BIODIVERSITAS
Volume 19, Number 6, November 2018
Pages: 2344-2352

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d190644

Short Communication: Correlation, path analysis, and heritability of phenotypic characters of bread wheat F_2 populations

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Manuscript received: 27 October 2018. Revision accepted: 19 November 2018.

Abstract. *Wahyu Y, Putri NE, Trikoesoemaningtyas, Sutjahjo SH, Nur A. 2018. Short Communication: Correlation, path analysis, and heritability of phenotypic characters of bread wheat F2 populations. Biodiversitas 19: 2344-2352.* Wheat varieties are still limited for Indonesia. A high yield wheat plant is necessary to be assembled by selecting plants from a segregated population. The selection will need information on some characters that contribute to the high yield and the relationship among the observed characters. This study aimed to determine the relationship between characters and the effects of the observed characters to grain yield per plant. This research was conducted from July 2017 to March 2018 at Balithi Experimental Farm (1100 m asl.), Cipanas, Cianjur District, West Java, Indonesia. The genetic material used were three F_2 population of bread wheat (G1/Se, HP/Se, and Ja/Se) and four parent genotypes. Observations were made on each individual of F_2 populations. Parent genotypes were planted by using completely randomized block design with three replications. The results showed that the number of a grain of non-main spike and the number of grain per plant characters had a high correlation in each F_2 population and these characters also had positive and significant direct effect to grain weight per plant. It could be a character selection for high yield breeding program. The broad sense heritability was medium to a high value for all characters in F_2 G1/Se and HP/Se populations.

Keywords: direct effect, genetic variability, high yield, selection character

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the important staple food whose consumption increases from year to year. Indonesia always imports wheat grain to fulfill their needs from Australia, Argentina, Canada, Ukraine, and America. Wheat grain imported were 7.4 million tons (2015), 10.5 million tons (2016), and 10.3 million tons (2017), with a value of US$ 2.1 billion, US$ 2.4 billion and US$ 2.3 billion, respectively (BPS 2018). An alternative can be done to reduce the country's large foreign exchange is to develop a tropical wheat plant in Indonesia.

Indonesia already has several varieties of wheat, including Selayar, Dewata, Nias, Guri 1, Guri 2, Guri 3, Guri 4, Guri 5, Guri 6, and Ganesa. These are introduced varieties, except for Ganesa that produced by a mutation breeding programme. Assembling of new varieties can be achieved by using both conventional and non-conventional breeding programme. A conventional approach can be made by hybridization.

Plant population resulted from hybridization has specific characteristics that are determined by the genetic background of their parents. The right parents will produce high genetic variability as a result of segregation that occurs in alleles that determine phenotypic characters. Acquaah (2007) stated that selection would be effective and efficient in populations with high genetic variability. It is better to use a selection character that has high heritability values (Wahidy et al. 2016). The most targeted selection characters are yield, but it has a low heritability (Carvalho et al. 2017). Yield character was controlled by the complex mechanism so that selection should be used some traits related to yield (Desheva 2016).

Indirect selection through the yield component requires knowledge of the relationship among characters (Khan et al. 2013). Correlation is an analysis that shows a linear relationship between two or more characters. Janmohammadi et al. (2014) reported that yield correlated with the number of spikelets, in which seed diameter and seed length correlated with 1000 grain weight. Furthermore, Dabi et al. (2016) confirmed that 1000 kernel weight, plant height and the number of seeds per spike were reported to be significantly correlated with yield. Mecha et al. (2017) added that the grain filling period had a positive correlation to the weight of 100 grains and yield. Biomass, harvest index, number of the productive tiller and 1000 grain weight are closely related to yield, and so, selection using these characters can improve crop yield potential (Kandel et al. 2017).

Studies of the correlation between yield and yield components have been widely reported but still cannot provide a clear picture of the urgency level of each component in determining yield (Rharrabti and Elhani 2014). Singh and Chaudhary (2007) asserted that path analysis provides information on the contribution of direct and indirect effects of causal factors on yield character. Singh and Upadhyay (2013) further explained that the significant and positive phenotypic direct effects were shown by yield per ha, followed by 1000 grain weight and the number of productive tillers to yield per plant. Spike length, days to maturity, the number of grain per spike has an adverse phenotypic direct effect on grain yield per plant.

We crossed Guri 1, HP1744, and Jarissa to Selayar variety to obtain F_1 and F_2 seeds. We planted F_2 seeds for each hybridization and would like to make the selection in each those populations. This study aimed to evaluate the relationship between characters in each F_2 population and to determine the characters that have a direct or indirect influence on yield per plant so it can be used as selection criteria.

