal cells. Therefore, the stomatal index reflects the density of stomata. Table

Table 1. Stomatal characteristics of wheat lines and variety in the highland Cipanas and the lowland Tajur

Genotypes	Stomatal size (μm)					
	Cipanas (highland)			Tajur (lowland)		
	SL	SD	SI	SL	SD	SI
CBF-6.CAMN110	30.83	7.64	21.43	27.00	8.92	24.14
CBF-6.CAMN15(122)	21.45	14.01	33.33	29.00	10.19	22.86
CBF-6.CAMN17(80)	29.33	11.46	34.62	23.00	6.37	18.52
CBF-6.CAMN20(158)	25.13	10.19	26.67	24.55	14.01	30.56
CBF-6.CAMN22(246)	26.50	10.19	25.00	26.18	14.01	30.56
CBF-6.CAMN23(265)	26.00	7.64	26.09	24.27	14.01	32.35
CBF-6.CAMN233	26.78	11.46	29.03	26.20	12.74	30.30
CBF-6.CAMN25(93)	25.89	11.46	26.47	38.44	11.46	27.27
CBF-6.CAMN26(268)	28.73	14.01	33.33	22.29	8.92	25.93
CBF-6.CAMN27(231)	28.22	11.46	29.03	24.86	8.92	23.33
CBF-6.CAMN4(174)	30.29	8.92	24.14	28.63	10.19	28.57
CBF-6.CAMN8(4)	22.82	14.01	32.35	29.00	10.19	27.59
CBF-7.CAMN115	25.00	10.19	24.24	30.29	8.92	22.58
CBF-7.CAMN119	28.62	16.56	35.14	29.75	5.10	13.79
CBF-7.CAMN121	26.22	11.46	27.27	28.18	14.01	29.73
CBF-7.CAMN123	28.00	8.92	21.88	22.60	12.74	29.41
CBF-7.CAMN142	30.20	12.74	30.30	25.43	8.92	22.58
CBF-7.CAMN154	32.00	7.64	22.22	26.20	12.74	29.41
CBF-7.CAMN159	25.67	7.64	23.08	28.88	10.19	21.62
CBF-7.CAMN171	29.33	11.46	31.03	29.22	11.46	31.03
CBF-7.CAMN192	31.75	6.37	17.24	32.20	6.37	19.23
CBF-7.CAMN256	28.14	8.92	31.82	23.09	14.01	33.33
CBF-7.CAMN51	27.71	8.92	23.33	30.83	7.64	20.00
CBF-7.CAMN53	27.18	14.01	34.38	24.67	11.46	27.27
CBF-7.CAMN60	24.67	7.64	20.69	22.58	15.29	34.29
CBF-7.CAMN95	27.33	11.46	30.00	32.75	10.19	23.53
Dewata	31.11	11.46	25.71	26.63	10.19	27.59
Guri-5	29.29	8.92	24.14	26.00	7.64	19.35
Guri-6 (wax)	30.00	11.46	26.47	21.71	8.92	22.58
Selayar	27.92	15.29	35.29	27.75	10.19	27.59
Mean	27.74	10.79	27.52	27.07	10.53	25.90

Note: SL= stomatal length; SD= stomatal density (stomata/μm); SI= stomatal index.

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Table 2. Combined analysis of variance of wheat lines and variety in the highland Cipanas and the lowland Tajur.

Characters	L	Pr(>F)	U(L)	Pr(>F)	G	Pr(>F)	GxL	Pr(>F)
Agronomy characters								
Plant height	***	<.0001	ns	0.2646	***	<.0001	***	<.0001
Flag leaf area	***	<.0001	ns	0.9663	***	<.0001	***	<.0001
Tiller number	***	<.0001	ns	0.0949	***	<.0001	***	<.0001
Yield characters								
100-seed weight	***	<.0001	ns	0.1279	ns	0.2152	ns	0.2919
Yield	***	<.0001	ns	0.6269	***	0.0025	***	0.001

Note: L= location, U(L)= replication in location, G= genotypes, GxL= genotype by location; *** significant at α=0.01, ns= not significant at α=0.05 according to F-test.

1 shows that plants at the Tajur has area's stomatal index which is relatively lower than that at Cipanas. The lower mean value of the population in the Tajur suggests that plants reduce water loss by decreasing stomatal density on leaves, aiming to maintain tissue water potential (Céccoli et al., 2022). The lower stomatal density further supports this. The regulation of stomata in response to transpiration is a plant strategy to reduce water loss by decreasing stomatal numbers under heat-stress conditions (Hammad and Ali, 2014).

