Genetic by environment interactions and stability of tropical wheat lines in Indonesian medium-plains

A Nur[1], K Syahruddin[1], M Azrai[1] and M Farid[2]

[1]Indonesia Cereal Research Institute (ICERI), Jl. Dr.Ratulangi No. 274 Maros, South Sulawesi, Indonesia.
[2]Department of Agronomy, Faculty of Agriculture, Hasanuddin University, Jl. Perintis kemerdekaan KM. 10 90245 Makassar, South Sulawesi, Indonesia.

E-mail: iceriamin76@gmail.com

Abstract. Wheat can adapt well in Indonesia in altitude of 1000-3000 m above sea level (asl) with production ranging 3-5 t/ha. Recently, Indonesia has released several varieties of wheat, but only a few varieties have an adaptation zone under 1000 m asl, which competes to horticultural crops. Therefore, it is important to study the genetic x environment (G x E) interactions and the yield stability of tropical wheat genotypes in the low-medium plains. The study was arranged using Randomized Completed Block Design with 3 replications and 9 genotypes at six locations. The data was analyzed for variant, variant combined and yield stability using STAR programs. The results showed that the environment, genotypes, and interaction of G X E had a highly significant effect on yield and yield components, except for seed weight/spike trait. Further analysis result showed the G4 genotype has significantly greater than the control for trait of days to flower, days to harvest, plant height and a number of panicles/meter. The G1, G4 and G5 genotypes have significantly higher yields than controls. The G4 and G5 genotypes have wide adaptability and G1 genotype has specific adaptability.

1. Introduction

Wheat in Indonesia has high economic value. This is reflected in the pattern of consumption and import of wheat in the form of seed and flour continue raises along with the increasing number of population, especially in urban areas. Currently, Indonesia is the second largest importer of wheat after Egypt. Based on data of USDA (2015 – 2017) for wheat import estimated wheat imports reached 10.7 million tons, increased approximately 9.8% from the year 2013 as much as 7.17 million tons [1].

The policy of wheat import to meet the increasing of public need is deemed less precise, considering the magnitude of foreign exchange depleted and the nation's economic dependence on the wheat exporting countries. Therefore, the effort to grow wheat in Indonesia is very important in order to reduce the dependence of wheat imports. However, the problem of unavailability of local genetic resources and limited introduced genetic resources made the development of wheat crops in Indonesia hampered. Wheat crops can basically adapt well in Indonesia at the altitude of 1000-3000 m above sea level (asl) with production reaching 3 ton ha^{-1} in Malino (1350 m asl) and 4 ton ha^{-1} in Tosari [2]. However, the planting of wheat on that altitude competes with horticultural products which have higher economic value, so it is important to produce wheat genotypes that can adapt in medium plains. The genotypes arose from the decline of wheat growing altitude was decreased wheat production due to stunted plant growth by the increasing temperature and humidity in medium plains.

The multilocation test aims to determine the yield and adaptability of the genotype in different locations and to examine the interaction of the environment x genotypes. According to [3], the G × E interaction information is very important for the countries with wide bio-geophysical variability such as Indonesia. The genotype adaptability can be observed by studying the interactions between the

environment x genotypes or the genotype x season [4]. The interaction information of the genotype x environment is useful to know the stability of the phenotype yields in order to ease the selection of varieties in the plant breeding program [5]. Genotype x Environment interaction decrease the genetic progression in plant breeding program by minimizing the association between the phenotype and genotype values, therefore multi-environment is essential to identify the superior genotypes in the final selection cycles [6].

The approach method to assessing the ability of G x E interactions is to use the methods proposed by Finlay and Wilkinson [4] and Eberhart and Russel [7]. This study aims to determine the stability of yield components and the yield of nine genotypes on eight test locations by looking at the G x E interactions using the models introduced by Finlay and Wilkinson [4] and Eberhart and Russel [7].