MATERIALS AND METHODS

Study area

The research was carried out at the experimental farm of Balithi, Cipanas, Cianjur District, West Java Province, Indonesia in July 2017 - March 2018. The study site has an altitude of 1100 m above sea level. The genetic material used was the seeds of three F_2 populations (G1/Se, HP/Se, and Ja/Se) and also four parent genotypes (Guri 1, HP1744, Jarissa, and Selayar). Guri 1 and Selayar are national varieties that have been released. The HP1744 genotype was a CYMMIT collection, and Jarissa was an introduced wheat variety from Slovakia.

Procedures

The genotypes were planted using Randomized Complete Block Design (RCBD) with three replications. The experimental unit was plot of 1 m x 5 m with a spacing of 30 cm x 20 cm, so there were 75 plants in each plot. One seed was planted in each hole. The character measurements were done on 10 sample plants for parents and all plants for F2 populations. Manure was given a month before planting as basic fertilizer at a dose of 20 kg ha^{-1}. The inorganic fertilizers used were urea, SP36, and KCl with doses of 150 kg ha^{-1}, 200 kg ha^{-1}, and 100 kg ha^{-1}, respectively. Urea was given in two stages: the first was 7-10 days after planting (DAP) and the second was 30 DAP. Granule insecticide with carbofuran as the active ingredient was given when planting, 5-10 grains per a hole. Pesticides were used at recommended doses to control pest and disease. Weeding was carried out every three weeks manually. Watering was done to adjust the conditions of the plants in the field to prevent wilting. Harvesting was done if the plant has turned into yellow and the seeds were hard when pressed with nails. Observation was recorded on plant height, days to flowering, days to harvesting, grain filling period, number of productive tillers, spike length, number of spikelet per spike, spikelet density, number of floret of main spike, number of grain of main spike the percentage of unfilled grain, number of grain of non-main spike, number of grain per plant, 100 grains weight, grain weight of main spike, grain weight of non-main spike, and grain weight per plant.

Data analysis

The broad-sense heritability was estimated according to Mahmud and Kramer (1951). Heritability was categorized into low (< 20%), moderate (20-50%), and high (> 50%) following (Syukur et al. 2010). Correlation coefficient and path analysis were done according to Singh and Chaudhary (2007). Phenotypic correlation coefficients of yield and its components were obtained through statistical package R program. After computing the correlation coefficient between all characters, path coefficient analysis was performed using phenotypic correlation considering yield (grain weight per plant) as the response variable and other characters as a predictor variable.

RESULTS AND DISCUSSION

Correlation analysis

All the characters observed had a significant and very significant correlation to grain weight per plant in the F_2 G1/Se population except for the spikelet density and the percentage of unfilled grain (Table 1). The number and grain weight of non-main spike had closed correlation to the number of grain per plant (r = 1) and grain weight per plant (r = 1), respectively. The characters that is closely related to grain weight per plant and positively correlated were grain weight of non-main spike (r = 1), number of a grain of non-main spike (r = 0.99), number of grain per plant (r = 0.99), and number of productive tillers (r = 0.95). This explained that the selection using these characters could improve grain weight per plant. Khan et al. (2013) and Desheva (2016) reported that the number of productive tillers of wheat had a positive and strong correlation to yield.

On the other hand, the grain filling period was negative and significant correlated to the grain weight per plant. The number of a grain of non-main spike (r = 0.99) and the number of grain per plant (r = 0.99) correlated high significantly and positive to the grain weight of non-main spike and grain weight per plant. The number of productive tillers had a tight and significant correlation to a number of a grain of non-main spike (r = 0.95), the number of grain per plant (r = 0.96), grain weight of non-main spike (r = 0.95), and grain weight per plant (r = 0.95). Mohsin et al. (2009) referred that number of productive tiller was highly positive and significantly correlated with grain yield.

