SHUTTLE BREEDING FOR IMPROVEMENT OF WHEAT ADAPTATION TO TROPICAL AGROECOSYSTEM

Trikoesoemaningtyas[1*], Azis Natawijaya[2], Mayasari Yamin[2], Yushi Mardiana[2], Jabal Rahmat Ashar[2], Amin Nur[3], Yudiwanti Wahyu[1]

[1] Department of Agonomy and Horticulture, Bogor Agricultural University, [2] Graduate Program Plant Breeding and Biotechnology, Bogor Agricultural University, [3] Cereal Crops Research Institute
*Corresponding author: trikadytia@gmail.com

ABSTRACT

The change in consumer preference has made wheat as an important food in Indonesia and imported more than 7 million tons of wheat each year. This study aims to develop wheat varieties adapted to tropical agroecosystem. A segregating population was developed from a cross between two introduced wheat lines Oasis and HP1744 and selection was conducted in a shuttle breeding program in two alternate selection environment of 1100 – 1600 m above sea level (asl) and 600 m asl from 2011 to 2016. The F2 and F3 generations were grown at 1100 m asl and the F4 generation was grown at 600 m asl with higher average temperature. A total of 160 genotypes was selected in F5 grown at 1100 m asl based on yield components and grown as F6 lines at 600 m asl. Selection was conducted based on yield components and ratio of empty florets. The resulting 25 lines were grown at two agroecosystems at 1600 m asl at Malino, South Sulawesi and at 600 m asl at Cisarua, West Java. Selection based on yield and sensitivity index showed that shuttle breeding was able to generate lines adapted to both high elevation and lower elevation tropical agroecosystems and also lines adapted to specific agroecosystem.

Keywords: adapted genotypes, alternate selection, shuttle breeding, sensitivity index

INTRODUCTION

There has been a change in Indonesian diet, many wheat-based are now become more familiar. This change in consumer preference has made wheat demand in Indonesia increased sharply in the past ten years. Indonesian wheat import increased from 6.6 million tons in 2013 to reach 9.9 million tons in 2017. This high import value has lead to an effort to produce wheat domestically.

Wheat has been grown in Indonesia for decades, however as a subtropical crop, wheat requires optimum temperature of 20- 25 ^{o}C. Mostly, wheat are grown in high altitude areas. This is the reason wheat production is very low, because of limited growing areas and competition horticulture crops. To increase wheat production, wheat has to be grown in middle to lower altitude areas. The main constraint of growing wheat in middle to low altitude areas, is high temperature stress. Natawijaya (2012) reported that high temperatures cause sterilization of wheat pollen. This may lead to a decrease in production as reported by Nur *et al* (2012) that high temperature stress can lead to a decrease in average seed weight per panicle on testing of 12 wheat genotypes at <400 m above sea level (asl). Similar results were reported by Febrianto (2014) on evaluation of wheat mutant lines at medium elevation.

Tolerance to high temperatures is generally defined as the ability of plants to grow and produce yield under high temperature conditions (Farooq *et al*, 2011). The properties of wheat tolerance to high temperature stress can be improved through the development of new varieties, in breeding programs aimed at producing high yielding wheat varieties and adaptable to high temperature stress. Department of Agronomy and Horticulture IPB together with Cereal Crops Research Institute, is developing wheat variety for tropical conditions at medium elevation (<600 m above sea level).

The selection of segregating population was conducted in a shuttle breeding method. This breeding method was developed by Norman E Borlaug in 1960s as a technique for growing successive plantingsa year in two locations with differing seasons, as a method of rapid generation advancement (Tanio *et al*, 2006). As a selection method shuttle breeding can be applied by conducting successive generations in two different environments. Shuttle breeding is widely used in wheat breeding program by CIMMYT in their international wheat nurseries (Reynolds & Borlaug, 2006). This paper reviewed the progress of a shuttle breeding program in the development of wheat varieties adapted to tropical agroecosystem from 2010 to 2016.

MATERIALS AND METHODS

The study was conducted from 2010 to 2016 at high elevation and medium elevation in Indonesia. The genetic materials used to develop population were introduced lines from India (Oasis, HP 1744, LAJ/Mo88 and Rabe/MO88), from Turkey (Basribey, Alibey and Menemen) and from CIMMYT (G21, G18 and H21) with two national varieties Dewata and Selayar.

Selection of parents was conducted in Cipanas, Cianjur Regency (1100 m asl) and at Bogor Regency (250 m asl) from May to September 2010. Selection was based on Sensitivity Index using number of empty florets. Crosses were then made between selected parental lines to develop populations. The three population of early segregating population of F2 were grown at high elevation (1100 m asl) from October 2011 to January 2012. One population, Oasis x HP 1744 was selected to be used in the shuttle breeding method. The F3 generation was grown at high elevation of 1100 m asl in Cipanas from April 2012 – August 2012 and the F4 generation was grown at 600 m asl in Cisarua, Bogor Regency, from February to May 2013.