The results of the combined analysis of variance in Table 2 showed that all characters were significantly affected by location, genotype, and interaction of location x genotype, except for 100-seed weight which was not affected by genotype and interaction of genotype x location. Table 3 present the mean values of genotypes across the location, and mean values of locations across the genotypes.

Plant height is measured from the base of the plant to the tip of the spike, excluding the awns. The analysis results indicate that the reference variety Guri-5 is the tallest, followed by genotypes CBF-7.CAMN60 and CBF-6.CAMN23(265), reaching a height of 78 cm. However, the lowest height was observed in CBF-7.CAMN192. In plant breeding, shorter crops are a desired trait to ease harvesting (Correia et al., 2022). The average height of Indonesian wheat is 160-170 cm, and the crops in our study are shorter that the general crop height. Plant height at the lowland Tajur is shorter than in the highland Cipanas, with significant differences. This could be attributed to high-temperature stresses that triggered the crops to enter the reproductive phase earlier.

The number of tillers is directly proportional to the productive tillers of wheat. The more tillers there are, the more productive tillers are generated. Most productive tillers in wheat have the potential to yield grains (Regmi et al., 2021). The data analysis results show that the number of tillers in the Cipanas area is significantly higher than in Tajur, with values of 65.05 and 51.84, respectively. The highest number of tillers was observed in the genotype CBF-6. CAMN23(265), which is 72.17. Lowland areas have relatively less water due to high evaporation caused by high temperatures, reducing soil water intake and affecting cuticle formation. Reduced cuticles can cause air storage in plants to not be optimal, thereby reducing assimilation in forming essential plant organs (Tiwari *et al*., 2017). This also affects the number of productive tillers. Productive tillers encompass a portion within a clump that possesses productive spikes and contributes to the yield. The data shows that the highest number of productive tillers is in CBF-6.CAMN233, which is 5.98, and CBF-6.CAMN8(4) is not significantly different from the reference varieties. Productive tillers across different locations also are not similar to the experiment. This may be since the number of spikes is not influenced by environmental differences. Productivity results in wheat are calculated based on plot yields, which leads to a similar number of spikes.

Flag leaf area is one of the indicators of wheat plants that can represent the level of photosynthesis (Liu et al.*,* 2021). The flag leaf is the main component of wheat growth stages. Flag leaf area indicates the cross-sectional area of sunlight received on the leaf surface. The broader the cross-section, the more light the plant receives. So that the energy obtained in the photosynthesis process is maximized, thus determining the rate of panicle filling from the assimilated results. However, the area of the flag leaf also has a relationship with the plant's transpiration process because the more comprehensive the flag leaf, the higher the evaporation process. So, sometimes, the leaves will curl their leaves as an adaptation to reduce water loss (Lamba et al., 2023). The larger the surface area exposed to light,

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www.j-tropical-crops.com

Received 15/08/2023; Revised 17/11/2023; Accepted 26/01/2024
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Table 3. The mean values of agronomic character of wheat lines and variety across locations.

