

Selection of wheat (*Triticum aestivum*) lines for the high altitude of Indonesia based on single- and multi-character adaptation

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Abstract. Nuraeni E, Wahyu Y, Trikoesoemaningtyas. 2021. Selection of wheat (*Triticum aestivum*) lines for the high altitude of Indonesia based on single- and multi-character adaptation. *Biodiversitas* 22: 5530-5535. The high demand for wheat in Indonesia encourages the assembly of wheat varieties adaptive to the tropical environment. The increase in wheat variability has been carried out through the crossing process, and it is necessary to evaluate the selection progress based on the adaptability of the genotypes resulting from the cross. This study aims to obtain information on the selection progress based on adaptation classes using single and multi-character of the F5 population. The study was conducted at the BB Biogen Experimental Field located at Ciwalen, West Java (925 masl), in August-December 2020. The F5 of HP1744/Selayar population was used as genetic material with two comparison varieties, namely Guri 1 and Guri 3. The adaptation class for a single character was determined based on seed weight per plant, while for multi-character based on the characters with a wedge between the high category heritability value and the correlation coefficient ≥ 0.5 . The result showed that the number of florets, seed weight per plant, number of tillers, number of productive tillers, and weight of seeds in the main panicle were selected as a reference for multi-character selection. The t-test showed that the adaptive and highly adaptive classes genotypes had higher yields than the comparison varieties. The selection differential which reflects the selection progress shows an increase in the mean value for all reference characters. Selection based on single-character adaptation resulted in a higher average value of seed weight in all classes compared to selection based on multi-character adaptation.

Keywords: Correlation, heritability, multi-character, seed weight per plant, selection

INTRODUCTION

Indonesia is the second-largest wheat importer after Egypt. The demand for wheat in Indonesia continues to increase due to the shift in people's consumption patterns towards flour-based foods and the high public preference for instant products. The dependence of food supply on imports will cause food insecurity, especially related to wheat products. Steps to develop wheat need to be taken to reduce the number of imports.

Unfavorable climate and land-use competition have become a major constraint for wheat cultivation in Indonesia. The tropical climate with high temperature and humidity is a limiting factor for wheat. Increasing temperature in wheat-growing areas has been reported to cause yield reductions of up to 22.49% and reduce morphological and agronomic performances (Shenoda et al. 2021). The decreasing of biomass resulted as an implication of being exposed to heat stress (Shenoda et al. 2021). Furthermore, heat stress occurs not only in daylight but also at night, known as night high temperature (NHT). It causes an unbalance sink-source regulation then leads to significant yield reduction (Gyawali et al. 2021). High temperatures also cause changes in the life cycle of wheat plants. The availability of wheat varieties suitable for the tropical climate is needed as the first step in the development of wheat in Indonesia. The assembly of wheat

varieties that are adaptable to high-temperature environments is also a global wheat development project in the face of future global climate change (Saha et al. 2020). In addition, availability of genetic material needs to be pursued to support wheat breeding schemes in Indonesia.

Diversity is a prerequisite for successful plant breeding for the desired character. One of the ways to increase diversity is through crosses. Wheat crosses were carried out in 2016 using varieties Guri 1 (G1), Guri 3 (G3), Jarissa (JA), HP1744 (HP) as female parents, and Selayar (Se) as male parents (Putri et al. 2020). The resulting populations include JA/Se, G1/Se, G3/Se, and HP/Se. Based on the evaluation of the F2 population, it is known that the HP/Se population has the highest number of transgressive segregants compared to other populations (Putri et al. 2020). Transgressive segregation is characterized by the extreme right and left values of the individual mean. The high transgressive segregation is expected to be able to produce potential lines.

Classification of adaptation in the population of HP/Se has been carried out by Putri et al. (2020) in the F2 generation based on the character of seed weight per plant, but the multi-character class determination process has not yet been carried out. It will affect the adaptive plant selection process in the next generation. Direct selection based on a single character reduces efficiency due to environment effect, polygenic, linkage, and nonadditive

gene action. Multi-character selection is an option to avoid those limitations (Fellahi et al. 2018). Multicharacter selection based on spike fertility and yield from Alonso et al. (2018) generates a higher yield and more stable genotypes than a single character. The characters used as the basis for determining the multi-character adaptation class are expected to be genetically inherited and support the improvement of the target character. Therefore, genetic advance is expected to occur in the selection process carried out in order to increase the chances of obtaining a genotype with the desired character.