Table 2 showed that days to flowering, days to harvesting, grain filling period, spike length, and spikelet density did not have a correlation with grain weight per plant in the F_2 HP/Se population. This result was different from those of Khan and Naqvi (2012), they stated spike length showed positive and highly significant correlation with yield under non-stress condition (normal). On the contrary, the number of productive tillers, the number of a grain of non-main spike (r = 0.96), the number of grain per plant (r = 0.96) and a number of a grain of non-main spike (r = 1) had a strong and positive correlation to grain weight per plant. Ramesh et al. (2016) reported that spike length and grain filling period exhibited significant phenotypic association with yield

The number of a grain of non-main spike of the population of F_2 Ja/Se did not correlate with the grain weight of per plants (yield), and it was different from the two previous populations. Only the number of grain per plant (r = 0.86) and grain weight of non-main spike (r = 1) which has a strong and positive correlation to grain yield per plant (Table 3). The number of a grain of non-main spike had a tight and significant correlation to the number of grain per plant.

Path analysis

Correlation values could not describe the causal relationship among characters to their direct and indirect effect through other characters. Khan et al. (2013) explained that path coefficient analysis provided a clue to the contribution of all components of yield to the grain yield. It also supplied an effective way to find out direct and indirect sources of correlation.

The number of grain per plant (p = 0.8551), days to flowering (p = 0.6172), and grain filling period (p = 0.4994) had a significant direct effect on grain weight per plant of the F_2 G1/Se population (Table 4). This table showed characters which had a small or adverse direct effect had an indirect impact through the number of grain per plant. Kumar et al. (2014) had a different result, in that the number grain per plant had a direct adverse effect to grain yield but had a positive and high indirect factor through number grain per spike. Neru et al. (2017) stated grain filling period had a direct negative factor to the grain yield per meter. Singh and Chaudhary (2007) reported that characters with a negative value for direct factor would be correlated through their indirect factors. The number of productive tillers and number of a grain of non-main spike had a greater indirect effect through a number of grain per plant of 0.8209 and 0.8551 values, respectively. This can be explained that the number of productive tillers and number of a grain of non-main spike correlated with the number of grain per plant, namely r = 0.96 and r = 1, respectively (Figure 1). Spike length have a small direct factor, but it influenced the number of grain per plant indirectly. It was also reported by Rahman et al. (2016). Ramesh et al. (2016) said that spike length, grains per spike, plant height, 50% heading and grain filling had the highest positive direct effect on grain yield.

Table 1. Correlation coefficient of G1/Se F_2 population

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16
X2	0.67 **															
X3	0.36 **	0.65 **														
X4	-0.43 **	-0.51 **	0.33 **													
X5	0.73 **	0.48 **	0.28 **	-0.28 **												
X6	0.69 **	0.46 **	0.18 ns	-0.36 **	0.80 **											
X7	0.63 **	0.44 **	0.22 **	-0.29 **	0.77 **	0.91 **										
X8	-0.07 ns	-0.07 ns	-0.15 ns	-0.08 ns	-0.13 ns	-0.09 ns	-0,48 **									
X9	0.64 **	0.42 **	0.20 **	-0.30 **	0.75 **	0.83 **	0.86 **	-0.33 **								
X10	0.63 **	0.36 **	0.23 **	-0.19 ns	0.70 **	0.74 **	0.72 **	-0.19 ns	0.84 **							
X11	-0.13 ns	0.03 ns	-0.10 ns	-0.15 ns	-0.11 ns	-0.03 ns	0.03 ns	-0.13 ns	0.03 ns	-0.49 **						
X12	0.07 **	0.46 **	0.30 **	-0.23 **	0.95 **	0.74 **	0.70 **	-0.10 ns	0.72 **	0.70 **	-0.16 ns					
X13	0.70 **	0.46 **	0.30 **	-0.23 **	0.96 **	0.74 **	0.70 **	-0.10 ns	0.73 **	0.71 **	-0.17 ns	1.00 **				
X14	0.33 **	0.32 **	0.45 **	0.12 ns	0.27 **	0.18 ns	0.29 ns	-0.30 **	0.29 **	0.37 **	-0.28 **	0.28 **	0.28 **			
X15	0.70 **	0.49 **	0.40 **	-0.16 ns	0.76 **	0.71 **	0.73 **	-0.26 ns	0.82 **	0.92 **	-0.40 **	0.76 **	0.77 **	0.58 **		
X16	0.70 **	0.48 **	0.32 **	-0.23 **	0.95 **	0.73 **	0.70 **	-0.11 ns	0.72 **	0.69 **	-0.16 ns	0.99 **	0.99 **	0.31 **	0.77 **	
X17	0.71 **	0.48 **	0.33 **	-0.23 **	0.95 **	0.74 **	0.71 **	-0.12 ns	0.73 **	0.70 **	-0.17 ns	0.99 **	0.99 **	0.32 **	0.78 **	1.00 **