2. Material and Methods

The research was conducted at six locations in Indonesia: Garut and Cisarua-West Java (2014), 600 m asl, Malino and Jeneponto-South Sulawesi (2014) Malino and Jeneponto-South Sulawesi (2015) 800 m asl, Malang-East Java (2015) altitude 600 m asl and Salatiga-Central Java (2015) 600 m asl. The experiment was conducted using Randomized Completed Block Design (RCBD) with three replications. Size of the plot was 1.5 m x 5 m. Genetic material used six genotypes and three national varieties as control (Guri3 Agritan, Guri5 Agritan and Dewata). Each genotype planted in 6 rows along 5 m with an intercropping distance 25 cm, the seeds are drawn in rows. The plants were fertilized by 150 kg.ha^{-1} Urea, 200 kg.ha^{-1} SP-36 and 100 kg.ha^{-1} KCl in the 10 Days-After-Planting (DAP) and the second fertilization using 150 kg.ha^{-1} Urea at 30 DAP. Before planting the seeds were given carbaryl insecticide 85% and at the time of planting the runway was given 17 kg.ha^{-1} of carbofuran.

The observation of agronomical trait includes days to flower (day), days to harvest (day), plant height (cm), panicle length (cm), number of spikelet, number of empty floret, void floret percentage, seed weight (g)/panicle, number of spike.m^{-2} , number of seeds/panicles, weight of 1000 seeds (g), and yield (ton.ha^{-1}). The data were analyzed using variance analysis, combined variance analysis following methods proposed by Singh and Chaudhary [8] with STAR program. If F-test shows significance of G x E interactions, continued with yield stability following methods in Finlay and Wilkinson [4] as well as Eberhart and Russel [7].

3. Result and Discussion

Combined variance analysis (table 1) showed that the environmental influence is highly independent to all observed trait. The genotypes have highly significant effect on the trait of days to flower, days to harvest, plant height, panicle length, number of panicles per meter, number of spikelet per panicle, number of seeds per panicle, weight of 1000 seeds and yield and have a significant effect on weight of seed/panicle. The interaction of G x E also had a highly significant effect on all observed trait. The same result is also shown by Nur [9] which showed that environmental influences are highly significant in almost all agronomic and yield trait excepted in the trait of days to flower. The study also showed that the interaction of G x E did not significantly affected the plant height, days to harvest, panicle length and number of panicles/m^2, contrasted to the recent study results which were highly different in those traits.

The results of this study indicated the entire agronomic and yield traits were strongly influenced by environment factor and G x E interactions. G x E interaction can assist in identifying trait that contribute to better plant performance and the environment that helps to evaluate the genotypes [10]. Wheat is a very sensitive to the environmental changes [11]. The results of Mohamed [12] showed that environment, genotype and the G x E interaction effected to yield trait. The Declining elevation of wheat cultivation caused heat stress [13] and high humidity. Heat stress was a major factor in decreasing yield in Egypt [14]. Heat stress also affected wheat productivity in tropical regions around the world [15]. Heat stress caused some agronomic trait of wheat change [16].

Highly significant of G x E interaction whether on the environment, the genotypes, and the interactions showed differences in response between genotypes and the response of each genotypes to the environments (table 2). On the agronomical trait, only the number of spikelet/panicle was not significantly different to the controls, but remained significantly different between the genotypes (table 2).

Table 1. Mean square of variance combined analysis on the agronomic trait and yield.

Traits	(E)	(G)	(G x E)	CV
Days to flower (HST)	1,177.13**	787.62**	167.08**	6,64
Days to harvest (HST)	1,218.16**	363.02**	64.62**	4,63
Plant height (cm)	2,316.67**	481.69**	123.08**	5,66
A number of spike/m^2	61,000.44**	43,269.50**	4,691.94**	18,4
A number of spike	57.62**	27.82**	8.22**	7,9
Spike length (cm)	7.28**	5.57**	1.43**	6,8
A number of seed/m^2	3,237.23**	174.24**	279.27**	13,3
Seed weight/spike (g)	6,24**	0,41*	0,46**	16,9
Weight of 1 L seeds (g)	330631.80**	20,645.91**	12954.28**	9.4
Weight of 1000 seeds (g)	826,62**	51,62**	32,39**	9,5
Yield (t/ha^{-1})	2,90**	1,46**	0,79**	15,5

Description:** = F : 1%; * = F : 5%; CV= variance coefficient

Table 2. Average of tropical wheat genotype trait on the Indonesian medium plains, 2014-2015.