This study aims to determine the adaptation class of F5 HP/Se wheat population in the high altitude based on single and multi-character characters. Furthermore, for the genotypes obtained from the analysis of multi-character adaptation classes, a selection differential was determined, which describes the genetic advance that can be achieved in the next generation of selection.

MATERIALS AND METHODS

Plant materials

The genetic material of the test was a population of F5 HP1744/Selayar derived from the assembly scheme of tropical wheat varieties, Bogor Agricultural University. Guri 1 and Guri 3 varieties from the Cereal Crops Research Institute, Maros, were used as comparisons.

Field experiment

The field trial was conducted from August to December 2020 at the BB Biogen experimental garden, Ciwalen, Kec. Sukaresmi, Kab. Cianjur, West Java, Indonesia at an altitude of 925 masl. During the experimental period, the minimum, maximum, and average temperatures were 21°C, 33.8°C, and 26.40°C. The average rainfall and humidity during the experiment were 203.24 mm and 77.64%, respectively. The experiment was carried out with individually spaced plantings. One row consists of 30 individuals with a spacing of 30 cm x 25 cm. The comparison varieties were randomly assigned between the test genotypes. Fertilizers used in the study were manure at a dose of 200 kg per hectare, 150 kg Urea per hectare, 100 kg KCl per hectare, and 150 kg SP36 per hectare. The dose of fertilizer was applied gradually at 14 DAP and 30 DAP. Pest control was carried out by applying an insecticide with an active ingredient of 70% propineb. Weed handling was carried out manually at 20 DAP, 50 DAP, and 70 DAP.

Observation characters

Observations were made on plant height (cm), number of tillers, flowering age (days after planting, DAP), number of productive tillers, percentage of non-productive tillers (%), flag leaf area (cm²), harvest age (DAP), safe weight (g), seed filling period (days), main panicle length (cm), main panicle seed weight (g), number of seeds in the main panicle, number of florets, number of empty florets, number of spikelets, weight of 100 seeds (g), number of seeds per plant, and seed weight per plant (g).

Statistical and genetic parameter analyses

Heritability, in a broad sense, describes the genetic proportion in plant performance. The environmental variability in this study was estimated from the observed characters of the comparison varieties based on the assumption that their genotype was homozygous for all loci. The estimation of phenotypic variance was determined based on the genotype of the F5 population. Based on Syukur (2018), the heritability category is divided into low (<20%), moderate (20-50%), and high (>50%).

$$H_{BS}^2 = \frac{\sigma_g^2}{\sigma_p^2} \quad \sigma_g^2 = \sigma_p^2 - \sigma_e^2$$

$$\sigma^2 = \frac{1}{n} \sum (x - \mu)^2 \quad CGV = \frac{\sqrt{\sigma_g^2}}{x}$$

Where: H_{BS}^2 : broad-sense heritability, σ_g^2 : genetic variability, σ_p^2 : phenotypic variability, σ_e^2 : environmental variability, σ^2 : variability, n : number of observations, x : value of observed character, μ : the average value of the observed character, CV: coefficient of variability.

The adaptation class was determined following the method of Walpole (1982) in Sastrosoemarmo et al. (2005) and Putri et al. (2020) based on a single character and multicharacter (Table 1). Seed weight per plant was the character used to classify the genotype's adaptation for single character. Characters with a wedge between the high category heritability values with a positive correlation with a coefficient ≥ 0.5 become a reference in determining the multicharacter adaptation class. The accumulated value of the adaptation of the selected characters is divided into adaptation classes, based on the formula below:

$$\Delta P : \frac{b-a}{n} \quad \Delta H : \frac{j-i}{n}$$

The t-test was carried out to compare the genotypes in the adaptation class with the performance of the comparison varieties.