A head to row planting was conducted for the F5 generation at high elevation (1100 m asl) from August to October 2013. The F6 lines were grown in two different elevations of 1600 m asl at Malino, South Sulawesi and at 600 m asl at Cisarua, West Java from March to July 2014. The seeds of from the F7 lines grown at high elevation were then used for selection based on sensitivity index at two different elevation of elevation of 1600 m asl at Malino, South Sulawesi and at 600 m asl at Cisarua, West Java, from October 2015 – January 2016. Observations were made for agronomic characters of plant height, number of tiller, productive tiller, days to flowering, days to maturity, spike length, no of spikelets/spike, spikelet density, % of empty spikelet, seed weight/spike. Selection was conducted based on single plant yield at F4 generation and as line basis for F5 to F7 generation. To determine the adaptation to lower elevation, selection was made based on sensitivity index $IS = (1 - \frac{Y_{is}}{Y_{io}})/(1 - \frac{X_{ts}}{X_{to}})$ (Fischer & Maurer 1978).

RESULTS AND DISCUSSION

A study on the 10 introduced genotypes and two national varieties showed that there is environmental and genetic interaction that made genotypes responded differently under different elevation. High temperature stress in low elevation environments significantly increases the rate of empty fluoret ratio for all genotypes; but there is no significant difference in the appearance of genotypes for this character in high-elevated environment. This character describes the ability of genotypes to produce pollen and functional stigma, its ability to maintain the pollination process, the ability to translocate photosynthate into panicles, and the ability to meet sink capacities. Selection based on ratio of empty florets using sensitivity index value, was able to identify one tolerant (Oasis) and moderately tolerant genotypes (HP1744, LAJ, Menemen, Alibey, Selayar, Dewata) that were used as parental lines in developing segregating populations (Table 1).

Table 1. Differential number of empty florets of wheat under high elevation and low elevation

Genotipe	Agroecosystem				IS
	High elevation		Low eleavtion		
	Mean	Rank	Mean	RanK	
Oasis	19.77	9	26.55	2	0.37
HP 1744	23.27	11	29.95	4	0.31
LAJ	20.87	10	30.55	5	0.50
Rabe	17.67	8	33.10	7	0.95
H-21	11.17	1	35.20	9	2.34
G-21	16.77	6	45.80	12	1.88
G-18	16.63	5	36.65	10	1.31
Menemen	15.43	3	25.17	1	0.69
Basribey	15.23	2	33.45	8	1.30
Alibey	15.60	4	26.85	3	0.78
Selayar	17.07	7	31.53	6	0.92
Dewata	24.97	12	39.70	11	0.64

IS = sensitivity index based on ratio of empty florets (Fisher & Mauer, 1978)

The shuttle breeding was carried out during the advancing of generation, by growing generation in alternate elevation. The early generations of F2 and F3 were grown at high elevation to optimize variability in the segregating population as shown in the genetic variability and broad sense heritability of agronomic characters (Table 2). The F4 generation was grown in high elevation, to evaluate the adaptation to higher temperature. The less favorable agroecosystem of low elevation areas decreased the variability of many agronomic characters, resulting in lower value of heritability (Table 2).

Tabel 2. Genetic variability and broad sense heritability of agronomic characters of the F3 generation (high elevation) and F4 generation (low elevation) of wheat

Characters	$\sigma^2 g$		h^2_{bs}	
	F3	F4	F3	F4
Vegetative stage				
Plant height	10.31	32.83	33.21	52.07
Flag leaf area	3.60	2.03	39.34	37.66
Total no of tiller	31.54	0.86	99.16	41.03
Generative Stage				
Days to maturity	2.19	136.02	46.08	90.30
% of empty floret	62.11	71.03	89.0	56.49
Yield component				
Seed weight of main spike	0.42	0.39	74.47	87.18
No of seed per spike	22.21	15.78	95.65	50.44
Seed weight per spike	0.07	0.02	98.08	57.23
No of seed per plant	430.16	531.29	74.28	77.90
Seed weight per plant	0.74	0.55	81.98	86.43

Table 3. Differential performance of F6 wheat lines under two different tropical agroecosystems