Genotypes	PH	DF	DH	SPM	SL	SPk
	--cm--	---days---			--cm--	
G1	80.85[b]	55.42[abc]	99.94[abc]	214.63[c]	16.96	9.16
G2	77.33[abc]	54.27[abc]	99.05[abc]	216.19[c]	18.59[ab]	8.77
G3	73.37[abc]	53.58[abc]	97.25[abc]	209.12[c]	16.05	8.19
G4	75.70[abc]	57.17[abc]	100.26[abc]	284.59[abc]	15.92	8.28
G5	84.12	62.11[abc]	103.73[bc]	320.50[abc]	17.07[a]	8.55
G6	74.61[abc]	55.46[abc]	98.94[abc]	248.3[c]	15.64	7.80
Guri3 (a)	82.42	59.78	105.74	251.37	16.65	8.99
Guri5 (b)	85.55	69.38	107.89	226.92	17.99	8.79
Dewata (c)	82.95	67.08	106,65	181.45	18.30	9.25
Mean	79.60	59.40	102.2	239.23	17.02	8.64
SE	0.92	0,80	0.96	8.96	0.13	0.32
5%LSD	2.57	2.25	2.70	25.08	0.38	0.91
CV (%)	5.6	6.6	4,6	18.36	7.86	9.43

Description: PH: Plant Height (cm), DF: Days to flower (Days), DH: Days to Harvest (Days),
SPM: Number of spike/m^2, SL: Spike Length (cm), SPk: Number of Spikelet/panicle
* The numbers in the same column followed by the letter are not significantly different to controls at the 5% level by Least Significant Different (LSD)

In agronomic trait, only G5 genotype showed non-significant different to the controls for plant height trait. For Indonesia medium-plains area, wind is a limitation factor causing many plants in turn decreasing crop production, because the strong wind will lay down the plant and causing unstable production. Therefore, short wheat crop is preferred because it is more wind resistant, although the weakness short plants is ease of attacked by rat [17]. In long panicle trait, the G2 genotypes showed significant differences with the controls of Guri3 and Guri5, while the G5 genotypes showed only significant differences to the Guri3.

The G4 and G5 genotypes indicated for higher number of panicles compared to controls.. The number of panicles indicates the potential of the genotype may form a seed, which is highly correlated with the ability of each panicle to produce fertile pollen, where fertile pollen is affected by ambient temperature. According to Rawson [18] high yielding in wheat crops is determined by the number of panicles per unit with productive tillers. Table 3 showed the trait of yield and yield components, 1000 seeds weight and weight of 1 litre of seed showing significant differences compared to control. This indicates that the influence of the environment in this location was considerable influenced the wheat

yield in medium-plains area. These results are supported by Mohamed [12], that the environment and G x E interactions are positively correlated to wheat yields.

Table 3. The average of tropical wheat yield component traits (2014-2015).

Genotypes	NSS	SwS	W1000 ---g----	W1L
G1	43.00	1.57	35.85 [abc]	717.093 [abc]
G2	43.39	1.49	33.88	677.537
G3	41.02	1.42	33.96	679.241
G4	41.59	1.26	30.27	605.389
G5	42.29	1.41	33.56	671.167
G6	37.21	1.26	33.85	677.000
Guri3 (a)	43.08	1.45	33.28	665.611
Guri5 (b)	47.45	1.66	32.77	655.370
Dewata (c)	43.53	1.48	33.90	678.074
Mean	42.51	1.44	33.48	669.610
SE	1.36	0.05	0.65	12.91
5% LSD	1.15	1.38	1.80	36.13
CV(%)	13.31	16.84	9.50	9,40

Description: value followed by different letters in the same column significantly different at LSD 5%. NSS: Number of seed/spike, SwS: Seed Weight/Spike., W1000: weight of 1000 seeds, W1L: Weight of 1litre of seed.