The selection was carried out on three adaptation classes (adaptive moderate, adaptive, and highly adaptive) for single and multi-character characters. The value of the determining character of the multi-character adaptation class in the selected genotype is used to analyze the progress of selection seen from the value of the selection differential. The selection differential is the difference between the mean value of specific characters in the initial and the selected populations. It is done to see the difference in the selection response in the two approaches. The selection differential was determined following Syukur et al. (2018):

$$S = \bar{X}_s - \bar{X}_0$$

Where: S: selection differential, \bar{X}_s : average value after selection, \bar{X}_0 : average value before selection

Classification of adaptation classes and heritability analysis in this study using the Microsoft Excel program. The accumulated data were analyzed using the STAR program to obtain information related to correlation and t-test.

Table 1. Adaptation classes for wheat based on single and multi-character

Group	Adaptation class	Class group	
		Single	Multi-character
1	Not adaptive	$x < (\Delta P + a)$	$x < (\Delta H + i)$
2	Less adaptive	$\Delta P + a \leq x < (\Delta P + a) + \Delta P$	$\Delta H + i \leq x < (\Delta H + i) + \Delta H$
3	Moderately adaptive	$(\Delta P + a) + \Delta P \leq x < (\Delta P + a) + 2\Delta P$	$(\Delta H + i) + \Delta H \leq x < (\Delta H + i) + 2\Delta H$
4	Adaptive	$(\Delta P + a) + 2\Delta P \leq x < (\Delta P + a) + 3\Delta P$	$(\Delta H + i) + 2\Delta H \leq x < (\Delta H + i) + 3\Delta H$
5	Highly adaptive	$x \geq (\Delta P + a) + 3\Delta P$	$x \geq (\Delta H + i) + 3\Delta H$

Note: ΔP : The difference between the maximum-minimum values, a : minimum value of observed character, x : observed character value, b : maximum value of observed character, j : greatest total score of genotype, i : smallest total score, ΔH : change in the result of the total score

RESULTS AND DISCUSSION

Determining the multi-character for adaptation classification

Seed weight per plant was used as single character for grouping the wheat lines adaptability, according to Putri et al. (2020). To develop the multi-character adaptation criteria, the broad-sense heritability and correlation coefficients of characters to seed weight per plant were considered. The results showed that among characters evaluated, there were 3, 4, and 12 ones categorized as high, medium, and low broad-sense heritability values, respectively (Table 2). The number of tillers, number of productive tillers, and percentage of empty tillers included vegetative characters with high heritability values (84.45%, 77.82%, and 85.9%). Vegetative characters with medium broad-sense heritability include flag leaf area and plant height. Weight of biomass (g) indicates the low category. Flowering age and harvest age showed high heritability values, but the seed filling period appeared to have low heritability values. Various heritability values were also seen in characters related to generative characters. The results indicated that seed weight per plant had a high heritability value of 99.77%. The number of florets, the number of empty florets, the weight of 100 seeds, the weight of seeds in the main panicle, the number of seeds in the main panicle also had high heritability values among all observed characters (Table 2).

The correlation analysis of observed characters on seed weight per plant is presented in Table 3. Three characters have no significant correlation, namely flowering age, harvest age, and seed filling period, and the rest have a significant and highly significant correlation. All correlated characters have positive values except for the percentage of non-productive tillers. On the characters that are included in the positively correlated category, there are several characters with a high correlation coefficient (above 0.5), they were number of tillers, number of productive tillers, weight of seeds in the main panicle, number of spikelets, number of florets, and the weight of the number of stems. Based on heritability and correlation values, the number of florets, seed weight on the main panicle, number of tillers,

number of productive tillers, and seed weight per plant were selected as the basis for determining the multi-character adaptation class.

Wheat lines adaptation class and differential selection

Based on Table 4, the mean value of the adaptive and highly adaptive classes has a greater value than Guri 3 and the two comparisons. The non-adaptive and less-adaptive classes showed a smaller value than Guri 3, while the moderate adaptive class was not statistically greater but had a higher average result than the two comparisons. Regarding the number of productive tillers, the genotype in the less adaptive class was lower than Guri 3. Seed weight in the main panicle in the moderate, adaptive, and highly adaptive class was higher than Guri 3.