Note: ** = significantly correlated at α 0.01, * = significantly correlated at α 0.05, ns = not significantly correlated at α 0.05, X1= plant height, X2 = days to flowering , X3 = days to harvesting , X4 = grain filling period, X5 = number of productive tillers, X6 = spike length, X7 = number of spikelet per spike, X8 = spikelet density, X9 = number of floret of main spike, X10 = number of grain of main spike, X11 = the percentage of unfilled grain, X12 = number of grain of non-main spike, X13 = number of grain per plant, X14 = 100 grains weight, X15 = grain weight of main spike, X16 = grain weight of non-main spike, and X17 = grain weight per plant

The number of a grain of non-main spike (p = 0.311), the number of grain per plant (p = 0.392), and the number of productive tillers (p = 0.216) had a significant direct effect compared to other characters (Table 5). The number of productive tillers had a greater indirect effect (p = 0.3562) than its direct effect (p = 0.2157) through the number of grain per plant. It also occurred to plant height, number of spikelet per spike, number of a floret of the main spike, number of a grain of the main spike, and grain weight of the main spike. The number of productive tillers had a large indirect effect through the number of grain per plant and its character also had a strong correlation (r = 0.96), likewise the number of the grain of non-main spike (r = 1) to the number of grain per plant (Figure 2).

The number of grain per plant had the most significant direct effect (p = 0.4512) to grain weight per plant in the Ja/Se population. Although the number of productive tillers and number of a grain of non-main spike had a small direct effect, it had a large indirect impact through the number of grain per plant (Table 6). The two characters whose had a very strong correlation to the number of grain per plant was the number of a grain of non-main spike (r = 1) (Figure 3).

The number of a grain of the main spike had a negative direct effect but a positive and large indirect effect through grain weight per plant (p = 0.2539) with a strong correlation (r = 0.86). Spike length had significant phenotypic correlation on grain yield (Table 3) but it had a negative direct factor. Ali and Shakor (2012) reported that spike length had a negative direct factor in Durum wheat population but a positive direct factor in bread wheat population.

Broad-sense heritability

Heritability is one of the genetic parameters which always including to choose a selection criterion. Mohammadi et al. (2012) said heritability described how much a character is controlled genetically. All characters in F_2 G1/Se and HP/Se populations had medium to high broad-sense heritability (Table 7). The number of grain and grain weight of the main spike and non-main spike had high broad-sense heritability values in all F_2 populations. It also confirmed by Nukasani et al. (2013), Sing et al. (2012), and Monpara (2011). Plant high in three F_2 populations was high. It indicated environmental factor was less influence to its phenotype. The same result was explained by Khan et al. (2013).

Table 2. Correlation coefficient of HP/Se F_2 population

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16
X2	0.40 **															
X3	0.35 **	0.60 **														
X4	-0.29 **	-0.72 **	0.13 ns													
X5	0.55 **	0.05 ns	0.08 ns	0.00 ns												
X6	0.12 ns	0.04 ns	0.03 ns	-0.02 ns	0.09 ns											
X7	0.54 **	0.31 **	0.20 *	-0.22 **	0.43 **	0.06 ns										
X8	0.02 ns	-0.02 ns	-0.01 ns	0.02 ns	0.00 ns	0.98 **	0.13 ns									
X9	0.37 **	0.05 ns	-0.03 ns	-0.09 ns	0.45 **	0.11 ns	0.45 **	0.01 ns								
X10	0.29 **	0.04 ns	-0.14 ns	-0.17 *	0.37 **	0.11 ns	0.58 **	-0.01 ns	0.63 **							
X11	-0.11 ns	0.02 ns	0.20 *	0.15 ns	-0.18 *	-0.06 ns	-0.43 **	0.03 ns	-0.15 ns	-0.85 **						
X12	0.52 **	0.05 ns	0.01 ns	-0.05 ns	0.91 **	0.09 ns	0.41 **	0.01 ns	0.45 **	0.43 **	-0.24 **					
X13	0.52 **	0.05 ns	0.01 ns	-0.05 ns	0.91 **	0.09 ns	0.42 **	0.01 ns	0.46 **	0.45 **	-0.27 **	1.00 **				
X14	0.00 ns	-0.28 **	-0.27 **	0.10 ns	0.24 **	-0.02 ns	-0.02 ns	-0.02 ns	0.09 ns	0.14 ns	-0.14 ns	0.25 **	0.25 **			
X15	0.15 ns	0.01 ns	-0.03 ns	-0.04 ns	0.22 **	0.03 ns	0.19 *	-0.0 1ns	0.27 **	0.21 **	0.11 ns	0.27 **	0.27 **	0.24 **		
X16	0.51 **	0.00 ns	-0.03 ns	-0.02 ns	0.92 **	0.10 ns	0.39 **	0.01 ns	0.46 **	0.43 **	0.23 **	0.96 **	0.96 **	0.35 **	0.29 **	
X17	0.51 **	0.00 ns	-0.03 ns	-0.03 ns	0.91 **	0.10 ns	0.39 **	0.01 ns	0.47 **	0.43 **	-0.24 **	0.96 **	0.96 **	0.36 **	0.36 **	1.00 **