Genotypes / Locations	Height	Tiller number	Flag leaf area	100-seed weight	Yield
Genotypes					
CBF-6.CAMN110	69.61^{ab}	47.77^{ab}	34.17^{bc}	2.62^{ab}	0.68^{abc}
CBF-6.CAMN15(122)	69.29^{ab}	69.04^{ab}	35.57^{bc}	2.53^{ab}	0.85^{abc}
CBF-6.CAMN17(80)	68.47^{ab}	70.2^{ab}	25.91^{c}	2.59^{ab}	0.89^{abc}
CBF-6.CAMN20(158)	69.4^{ab}	70.22^{ab}	35.24^{bc}	2.74^{ab}	0.72^{abc}
CBF-6.CAMN22(246)	76.8^{ab}	56.15^{ab}	24.77^{c}	2.70^{ab}	0.82^{abc}
CBF-6.CAMN23(265)	78.21^{a}	72.17^{a}	32.06^{bc}	2.63^{ab}	0.92^{ab}
CBF-6.CAMN233	68.65^{ab}	65.55^{ab}	38.84^{abc}	2.57^{ab}	0.79^{abc}
CBF-6.CAMN25(93)	69.05^{ab}	44.96^{ab}	38.47^{abc}	2.14^{b}	0.94^{ab}
CBF-6.CAMN26(268)	69.06^{ab}	62.95^{ab}	43.07^{abc}	2.50^{ab}	0.51^{abc}
CBF-6.CAMN27(231)	69.45^{ab}	69.64^{ab}	21.15^{c}	2.60^{ab}	0.72^{abc}
CBF-6.CAMN4(174)	68.53^{ab}	69.45^{ab}	35.33^{bc}	2.60^{ab}	0.86^{ab}
CBF-6.CAMN8(4)	68.37^{ab}	48.89^{ab}	25.13^{c}	2.45^{ab}	0.69^{abc}
CBF-7.CAMN115	68.34^{ab}	46.00^{ab}	30.44^{bc}	2.06^{b}	0.71^{abc}
CBF-7.CAMN119	68.26^{ab}	70.37^{ab}	33.78^{bc}	2.62^{ab}	0.96^{a}
CBF-7.CAMN121	68.08^{ab}	59.89^{ab}	29.79^{bc}	2.66^{ab}	0.72^{abc}
CBF-7.CAMN123	69.95^{ab}	68.14^{ab}	28.17^{bc}	2.65^{ab}	0.77^{abc}
CBF-7.CAMN142	72.51^{ab}	56.28^{ab}	41.49^{abc}	2.25^{ab}	0.67^{abc}
CBF-7.CAMN154	69.45^{ab}	55.89^{ab}	26.00^{c}	2.51^{ab}	0.92^{a}
CBF-7.CAMN159	68.86^{ab}	51.53^{ab}	26.23^{c}	2.41^{ab}	0.51^{abc}
CBF-7.CAMN171	70.26^{ab}	62.9^{ab}	29.74^{bc}	3.95^{a}	0.87^{abc}
CBF-7.CAMN192	66.30^{b}	68.07^{ab}	26.04^{c}	2.49^{ab}	0.74^{abc}
CBF-7.CAMN256	68.59^{ab}	55.04^{ab}	39.98^{abc}	2.26^{ab}	0.60^{abc}
CBF-7.CAMN51	70.83^{ab}	54.26^{ab}	28.06^{bc}	2.65^{ab}	0.94^{ab}
CBF-7.CAMN53	67.75^{ab}	59.01^{ab}	21.18^{c}	2.48^{ab}	0.88^{abc}
CBF-7.CAMN60	78.23^{a}	68.52^{ab}	79.58^{a}	2.29^{ab}	0.49^{abc}
CBF-7.CAMN95	72.64^{ab}	54.22^{ab}	22.50^{c}	2.18^{b}	0.51^{abc}
Dewata	76.06^{ab}	45.05^{ab}	81.70^{a}	2.13^{b}	0.18^{bc}
Guri-5	78.59^{a}	39.47^{b}	59.88^{abc}	2.10^{b}	0.16^{c}
Guri-6 (wax)	75.40^{ab}	51.94^{ab}	69.87^{ab}	2.01^{b}	0.41^{abc}
Selayar	76.70^{ab}	39.83^{b}	35.11^{bc}	2.60^{ab}	0.71^{abc}
Locations					
Tajur	69.13^{b}	51.84^{b}	13.19^{b}	2.27^{b}	0.059^{b}
Cipanas	72.98^{a}	65.05^{a}	60.09^{a}	2.73^{a}	1.352^{a}

Note: Means followed by the same letter for each variable for genotypes or locations are not significantly different based on Tukey Test (HSD-test) at α=0.05.

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Received 15/08/2023; Revised 17/11/2023; Accepted 26/01/2024
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Table 4. The broad-sense heritability (h^2_{bs}) values of the wheat genotype traits in the highland (Cipanas) and the lowland (Tajur).

Character	Cipanas		Tajur	
	h^2_{bs}	Categorized	h^2_{bs}	Categorized
PH	0.98	High	0.32	Moderate
TN	0.70	High	0.54	High
FLA	0.77	High	0.49	Moderate
100-SW	0.86	High	0.01	Low
YW	0.44	Moderate	0.00	Low

Note: PH= plant height; FLA= flag leaf area; TN= tiller number; 100-SW= 100 seed weight; YW= yield weight; h^2_{bs}= broad-sense heritability. Heritability is categorized as low if the value is less than 20%, moderate if it falls within the 20-50% range, and high if it surpasses 50% (Sobir and Syukur 2015).

Table 5. The stress sensitivity index of wheat genotypes based on the yield-related traits.