The average value of all adaptation classes based on single character was higher than that of multi-character (Table 5). Moderate adaptive class in single (30.46 g) and multi-character (20.43 g), even has a difference of 10.03 g. The number of genotypes in a highly adaptive class in a single character is more than in multi-character. An increase in the number of genotypes in the moderate and adaptive classes experienced an increase in multi-character. The selection process was carried out in moderate, adaptive, and highly adaptive classes and resulted in a different number of selected genotypes, i.e. for single character, 20 genotypes were obtained, and 55 ones for multi-character, and if both values were converted into percentages, it would be 11.7% and 32.16%.

Selection of moderate, adaptive, and highly adaptive classes either through single or multi-character methods does not only affect the weight of crop seeds but also affects the other four determining characters. Table 6 shows the selection differential and the percentage increase in observed character values after and before the selection is seen from two approaches. The mean value of seed weight per plant increased by 26.41 g in the single character approach and 13.11 g in the multicharacter. The percentage increase in both approaches was 226.31% and 112.34%, respectively. Overall, all characters showed a greater improvement in the single character approach than the multicharacter approach.

Table 2. Broad-sense heritability value and genotypic variability in wheat

Characters	σ^2_P	σ^2_G	$H^2_{BS}(\%)$	Category	CGV (%)
Plant height (cm)	82.75	27.60	33.36	Medium	0.54
Number of tillers	83.85	70.81	84.45	High	5.60
Flowering age (DAP)	1.83	1.83	100.00	High	0.03
Number of productive tillers	77.55	60.35	77.82	High	5.48
Percentage of non productive tillers (%)	364.07	310.87	85.39	High	16.41
Flag leaf area (cm ²)	24.40	10.89	44.64	Medium	0.21
Harvest age (DAP)	26.77	20.77	77.59	High	0.21
Weight of biomass (g)	727.41	-100.66	0.00	Low	0.00
Seed filling period (days)	0.16	-5.84	0.00	Low	0.00
Main panicle length (cm)	1.37	-0.11	0.00	Low	0.00
Main panicle seed weight (g)	0.38	0.36	94.74	High	0.20
Number of seeds of main panicle	127.22	98.58	77.49	High	2.68
Number of florets	142.98	77.22	54.01	High	0.58
Number of empty florets	43.39	25.20	58.07	High	1.53
Number of spikelets	8.08	2.24	27.68	Medium	0.15
Weight of 100 seeds (g)	1.24	1.23	98.84	High	0.30
Number of seeds per plant	532.32	-6515.10	0.00	Low	0.00
Seed weight per plant (g)	148.23	147.89	99.77	High	12.66

Note: σ^2_P : phenotypic variability, σ^2_G : genotypic variability, H^2_{BS} : broad-sense heritability, CGV: coefficient of genotypic variability, negative value of genotypic variability count as zero for further calculation

Table 3. Correlation of observed characters to seed weight per plant in wheat

	X1	X2	X3	X4	X5	X6	X8	X9	X10
X7	0.56 **	0.59 **	0.52 **	0.17 *	0.44 **	0.59 **	0.45 **	0.85 **	0.88 **
X7	X11 -0.48 **	X12 0.36 **	X13 0.46 **	X14 0.79 **	X15 0.29 **	X16 -0.02 ns	X17 0.12 ns	X18 0.14 ns	

Note: **significantly correlated at the 1% level, *significantly correlated at the 5% level, ns: not significantly correlated at the 5% level, X1: number of spikelets, X2: number of florets, X3: number of main panicle seeds, X4: number of empty florets, X5: weight of 100 seeds (g), X6: seed weight of main panicle (g), X7: seed weight per plant, X8: flag leaf area (cm), X9: number of tillers, X10: number of productive tillers, X11: percentage of non-productive tillers, X12: length of main panicle (cm), X13: plant height (cm), X14: weight of safe (g), X15: number of seeds per plant, X16: age of flowering (DAP), X17: age of harvesting (DAP), X18: period of seed filling (day).