Tabel 4. Yield average at 12% (tons.ha^{-1}) moisture content of wheat (2014 – 2015).

Genotypes	Yield (ton.ha^{-1})								Average
	L1	L2	L3	L4	L5	L6	L7	L8	
G1	2.48[a]	3.01[a]	3.26[ab]	2.33[a]	1.96[b]	2.72[a]	1.77[d]	1.69[bc]	2.40[a]
G2	2.01[bc]	2.76[ab]	2.61[ad]	1.44[d]	1.58[bc]	1.86[bd]	1.65[d]	1.64[bc]	1.94[cd]
G3	1.55[d]	2.28[bc]	2.15[cd]	1.51[cd]	1.43[c]	1.56[cd]	2.32[c]	0.88[e]	1.71[d]
G4	2.25[ab]	2.13[c]	3.49[a]	1.77[bc]	0.74[d]	2.18[ac]	2.93[a]	2.72[a]	2.28[ab]
G5	2.23[ab]	2.07[c]	2.55[ad]	1.88[b]	2.43[a]	1.56[cd]	2.70[b]	2.55[a]	2.24[ab]
G6	1.49[d]	1.35[d]	0.93[e]	1.96[b]	1.89[b]	2.40[ab]	2.30[c]	2.83[a]	1.89[cd]
Guri3	2.05[ac]	2.11[c]	1.83[de]	1.67[bd]	1.77[bc]	1.49[de]	3.08[a]	1.22[de]	1.90[cd]
Guri5	2.20[ab]	2.42[ac]	2.94[ac]	1.49[cd]	0.87[d]	1.83[bd]	2.62[b]	1.84[b]	2.03[bc]
Dewata	1.67[cd]	1.91[cd]	2.32[bd]	1.38[d]	1.55[bc]	0.93[e]	2.57[b]	1.40[cd]	1.72[d]
Genotype	**	**	**	**	**	**	**	**	
CV	13.2	15,9	20	10,7	15,2	19,6	4,1	11,3	
LSD	0,45	0,61	0,9	0,32	0,42	0,63	0,20	0,36	
Average	1.99[bc]	2.23[ab]	2.45[a]	1.71[de]	1.58[e]	1.84[ce]	2.44[a]	1.86[cd]	

Description: L1 = Garut-WJ 2014; L2 = Jeneponto-SS 2014; L3 = Malino-SS 2014, L4 = Cisarua-WJ 2014, L5 = Malang-EJ 2015; L6 = Salatiga-CJ 2015; L7 = Jeneponto-SS 2015, L8 = Malino-SS 2015.

In order to obtain varieties that have high-yield potential, direct selection by choosing a long panicle, short stalk and more number of spikelet/panicle traits. This is consistent with the results of Walton (1971) study in [19], where wheat selection should be directed to the trait and also increase the flag leaf and panicle length traits. Longer flag leaves and shorter stem stalk lead to increased yield.

To determine the stability and adaptability of genotypes in various environments, a stability analysis of yields is necessary (table 4). It is important to identify which genotypes are widely adapted, so that they can be developed in larger environments or specific genotypes developed at specific locations. The G5 genotype was significantly superior to all controls in many locations. The breeding approach for selecting high-yielding genotype is determined by the purpose of assembling varieties, for instance environmentally-specific varieties [20] or stable varieties and adapting to large environments [21]. Based on this, the yield stability analysis by Finlay and Wilkinson [4] method involved all environments and seasons to determine the adaptability level of genotypes as presented in table 5.