Note: ** = significantly correlated at α 0.01, * = significantly correlated at α 0.05, ns = not significantly correlated at α 0.05, X1= plant height, X2 = days to flowering , X3 = days to harvesting , X4 = grain filling period, X5 = number of productive tillers, X6 = spike length, X7 = number of spikelet per spike, X8 = spikelet density, X9 = number of floret of main spike, X10 = number of grain of main spike, X11 = the percentage of unfilled grain, X12 = number of grain of non-main spike, X13 = number of grain per plant, X14 = 100 grains weight, X15 = grain weight of main spike, X16 = grain weight of non-main spike, and X17 = grain weight per plant

Table 3. Correlation coefficient of Ja/Se F_2 population

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16
X2	0.26 **															
X3	0.20 *	0.62 **														
X4	-0.15 ns	-0.72 **	0.10 ns													
X5	0.52 **	0.09 ns	0.22 **	0.07 ns												
X6	0.47 **	0.10 ns	0.09 ns	-0.05 ns	0.53 **											
X7	0.34 **	0.09 ns	0.08 ns	-0.05 ns	0.39 **	0.69 **										
X8	0.13 ns	-0.01 ns	0.01 ns	0.02 ns	0.19 *	0.41 **	-0.38 **									
X9	0.19 *	0.10 ns	0.08 ns	-0.06 ns	0.27 **	0.51 **	0.51 **	0.02 ns								
X10	0.20 *	-0.07 ns	-0.07 ns	0.03 ns	0.31 **	0.42 **	0.43 **	0.00 ns	0.68 **							
X11	-0.08 ns	0.19 *	0.16 ns	-0.09 ns	-0.16 ns	-0.13 ns	-0.15 ns	0.04 ns	-0.11 ns	-0.79 *						
X12	0.30 **	-0.07 ns	0.04 ns	0.12 ns	0.66 ns	0.49 ns	0.46 **	0.06 ns	0.40 **	0.57 **	-0.41 **					
X13	0.30 **	-0.07 ns	0.04 ns	0.12 ns	0.66 ns	0.49 ns	0.46 **	0.06 ns	0.41 **	0.59 **	-0.42 **	1.00 **				
X14	0.07 ns	-0.20 *	-0.14 ns	0.13 ns	-0.17 *	-0.02 ns	-0.08 ns	0.06 ns	0.01 ns	0.20 *	-0.27 **	0.06 ns	0.07 ns			
X15	0.27 **	-0.11 ns	-0.13 ns	0.03 ns	0.24 **	0.33 **	0.33 **	-0.01 ns	0.58 **	0.86 **	-0.69 **	0.49 ns	0.50 **	0.47 **		
X16	0.37 **	0.01 ns	0.04 ns	0.03 ns	0.61 **	0.47 **	0.43 **	0.06 ns	0.42 **	0.60 **	-0.45 **	0.86 ns	0.86 **	0.28 ns	0.63 **	
X17	0.37 **	-0.01 ns	0.02 ns	0.03 ns	0.61 **	0.47 **	0.43 **	0.05 ns	0.43 **	0.63 **	-0.48 **	0.86 ns	0.86 **	0.29 **	0.66 **	1.00 **

Note: ** = significantly correlated at α 0.01, * = significantly correlated at α 0.05, ns = not significantly correlated at α 0.05, X1= plant height, X2 = days to flowering , X3 = days to harvesting , X4 = grain filling period, X5 = number of productive tillers, X6 = spike length, X7 = number of spikelet per spike, X8 = spikelet density, X9 = number of floret of main spike, X10 = number of grain of main spike, X11 = the percentage of unfilled grain, X12 = number of grain of non-main spike, X13 = number of grain per plant, X14 = 100 grains weight, X15 = grain weight of main spike, X16 = grain weight of non-main spike, and X17 = grain weight per plant.