Discussion

Evaluation of the genetic material of the cross was carried out to identify potential superior genetics in the target character. The superior character performance can be controlled by genetic, environmental, or interaction factors between the two. Broad sense heritability can be used to analyze the magnitude of genetic factors in plant performance by looking at the genetic proportions in the phenotypic diversity of the population. The character of the number of tillers and the number of productive tillers in this study were included in the high category. In the development of tropical wheat, environmental factors, especially altitude, significantly affect the character of plant height and the number of tillers (Altuhaish et al. 2014). The heritability categories of the two characters are in accordance with the research results of Wahyu et al. (2018) and Putri et al. (2020), which is included in the high category. The consistent high broad sense heritability category on the number of tillers and the number of productive tillers in the F2 generation (Putri et al. 2020) and in this study (F5) indicates that the genetic variation is greater than the phenotypic. The high broad-sense

heritability on the number of tillers is also found in Fellahi et al. (2018). It is able to support the screening process in the initial generation so that it is expected to increase the time efficiency of the selection program with a variety of environments that are conditioned to be homogeneous, in accordance with the findings of Bellatreche et al. (2017) which states that vegetative characters are able to support characters related to generative.

The environmental variables in the character of the seed filling period were higher, causing a negative value for the genetic variance produced. In addition to the character of the seed filling period, negative variance values were also seen in the number of seeds per plant, panicle length, and grain weight. More significant environmental variation produces genetic variance with negative notation and is considered zero so that the heritability value becomes zero. It shows the strong influence of the environment on the character's performance. Characters with strong environmental influence are not recommended as a reference for selection because their sensitivity to environmental changes can bias the selection results (Bhushan et al. 2013).

Single character selection is easier to do but has the potential to eliminate other superior characters. The linked gene's condition can also trigger the expression of unwanted characters (Syukur et al. 2018). It is the basis for selecting multi-character selection with characters that correlate with seed weight per plant in this study. Seed weight per plant was also assessed as a correlated factor with the tolerance level of plants to high temperatures (Ameen 2012). The stronger the correlation, the correlation coefficient will approach the numbers 1 and -1. If the correlation is significantly positive, then the increase in the value of the character X is linear to the increase in the weight of the seeds per plant and vice versa.

The selection of characters that are used as the basis for the multi-character adaptation class is expected to increase yields with greater genetic control so that characters with high heritability values are selected with a strong positive correlation (>0.5). In some conditions, negative correlations are desired in the plant breeding process, such as flowering age and harvest age, because they are considered to increase yields (Pozo et al. 2019). Flowering habituation can be an indicator to analyze the adaptability of wheat. Its control by different alleles for responding to environmental changes (Gao et al. 2014). These factors were not included in the weighting process in taking the multi-character adaptation class because there was no significant correlation between plant age and yield. The positive correlation was shown among the weight of rootstock, grain yield, grain number and the number of tillers, even so on Barbero et al. (2021). The higher seed weight value compared to the comparison varieties indicated the potential for superior genotypes. The success of the wheat breeding process was seen from the shift in the mean population value between the varieties that had been released and the candidate genotypes that would be developed further (Pozo et al. 2019). The increase in seed weight per plant was also assessed as a potential tolerant character to high-temperature stress in wheat.

A genotype is said to be adaptive if it can pass through all phases from germination to grain maturation (Hyles et al. 2020). Seed weight per plant is considered an effective indicator to measure the physiological ability of plants to adapt to stressful conditions (Li et al. 2018). Photosynthate accumulation supported by the function of other plant organs will be seen in the results. The yield in the cereal crop group was seed weight per plant.

Adaptation class is able to provide potential genotype information that can be developed in the evaluation of the next generation. Table 4 shows that the determination of the adaptation class based on a single character resulted in a higher average value of seed weight in all classes compared to selection based on multiple characters. On the other hand, the selection of multi-character genotypes resulted in a higher number of moderate and adaptive genotypes. It is in line with Fellahi et al. (2018), which state that the determination based on sole character allows the selection of higher genetic advances with the lower

number of selected genotypes. This is supported by the increasing number of genotypes in this study's quite adaptive and adaptive class. Those findings indicated that a single character is effectively used on the advanced generation while the multi-character approach fits the early generation.