Genotype	Yield (tons.ha^{-1})		SSI	Criteria	Genotype	Yields (tons. ha^{-1})		SSI	Criteria
	Cipanas	Tajur				Cipanas	Tajur		
CBF-6.CAMN110	1.24	0.11	0.95	Mod.	CBF-7. CAMN123	1.50	0.03	1.02	Sens.
CBF-6. CAMN15(122)	1.66	0.05	1.01	Sens.	CBF-7. CAMN142	1.21	0.13	0.93	Mod.
CBF-6.CAMN17(80)	1.74	0.03	1.03	Sens.	CBF-7. CAMN154	1.74	0.09	0.99	Mod.
CBF-6. CAMN20(158)	1.39	0.04	1.01	Sens.	CBF-7. CAMN159	0.97	0.05	1.00	Mod.
CBF-6. CAMN22(246)	1.56	0.08	0.99	Mod.	CBF-7. CAMN171	1.70	0.03	1.02	Sens.
CBF-6. CAMN23(265)	1.78	0.06	1.01	Sens.	CBF-7. CAMN192	1.46	0.03	1.02	Sens.
CBF-6.CAMN233	1.52	0.07	1.00	Mod.	CBF-7. CAMN256	1.13	0.08	0.97	Mod.
CBF-6.CAMN25(93)	1.86	0.01	1.04	Sens.	CBF-7.CAMN51	1.84	0.05	1.02	Sens.
CBF-6. CAMN26(268)	1.00	0.03	1.02	Sens.	CBF-7.CAMN53	1.70	0.05	1.01	Sens.
CBF-6. CAMN27(231)	1.30	0.14	0.93	Mod.	CBF-7.CAMN60	0.97	0.02	1.03	Sens.
CBF-6.CAMN4(174)	1.66	0.05	1.01	Sens.	CBF-7.CAMN95	0.96	0.06	0.98	Mod.
CBF-6.CAMN8(4)	1.36	0.03	1.02	Sens.	Dewata	0.28	0.09	0.71	Mod.
CBF-7.CAMN115	1.35	0.07	0.99	Mod.	Guri-5	0.27	0.05	0.85	Mod.
CBF-7.CAMN119	1.86	0.05	1.02	Sens.	Guri-6 (wax)	0.74	0.09	0.91	Mod.
CBF-7.CAMN121	1.41	0.04	1.01	Sens.	Selayar	1.39	0.03	1.02	Sens.

Note: Mod. = moderate tolerant; Sens. = sensitive (not tolerant); SSI= The stress sensitivity index

Received 15/08/2023; Revised 17/11/2023; Accepted 26/01/2024
https://doi.org/10.29244/jtcs.11.01.9-18

the higher the energy absorbed for photosynthesis, resulting in increased photosynthetic yield (Taiz and Zeiger, 2002). Based on the experimental mean values, it is observed that the tested genotype with the largest leaf area is CBF-7.CAMN60, measuring 78.23 cm², is not significantly different from the reference variety Dewata with a leaf area of 81.70 cm². Location differences also yield significant results, with the Tajur area having a mean value of 13.19 cm² compared to Cipanas with 60.09 cm². This variation can be attributed to climatic conditions and elevation differences between the experimental areas. Fender et al., (2011) stated that environmental factors can influence leaf area, causing organ reduction due to water deficiency.

The weight of 100-seeds and yield potential in the highland Cipanas is greater than those in the lowland Tajur. Productivity results in Cipanas show 100-SW of 2.73 g with a yield of 1.35 $t.ha^{-1}$, whereas the weight per genotype CBF-7.CAMN119, 100-SW is 2.62 g, and the potential yield is 0.96 $t.ha^{-1}$ (Table 3). Differences in the two locations can cause varying productivity results due to high-temperature stress, which triggers a decrease in yield due to the plant's adaptive response, namely avoidance (Hu et al., 2023). High temperatures can increase water evaporation to reduce materials in the photosynthesis process. Reduced water can inhibit the formation of assimilate, stored in wheat panicles. As a result, productivity tends to decrease (Mahdavi et al., 2022).

Broad-sense heritability is the ratio of genetic variance to phenotypic variance, and within genetic variance, there exist additive, dominant, and epistatic effects (Majhi, 2019). Traits with high heritability are used as selection criteria to select lines by the defined breeding objectives. Table 4 shows that in the highland (Cipanas), most traits exhibit high heritability, making these traits suitable for selection purposes for various breeding goals. In the lowland (Tajur), only flowering time, harvest time, and tiller counts exhibit high heritability. The variation in heritability values in the lowland location (Tajur) compared to the highland location (Cipanas) shows that the characters observed in the lowland are still influenced by the environment, resulting in phenotypic differences in the two environments.