Characters	Mean Value		Difference	t-value
	High elevation	Low elevation		
Vegetative stage				
Plant height (cm)	76.48	58.55	17.93	2.22*
No of tiller	25.31	14.66	10.65	1.81*
No of productive tiller	20.71	12.57	8.14	1.29*
Generative stage				
Days to flowering (DAP)	64.94	54.13	10.50	1.79*
Days to maturity (DAP)	132	101.79	30.21	0.49*
Length of spike (cm)	9.87	9.51	0.36	0.13*
No of spikelet	20.15	18.39	1.76	0.47*
Spikelet density	2.04	1.93	0.11	0.04*
Empty florets (%)	28.68	50.08	-21.40	5.09*
Grain filling rate (g/day)	0.31	0.08	0.23	0.04*
Yield components				
No of seed main spike	43.22	27.82	15.40	3.03*
Seed weight main spike (g)	2.67	1.79	0.88	0.18*
No of seed per plant	555.15	115.05	440.10	55.69*
Seed weight per plant (g)	20.29	3.88	16.41	2.18*

As alternate environment, the F5 generation was planted as head to row in high elevation of 1000 m above sea level. The F6 generation was planted in high elevation and in low elevation. The suboptimum condition at low elevation, mainly higher average temperature, caused reduction in all agronomic characters of F6 lines, from plant height, days to maturity and yield components (Table 3). The average temperature form March to July at 1600 m above sea level at

Malino was 20°C and was 26°C at 600 m above sea level at Cipanas. We observed that the F6 lines reach maturity faster and produced less tiller under high temperature stress at low elevation (Table 3). Similar results were reported by Nur *et al* (2012) and Altuhaish *et al* (2014) on evaluating introduced wheat lines at two different elevations. The combination of shorter grain filling period, and lower tiller number resulted in lower yield under high temperature (Farooq *et al* 2011, Mondal *et al* 2016).

Tabel 4. Potential yield (ton/ha) of wheat lines grown under two different elevation

Name of Lines	Yield (ton/ha) ± SE	
	Malino (1600 m asl)	Cisarua (600 m asl)
O/HP-12-A28-5-1	2.68 ± 0.58	2.08 ± 0.04
O/HP-78-A-29-3-3	2.45 ± 0.02	2.14 ± 0.33
O/HP-82-A-15-1-4	2.69 ± 0.61	2.33 ± 0.40
O/HP-78-A2-2-5	3.14 ± 0.88	1.94 ± 0.19
O/HP-12-A1-1-9	2.96 ± 0.79	2.33 ± 0.39
O/HP-78-A22-3-7	3.30 ± 0.27	1.92 ± 0.13
O/HP-78-A22-5-10	2.83 ± 0.17	2.16 ± 0.40
O/HP-6-A8-2-10	2.71 ± 0.40	2.53 ± 0.51
O/HP-22-A27-1-10	3.90 ± 0.35	2.29 ± 0.12
O/HP-93-A1-1-3	2.95 ± 0.77	2.38 ± 0.19
O/HP-14-A19-1-8	1.63 ± 0.15	2.24 ± 0.19
O/HP-12-A5-4-5	3.28 ± 0.16	2.29 ± 0.41
O/HP-12-A25-3-7	1.89 ± 0.04	2.07 ± 0.24
O/HP-82-A7-2-6	2.26 ± 0.28	2.00 ± 0.29
O/HP-49-A1-1-4	2.89 ± 0.33	1.92 ± 0.09
O/HP-78-A2-1-9	2.65 ± 0.33	2.14 ± 0.18
O/HP-14-A21-5-7	2.69 ± 0.27	2.25 ± 0.23
O/HP-14-A10-2-10	1.93 ± 0.07	2.44 ± 0.44
O/HP-78-A2-5-2	2.61 ± 0.40	2.46 ± 0.62
O/HP-12-A25-2-6	2.58 ± 0.32	2.28 ± 0.24
O/HP-14-A10-3-3	1.97 ± 0.20	2.17 ± 0.16
O/HP-82-A15-2-3	3.25 ± 0.66	2.25 ± 0.73
O/HP-93-A3-1-9	2.95 ± 0.21	2.10 ± 0.21
O/HP-12-A23-1-10	1.75 ± 0.46	2.37 ± 0.68
O/HP-12-A1-2-2	2.73 ± 0.46	2.31 ± 0.42
Guri 1	2.78 ± 0.43	2.01 ± 0.24
Guri 2	2.25 ± 0.12	2.37 ± 0.32
Selayar	3.36 ± 0.08	2.20 ± 0.39
Dewata	2.36 ± 0.24	1.91 ± 0.24
Oasis	3.90 ± 0.18	2.22 ± 0.08
HP1744	2.88 ± 0.02	2.07 ± 0.32

The performance of the F6 lines were evaluated based on sensitivity index of seed weight per plant. The results showed a high variability of sensitivity index in the F6 generation ranged from 051 (tolerant) to 1.19 (sensitive). The parental line, Oasis, has sensitivity index of 0.99 grouped as medium tolerant, and HP1744 is classified as sensitive to high temperature of the low elevation with SI of 1.09. From a total of 48 lines, 18 lines were selected to be evaluated in a replicated yield trials.