The average seed weight in the adaptive and highly adaptive classes in this study was lower than the average adaptive class (60.87 g) and highly adaptive (93.13 g) in the F2 generation (Putri et al. 2020). The difference in planting time between the F2 and F5 generations caused a significant difference in yield. The higher intensity of rain at the time of planting affects the yield of wheat. It was also found by Pozo et al. 2019 which states that the irrigation process in wheat cultivation affects wheat. This means that the potential for wheat development in the rainy season in a tropical environment will face the risk of decreasing productivity. Fujimura et al. (2010) stated that the factors of growing season and altitude cause differences in the response of plant agro-morphological characters that affect yields.

The selection differential shows an increase in the character value caused by the selection effect. In evaluating the results of crosses, it is necessary to know this so that the success of the selection process is more measurable. A higher selection intensity causes a high selection differential on a single character. That is, the more stringent genotype selection will lead to a greater increase in seed weight. In the next generation oriented to the release of varieties, selected genotypes with high yield weights are more desirable. The increase in the mean seed weight per plant from before and after selection with both adaptation class approaches was greater than the F5 generation of wheat analysis conducted by Meier et al. (2019). This shows that the selection of genotypes based on the adaptation class can be used as an approach in the selection of developed lines.

Table 4. Recapitulation of t-test of wheat lines adaptation class based on selected characters against comparison varieties

Adaptation class	MPW	FLO	SWP	TN	PTN
Not adaptive	1.7	39.6b ⁻	2.4ab ⁻	4.9b ⁻	3.6b ⁻
Less adaptive	2.0	54.1b ⁻	9.8b ⁻	12.3b ⁻	10.6b ⁻
Moderately adaptive	2.3b	61.3	20.4	22.0	19.8
Adaptive	2.3b	64.7	37.4b	32.4	31.1
Highly adaptive	3.0b	72.0	55.8ab	38.0	37.0
Guri 1	1.3	70.5	8.5	15.0	12.5
Guri 3	1.3	59.3	8.5	20.7	18.3

Note: a: significantly higher than Guri 1, b: significantly higher than Guri 3, b⁻: significantly lower than Guri 3, ab: significantly higher than Guri 1 and Guri 3, MPW: main panicle weight (g), FLO: floret number, SWP: seed weight per plant (g), TN: tiller number, PTN: productive tiller number

Table 5. Differences in seed weight per plant in the adaptation class based on single and multi-character characters in wheat

Group	Single			Multi-character		
	Class	n	Average (g)	Class	n	Average (g)
Not adaptive	< 12.04	107	4.47	< 9	69	2.38
Less adaptive	12.05-23.79	44	17.28	9.0-13.0	47	9.83
Adaptive moderate	23.80-35.54	12	30.46	14.0-18.0	42	20.43
Adaptive	35.55-47.29	3	38.63	19.0-23.0	12	37.44
Highly adaptive	> 49.29	5	56.04	> 23	1	55.80
Total		171			171	

Note: n: number of genotypes, Average: average of seed weight per plant

Table 6. Selection differential and percentage increase in the mean reference character based on single and multi-character adaptation classes

Characters	X ₀	X _s		S		% Enhancement	
		T	M	T	M	T	M
Seed weight per plant (g)	11.67	38.08	24.78	26.41	13.11	226.31	112.34
Number of florets	50.56	61.80	60.64	11.24	10.08	22.23	19.94
Main panicle seed weight (g)	1.76	2.25	2.32	0.49	0.56	27.84	31.82
Number of tillers	12.60	27.90	23.38	15.30	10.78	121.43	85.56
Number of productive tillers	11.22	26.30	21.44	15.08	10.22	134.40	91.09

Note: T: single character-based adaptation class, M: multi-character based adaptation class, X_s: average value after selection, X₀: average value before selection S: selection differential

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