Table 4. Path analysis of G1/Se F_2 population

X	Direct effect	Indirect effect												
		X1	X2	X3	X4	X5	X6	X7	X9	X10	X12	X13	X14	X15
X1	0.020		0.414	-0.201	-0.215	-0.024	-0.003	0.013	0.015	-0.086	0.074	0.599	0.000	0.102
X2	0.620	0.016		-0.363	-0.255	-0.016	-0.002	0.009	0,010	-0.049	0.048	0.393	0.000	0.071
X3	-0.560	0.008	0.401		0.165	-0.009	-0.001	0.004	0.005	-0.031	0.032	0.257	0.000	0.058
X4	0.500	-0.010	-0.315	-0.184		0.009	0.002	-0.006	-0.007	0.026	-0.024	-0.197	0.000	-0.023
X5	-0.030	0.017	0.296	-0.156	-0.140		-0.003	0.015	0.017	-0.095	0.100	0.821	0.000	0.110
X6	0.000	0.016	0.284	-0.101	-0.180	-0.026		0.018	0.019	-0.101	0.078	0.633	0.000	0.103
X7	0.020	0.015	0.272	-0.123	-0.145	-0.025	-0.004		0.020	-0.098	0.074	0.599	0.000	0.106
X9	0.020	0.015	0.259	-0.112	-0.150	-0.024	-0.004	0.017		-0.114	0.076	0.624	0.000	0.119
X10	-0.140	0.015	0.222	-0.129	-0.095	-0.023	-0.003	0.014	0.020		0.074	0.607	0.000	0.134
X12	0.110	0.016	0.284	-0.168	-0.115	-0.031	-0.003	0.014	0.017	-0.095		0.855	0.000	0.110
X13	0.860	0.016	0.284	-0.168	-0.115	-0.031	-0.003	0.014	0.017	-0.097	0.105		0.000	0.112
X14	0.000	0.008	0.198	-0.251	0.060	-0.009	-0.001	0.006	0.007	-0.050	0.029	0.239		0.084
X15	0.150	0.016	0.302	-0.224	-0.080	-0.025	-0.001	0.015	0.019	-0.125	0.080	0.658	0.000	
Residu		0.143												

Note: X1 = plant height, X2 = days to flowering , X3 = days to harvesting , X4 = grain filling period, X5 = number of productive tillers, X6 = spike length, X7 = number of spikelet per spike, X9 = number of floret of main spike, X10 = number of grain of main spike, X12 = number of grain of non-main spike, X13 = number of grain per plant, X14 = 100 grains weight, X15 = grain weight of main spike.

Table 5. Path analysis of HP/Se F_2 population

X	Direct effect	Indirect effect									
		X1	**X5**	**X7**	**X8**	**X10**	**X11**	**X12**	**X13**	**X14**	**X15**
X1	0.021		0.119	-0.019	0.009	0.001	0.000	0.162	0.204	0.000	0.014
X5	0.216	0.012		-0.015	0.010	0.002	0.000	0.283	0.356	0.026	0.021
X7	-0.035	0.11	0.093		0.010	0.003	0.000	0.128	0.164	-0.002	0.018
X8	0.023	0.008	0.097	-0.016		0.003	0.000	0.140	0.180	0.010	0.025
X10	0.005	0.006	0.080	-0.020	0.014		0.001	0.134	0.176	0.015	0.020
X11	-0.001	-0.002	-0.039	0.015	-0.003	-0.004		-0.075	-0.106	-0.015	-0.10
X12	0.311	0.011	0.196	-0.014	0.010	0.002	0.000		0.392	0.027	0.025
X13	0.392	0.011	0.196	-0.015	0.011	0.002	0.000	0.311		0.027	0.025
X14	0.107	0.000	0.052	0.001	0.002	0.001	0.000	0.078	0.098		0.022
X15	0.094	0.003	0.047	-0.007	0.006	0.001	0.000	0.084	0.106	0.026	
Residu		0.217									

Note: X1 = plant height, X2 = days to flowering , X3 = days to harvesting , X4 = grain filling period, X5 = number of productive tillers, X6 = spike length, X7 = number of spikelet per spike, X9 = number of floret of main spike, X10 = number of grain of main spike, X12 = number of grain of non-main spike, X13 = number of grain per plant, X14 = 100 grains weight, X15 = grain weight of main spike.