The replicated yield trials were conducted in two different elevations of 1600 m above sea level and 600 m above sea level. A total of 25 lines were evaluated consisted of the 18 selected lines and 7 sensitive lines. Most lines produced higher yield when grown at higher elevation, some lines even produced more than 3 tons /ha, namely O/HP-78-A2-2-5, O/HP-78-A22-3-7, O/HP-22-A27-1-10, O/HP-12-A5-4-5 and O/HP-82-A15-2-3 with yield ranged from 3.14 to 3.90 ton /ha, however, these lines produced much lower yield when grown at lower elevation (Table 4). Several lines produced higher yield when grown at lower elevation, namely O/HP-14-A19-1-8, O/HP-14-A10-2-10, O/HP-12-A25-3-7, and O/HP-12-A23-1-10. These results clearly showed a significant qualitative genotypes x environment interaction, which causes changes in the ranking of the wheat lines at different elevations as observed in previous studies (Natawijaya 2012, Nur *et al*. 2012, Altuhaish *et al* 2014).

The results of the yield trials also showed that some of the selected lines were able to maintain yield under high temperature stress of the lower elevation, which indicates adaptation to tropical agroecosystem. These lines produced from 2.26 ton/ha – 2.75 ton/ha at high elevation and from 2.00 ton/ha to 2.33 ton/ha at lower elevation, namely O/HP-82-A7-2-6, O/HP-12-A25-2-6, O/HP-78-A-29-3-3, O/HP-82-A-15-1-4, O/HP-12-A1-2-2 and O/HP-14-A21-5-7 (Table 4). These stable lines were classified as medium tolerant with sensitivity index ranged from 0.55 to 0.83

In a breeding program selection can be conducted in suboptimum or stress condition for successive generations known as direct breeding or conducted optimum condition known as indirect breeding. Both method of selection produced advanced lines with narrow adaptation. The performance of the advanced lines of wheat derived from the cross of Oasis x HP 1744 in agroecosystems with different elevation showed that shuttle breeding methods was able to produced genotypes with wide adaptations. The advantage of shuttle breeding have been reported in several studies in wheat breeding program (Tanio *et al* 2006, He *et al* 2000) and rice breeding program (Mallik *et al* 2002).

CONCLUSION

A shuttle breeding method with two alternating selection environments was able to produce wheat breeding lines with good adaptation to low elevation tropical agroecosystem with high temperature stress.

REFERENCES

Altuhaish AAK, Miftahudin, Trikoesoemaningtyas, Yahya S. 2014. Field Adaptation of some introduced wheat (*Triticum aestivum* L) genotypes in two altitudes of tropical agroecosystem environment of Indonesia. *Biosci Hayati J.* 21(1): 31-38.

Farooq M, H Bramley, JA Palta, KHM Siddique. 2011. Heat stress in wheat during reproductive and grain filling phases. Critical Review in Plant Science. 30:1-17.

Febrianto EB. 2014. Selection of putative mutant lines of wheat (*Triticum aestivum* L) in medium elevation in the tropic. Thesis. Graduate School Bogor Agricultural University, Bogor.

Fischer RA, Maurer R.1978. Drought resistance in spring wheat cultivars. *Aust. J. Agric. Res.* 29:897-912.

He ZH, M van Ginkel, L Gilchrist, S Rajaram. 2000. Progress of China/CIMMYT shuttle breeding program and germplasm exchange aimed at combining high yield potential with scab resistance. National Fusarium Head Blight Forum. Kentucky

Mallik S, BK Mandal, SN Sen, S Sarkarung. 2002. Shuttle breeding : an effective tool for rice variety improvement in rainfed lowland. Current Science 83: 1097-1102

Mondal S, RP Singh, ER Mason, J Huerta-Espino, E Autrique, AK Joshi. 2016. Grain yield, adaptation and progress on breeding for early maturing and heat tolerant wheat lines in South India. Field Crop Research 192:78-85.

Natawijaya A. 2012. Genetic analysis and early generation selection of wheat (*Triticum aestivum L.).* [Thesis]. Graduate School Bogor Agricultural University, Bogor.

Nur A, Trikoesoemaningtyas, Khumaida N, Yahya S. 2012. Evaluation and genetic variability of 12 wheat introduced lines in the tropic. J Agrivigor 11(2):230-243.

Reynold MP , N E Borlaug. 2006. Impact of breeding in international collaborative wheat improvement. Journal Agriculture Science 144: 3-17

Tanio M, K Kato, N Ishikawa, T Tabiki, Z Nishio, K Nakamichi, Y Tanamura, M Sato, M Matsuoka. 2006. Effect of shuttle breeding on heading traits of Japanese wheat. Breeding Science 56: 311-320.