The development of wheat in the lowland areas requires genotypes capable of maintaining yield potential in the lowlands while preserving their productivity in the highlands. The sensitivity index offers insights into yield reduction in lowland environments. Genotypes suitable for development in intermediate or lowland areas have a low sensitivity index and high yield potential in highland areas. The sensitivity index analysis in Table 5 reveals that among the four reference varieties, Selayar is categorized as sensitive, while Dewata, Guri-5, and Guri-6 (wax) are classified as moderate. Despite Selayar being sensitive, its yield potential surpasses the other three varieties. Out of the 26 convergent breeding cross lines tested, 10 lines are classified as moderate (moderately tolerant) to heat stress in lowland environments, indicating potential for testing in multiple locations. Poudel and Poudel (2020) state that heat stress disrupts plants' crucial physiological and biochemical processes. Additionally, heat stress reduces grain count, photosynthesis activity, chlorophyll content, and starch synthesis in the endosperm.

Conclusion

The characteristics of stomata in Cipanas, including size, density, and index, are greater than those in Tajur, specifically stomatal density (SD) at 10.79 and stomatal index (SI) at 27.52. The tallest plants were was recorded in CBF-6.CAMN23(265), the greatest number of tillers in CBF-6.CAMN233 and CBF-6.CAMN8(4), the widest flag leaf area in CBF-7.CAMN60, and the best weight of 100 seeds, along with overall results, in CBF-7.CAMN119. The sensitivity index of the studied genotypes and wheat varieties falls within the medium and sensitive criteria. Genotypes classified under the moderate criteria include CBF-6.CAMN110, CBF-6.CAMN22(246), CBF-6.CAMN233, CBF-6.CAMN27(231), CBF-7.CAMN115, CBF-7.CAMN142, CBF-7.CAMN154, CBF-7.CAMN159, CBF-7.CAMN256, and CBF-7.CAMN95. The genotypes resulting from our selection in this study can be used as for the future breeding. Lines that have high productivity and are resistant to stress can be used as parent lines in developing wheat in Indonesia.

References

Agricultural Instrumentation Standardization Agency. (2023). "New Superior Varieties of Indonesian Wheat." https://pustaka.setjen.pertanian.go.id/index-berita/787-varietas-unggul-baru-gandum. [July 1, 2023].

Céccoli, G., Ortiz, S.A.G., Buttarelli, M.S., Pisarello, M.L., Muñoz, F.F., Daurelio, L.D., Bouzo, C.A., Panigo, E.S., and Perez, A.A. (2022). Salinity tolerance determination in four sunflower (*Helianthus annuus* L.) hybrids using yield parameters and principal components analysis model. *Annals of Agricultural Sciences* **67**, 211–219.

Received 15/08/2023; Revised 17/11/2023; Accepted 26/01/2024
https://doi.org/10.29244/jtcs.11.01.9-18

Correia, P.M.P., Westergaard, J.C., da Silva, A.B., Roitsch, T., Carmo-Silva, E., and da Silva, J.M. (2022). High-throughput phenotyping of physiological traits for wheat resilience to high temperature and drought stress. *Journal of Experimental Botany* **73**, 1-5.

Draz, I.S., Abou-Elseoud, M.S., Kamara, A.E.M., Alaa-Eldein, O.A.E., and El-Bebany, A.F. (2015). Screening of wheat genotypes for leaf rust resistance along with grain yield. *Annals of Agricultural Sciences* **60**, 29–39.

Fender, A.C., Mantilla-Contreras, J., and Leuschner, C. (2011). Multiple environmental control of leaf area and its significance for productivity in beech saplings. *Trees* **25**, 847–857. doi:10.1007/s00468-011-0560-z

Fischer, R.A., and Maurer, R. (1978). Drought resistance in spring wheat cultivars. I. Grain yield responses. *Australian Journal of Agricultural Research* **29**, 897-912. https://doi.org/10.1071/AR9780897

Hallauer, A.R., and Miranda, J. (1988). “Quantitative Genetics in Maize Breeding” pp 33-67. Ames Iowa State University Press

Hamam, K.A., and Negim, O. (2014). Evaluation of wheat genotypes and some soil properties under saline water irrigation. *Annals of Agricultural Sciences* **59**, 165–176.