Table 6. Path analysis of Ja/Se F_2 population

X	Direct effect	Indirect effect										
		X1	**X5**	**X6**	**X7**	**X8**	**X10**	**X11**	**X12**	**X13**	**X14**	**X15**
X1	0.027		0.083	-0.012	0.017	0.044	-0.097	0.023	0.059	0.135	0.011	0.080
X5	0.159	0.014		-0.013	0.020	0.062	-0.150	0.047	0.129	0.298	-0.026	0.071
X6	-0.025	0.013	0.084		0.035	0.118	-0.204	0.038	0.096	0.221	-0.003	0.097
X7	0.050	0.009	0.062	-0.017		0.118	-0.208	0.044	0.090	0.208	-0.012	0.097
X8	0.230	0.005	0.043	-0.013	0.026		-0.330	0.032	0.078	0.185	0.002	0.171
X10	-0.485	0.006	0.049	-0.011	0.022	0.157		0.230	0.112	0.266	0.031	0.254
X11	-0.291	-0.002	-0.025	0.003	-0.008	-0.025	0.383		-0.080	-0.190	-0.041	-0.204
X11	0.196	0.008	0.105	-0.012	0.023	0.092	-0.276	0.119		0.451	0.009	0.145
X13	0.451	0.008	0.105	-0.012	0.023	0.095	-0.286	0.122	0.196		0.011	0.148
X14	0.153	0.002	-0.027	0.001	-0.004	0.002	-0.097	0.079	0.012	0.032		0.139
X15	0.295	0.007	0.038	-0.008	0.017	0.134	-0.417	0.201	0.096	0.226	0.072	
Residu		0.392										

Note: X1 = plant height, X2 = days to flowering , X3 = days to harvesting , X4 = grain filling period, X5 = number of productive tillers, X6 = spike length, X7 = number of spikelet per spike, X9 = number of floret of main spike, X10 = number of grain of main spike, X12 = number of grain of non-main spike, X13 = number of grain per plant, X14 = 100 grains weight, X15 = grain weight of main spike.

Table 7. Broad-sense heritability (h^2_{bs}) of F_2 populations

Characters	**F_2 populations**		
	G1/Se	**HP/Se**	**Ja/Se**
		h^2_{bs} (%)	
PH	91.53	63.73	87.68
DF	88.93	83.12	94.11
DH	85.41	80.72	80.39
GFP	96.81	94.49	96.87
NPT	64.58	69.27	65.61
SL	88.85	98.83	29.51
NSS	81.60	61.53	48.04
SD	44.36	98.05	0.00
NFMS	89.99	37.90	52.46
NGMS	71.37	65.88	66.38
PUG	21.58	31.29	10.66
NGNMS	68.55	67.05	93.11
NGP	69.50	67.15	92.98
HGW	85.01	32.57	47.69
GWMS	64.62	91.72	70.29
GMNMS	69.36	66.77	85.61
GWP	69.98	67.04	85.09

Note: PH (plant height), DF (days to flowering), DH (days to harvesting), GFP (grain filling period), NPT (number of productive tillers), SL (spike length), NSS (number of spikelet per spike), SD (spikelet density), NFMS (number of floret of main spike), NGMS (number of grain of main spike), PUG (the percentage of unfilled grain), NGNMS (number of grain of non-main spike), NGP (number of grain per plant), HGW (100 grains weight), GWMS (grain weight of main spike), GWNMS (grain weight of non-main spike), and GWP (grain weight per plant).

Grain weight per spike was determined by spike length and number of grain per spike. It revealed that spike length had high broad-sense heritability for F_2 G1/Se and HP/Se populations but number grain per spike was high for all populations (Table 7). Guendouz et al. (2014) suggested number grain per spike could be increasing grain yield so it could be used for indirect selection. Kumar et al. (2018) reported in his research that the number of grain per spike had 91% for broad-sense heritability. It was also stated by Rathwa et al. (2018), Hakimi et al. (2017).