According to Finlay and Wilkinson [4] a genotypes having a regression coefficient (bi) = 1 and the yield average higher than the total mean, it is expressed as a stable genotypes with high adaptability to all environments. From the results of the analysis in some environments it is shown that almost all genotypes have bi values that were not significantly different to 1 except in the G5 genotypes with bi = 0.53, so it can be said that almost all test genotypes are stable in all locations. This suggests that the G5 genotype has static stability where plant performance will be the same in all environments and shows an increase in resistance to environmental changes or in other words insensitive to the environment, so can be adapted in suboptimal environments. While the G2, G3, G4 and G6 genotypes have dynamic stability because the performance of plants is not same in all environments and have increased sensitivity to environmental changes, which causes plants adapted to optimal environment. In table 5 showed that the G2 genotypes as a stable genotypes with high adaptability to all environments. G1 and G5 genotypes have higher yield than the average total yield, but quite unstable in all environments.

Table 5. Average and stability of wheat yield based on environment combined analysis

Genotypes	Range	Av	bi	SE	Sdi	GCI	GCR	SD	R^2(%)
G1	1,8 – 3,3	2.4	0.67	0.66	0.57	0.29	0.08	0.33	4.00
G2	1,4 – 2,8	1.9	0.94	0.47	0.41	0.14	0.00	0.17	0.00
G3	1,4 – 2,3	1.7	1.21	0.38	0.33	0.10	0.03	0.11	5.00
G4	0,7 – 3,5	2.3	2.07	0.58	0.51	0.34	0.85	0.26	36.00
G5	1,6 – 2,7	2.2	0.53	0.44	0.38	0.15	0.17	0.14	16.00
G6	0,9 – 2,8	1.9	-0.8*	0.70	0.61	0.66	2.44	0.37	52.00
Guri3	1,2 – 3,1	1.9	1.08	0.53	0.46	0.18	0.00	0.21	0.00
Guri5	0,9 – 2,9	2.0	1.9*	0.23	0.2	0.13	0.65	0.04	73.00
Dewata	0,9 – 2,6	1.7	1.37	0.36	0.31	0.10	0.10	0.10	15 .00
Average		2.0	1.12	0.48	0.42	0.23	0.48	0.19	22.33

Description: bi = genotype average regression on environment index, * = significantly different to 1; Av = Average; SE = Standard Error, GCI = Genotypes contribution to mean squared interaction, GCR = Genotypes contribution to regression components on G x E interaction; SD = mean squared deviation, R^2 = *Squared Correlation*

4. Conclusion

- There were a highly significant interaction in the environment, genotype and GxE interaction to all traits.
- G1 genotype has a potential yield and average yield of 3.3 tons.ha^{-1} and 2.4 tons.ha^{-1}, higher than all controls. This genotype has a shorter days to flower and days to harvest and higher weight of 1000 seeds compared to control. This genotype has adaptive yield in the suboptimal environment based on yield stability analysis.

- G4 genotype has the yield potential and an average yield around 3.5 tons.ha^{-1} and 2.3 tons.ha^{-1}, significantly superior to controls. This genotype has adaptive yield in an optimal environment based on yield stability analysis.
- The G5 genotype has a yield potential and an average yield around 2.7 tons.ha^{-1}of 2.2 tons.ha^{-1}, the mean yield was superior to the Dewata variety and relatively equal to Guri5 variety. The genotype has adaptive yield in the sub-optimal environment based on yield stability analysis.