Hammad, S.A.R., and Ali, O.A.M. (2014). Physiological and biochemical studies on drought tolerance of wheat plants by application of amino acids and yeast extract. *Annals of Agricultural Sciences* **59**, 133–145.

Hu, H., Chen, L., Huang, Y., Wang, K., Bai, X., and Pan, H. (2023). CUT&tag-seq analysis of heat stress response in broiler liver provides novel insights into the improved thermotolerance by dietary phloretin. *Annals of Agricultural Sciences* **68**, 12–20.

Lamba, K., Kumar, M., Singh, V., Chaudhary, L., Sharma, R., Yashveer, S., and Dalal, M.S. (2023). Heat stress tolerance indices for identification of the heat tolerant wheat genotypes. *Scientific Reports* **13**. doi:10.1038/s41598-023-37634-8

Liu, X., Yin, B., Hu, Z., Bao, X., Wang, Y., and Zhen, W. (2021). Physiological response of flag leaf and yield formation of winter wheat under different spring restrictive irrigation regimes in the Haihe Plain, China. *Journal of Integrative Agriculture* **20**, 2343–2359. doi:10.1016/s2095-3119(20)63352-4

Ma, C., Xie, P., Zhang, K., Yang, J., Li, X., Liu, F., Lin, L., and Zhang, H. (2021). Contribution of the flag leaf to lead absorption in wheat grain at the grain-filling stage. *Ecotoxicology and Environmental Safety* **225**, 112722.

Mahdavi, S., Arzani, A., Maibody, S.A.M.M., and Kadivar, M. (2022). Grain and flour quality of wheat genotypes grown under heat stress. *Saudi Journal of Biological Sciences* **29**, 103417.

Majhi, P.K. (2019). “Heritability and Its Genetic Worth for Plant Breeding.” AkiNik Publications.

Nur, A., Syahruddin, K., and Mejaya, M.J. (2015). Genetic improvement of tropical wheat tolerant to high temperatures and challenges in development in lowland areas. *Journal of Agricultural Research and Development* **34**, 19.

Poudel, P.B., and Poudel, M.R. (2020). Heat stress effects and tolerance in wheat: a review. *Journal of Biology and Today’s World* **9**, 1–6.

Regmi, S., Poudel, B., Ojha, B.R., Kharel, R., Joshi, P., Khanal, S., and Kandel, B.P. (2021). estimation of genetic parameters of different wheat genotype traits in Chitwan, Nepal. *International Journal of Agronomy* **21**, 1-10.

Said, A.A. (2014). Generation mean analysis in wheat (*Triticum aestivum* L.) under drought stress conditions. *Annals of Agricultural Sciences* **59**, 177–184.

Salim, B.B.M. (2016). Influence of biochar and seaweed extract applications on growth, yield, and mineral composition of wheat (*Triticum aestivum* L.) under sandy soil conditions. *Annals of Agricultural Sciences* **61**, 257–265.

Sembiring, H. (2016). “Technical Guidelines for Wheat Cultivation Development 2016.” In Directorate General of Food Crops: Ministry of Agriculture.

Siddiq E, Vemireddy L, Nagaraju J. (2012). Basmati rice: genetics, breeding and trade. *Agricultural Research* **1**, 25–36.

Received 15/08/2023; Revised 17/11/2023; Accepted 26/01/2024
https://doi.org/10.29244/jtcs.11.01.9-18

Sobir and Syukur, M. (2015). "Genetika Tanaman". IPB Press, Bogor, Indonesia.

Stansfield, R. (1983). "Genetics", translated by Mohidin A, Apandi, Lanny T (1991) pp. 78-82. Erlangga, Jakarta, Indonesia.

Taiz, L. and Zeiger, E. (2002). "Plant Physiology: (3rd ed) pp 67-86. Sinauer Associates Publishers. Sunderland.

Tiwari, A., Prasad, S., Jaiswal, B., Gyanendra, K., Singh, S., and Singh, K.N. (2017). Effect of heat stress on yield attributing traits in wheat (*Triticum aestivum* L.). *International Journal of Current Microbiology and Applied Sciences* **6**, 2738–2744. doi:10.20546/ijcmas.2017.612.317

Wulandari, J.E., Yulianah, I., and Saptadi, D. (2016). Heritability and genetic progress of four F2 populations tomatoes (*Lycopersicum Esculentum* Mill.) in organic cultivation. *Journal Plant Protection* **4**, 361-369.