References

[1] USDA 2018 *Grain: world market and trade* (United State: Foreign Agricultural Service/USDA) 61p.
[2] Hamdani M, Widodo S, Ismail and Dahlan M M 2002 *Evaluasi galur gandum introduksi dan CIMMYT* Pros. Kongres IV dan Simposium Nasional PERIPI (Yogyakarta : UGM)
[3] Baihaki A and Wicaksana N 2005 Interaksi genotip x lingkungan, Adaptabilitas dan stabilitas hasil dalam pengembangan tanaman varietas unggul di Indonesia *Zuriat* **16** (1) 1 – 8
[4] Finlay K W and Wilkinson G N 1963 The analysis of adaptation in plant breeding program *Aust. J. Agric. Res*. **13** 742-754
[5] Admassu S, Nigussie M and Zelleke H 2008 Genotype Enviroment Interaction and Stabililty Analysis for Grain Yield of Maize (*Zea mays*. L) in Ethiopia *Asian J of Plant Sci.***7** (2) 163-169
[6] Hassan M S, Mohamed G I, El-Said R 2013 Stability analysis of grain weight and its component of some durum wheat genotypes (*Triticum durum* L) under different environments *Asian J crop sci*. **2** 179-189
[7] Eberhart S A and Russel W A 1966 Stability parameters for comparing varieties *Crop Sci*. **6** 36-40
[8] Singh R K and Chaudhary B D 1985 *Biometrical Methods in Quantitative Genetics Analysis* (New Delhi : Kalyani Publisher) p 318.
[9] Nur A 2014 Interaksi Genetik x Lingkungan dan Variabilitas Genetik Galur Gandum Introduksi (*Triticum aestivum* L) di Agroekosistem Tropika *J Agrobiogen* **10** (3) 93 – 100
[10] Yan W, Cornelius P L, Crossa J and Hunt L A 2001 Two types of GGE biplots for analyzing multi-environment trial data *Crop. Sci.* **41** 656 – 663
[11] Kang M S 2004 Breeding: Genotype-by-environment interaction for crop cultivar development. *Adv. Agron*. **62** 199-252
[12] Mohamed N E M 2013 Genotype by environment interactions for grain yield in bread wheat (*Triticum aestivum* L.). *J. Plant Breed. Crop Sci* **5** (7) 150-157
[13] Altuhaish K A, Miftahuddin, Trikoesoemaningtyas and Sudirman Y 2014 Field Adaptation of some introduced Wheat (*Triticum aestivum* L) Genotypes in Two Altitudes of Tropical Agro Ecosystem Environment of Indonesia *HAYATI J Biosci* **21** (1) 31 -38
[14] Kheiralla K A, El-Morshidy M A and Zakeria M M 2001 Inheritance of earliness and yield in bread wheat under favorable and late sowing dates 2nd *Plant Breed. Cont.*, October, Assiut Univ. 2001 (1) p 219-239
[15] Ashraf M and Harris P J C 2005 *Abiotic stress: Plant Resistance through breeding and molecular approaches* (New York : Haworth Press Inc) pp 3-18.
[16] Yamin M 2014 *Pendugaan komponen ragam karakter agronomi gandum (Triticum aestivum L,) dan identifikasi marka Simple Sequence Repeat (SSR) terpaut suhu tinggi menggunakan Bulk Segregant analysis (BSA)* (Bogor :IPB)
[17] Nur A 2015 Perbaikan genetik gandum tropis toleran suhu tinggi dan permasalahan pengembangannya pada dataran rendah *J. Pen. Pert. Tan. Pangan* **34** (1) 19 -30
[18] Rawson H M 1987 *Effect of high temperature on the development and yield of wheat practices to reduce deleterions effects* (*Wheat production in tropical environments ed.* Klatt A R *A Proc.of Int. Conf.*) January 19-23 1987 CIMMYT pp 44-62
[19] Bahar H, Sumartono and Nasrullah 1988 Sidik lintas beberapa karakter tanaman terigu

      (*Triticum aestivum* L.) *Berkala Penelitian Pasca Sarjana UGM* **2** 145 – 153

[20]   Kang M S and Miller J D 1984 Genotype x environment interactions for cane and sugar yield and their implications in sugarcane breeding *Crop Sci.* **24** 435-440

[21]   Subandi 1981 Genotype x environment interactions in corn varieties test *Food Crop* **65** 1-9