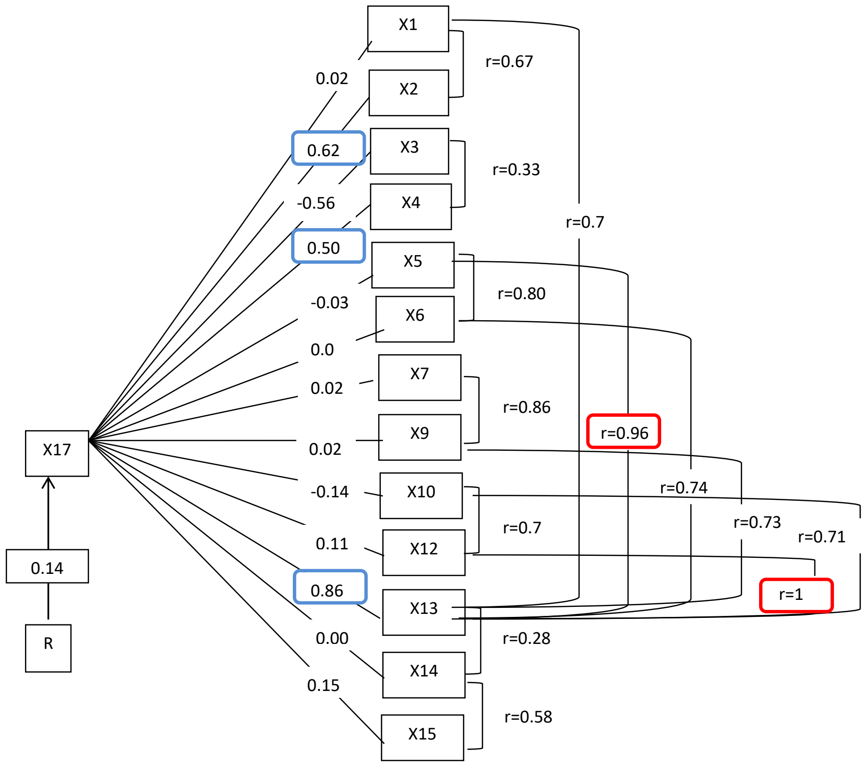

Figure 1. Path diagram of F_2 G1/Se population. Note: X1 = days to plant height, X2 = days to flowering, X3 = days to harvesting, X4 = grain filling period, X5 = number of productive tillers, X6 = spike length, X7 = number of spikelet per spike, X9 = number of floret of main spike, X10 = number of grain of main spike, X12 = number of grain of non-main spike, X13 = number of grain per plant, X14 = 100 grains weight, X15 = grain weight of main spike, X17 = grain weight per plant

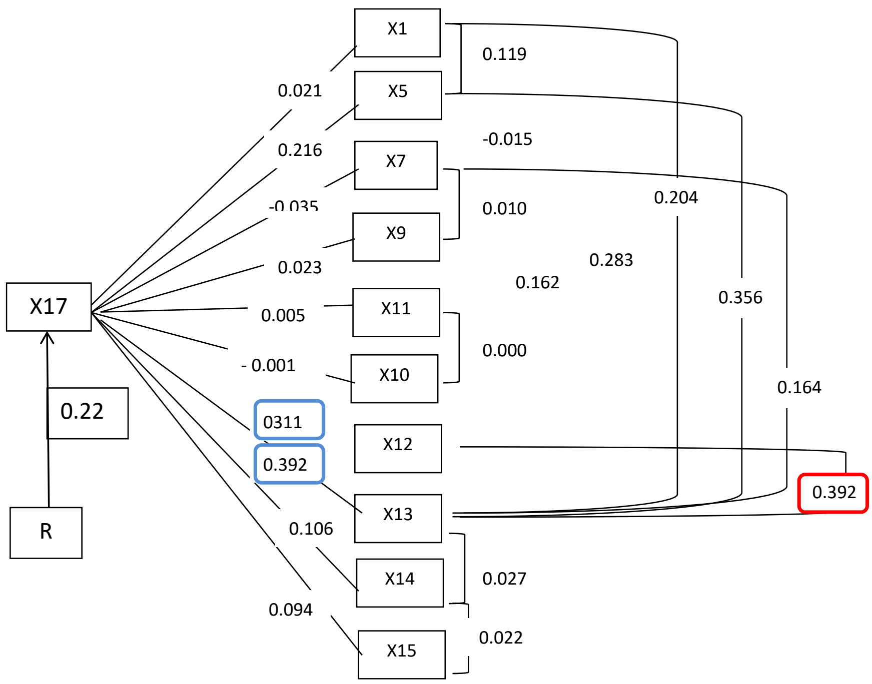

Figure 2. Path diagram of F_2 HP/Se Population. Note: X1 = days to plant height, X5 = number of productive tillers, X7 = number of spikelet per spike , X9 = number of floret of main spike, X10 = number of grain of main spike, X11 = the percentage of unfilled grain, X12 = number of grain of non-main spike, X13 = number of grain per plant, X14 = 100 grains weight, X15 = grain weight of main spike, X17 = grain weight per plant

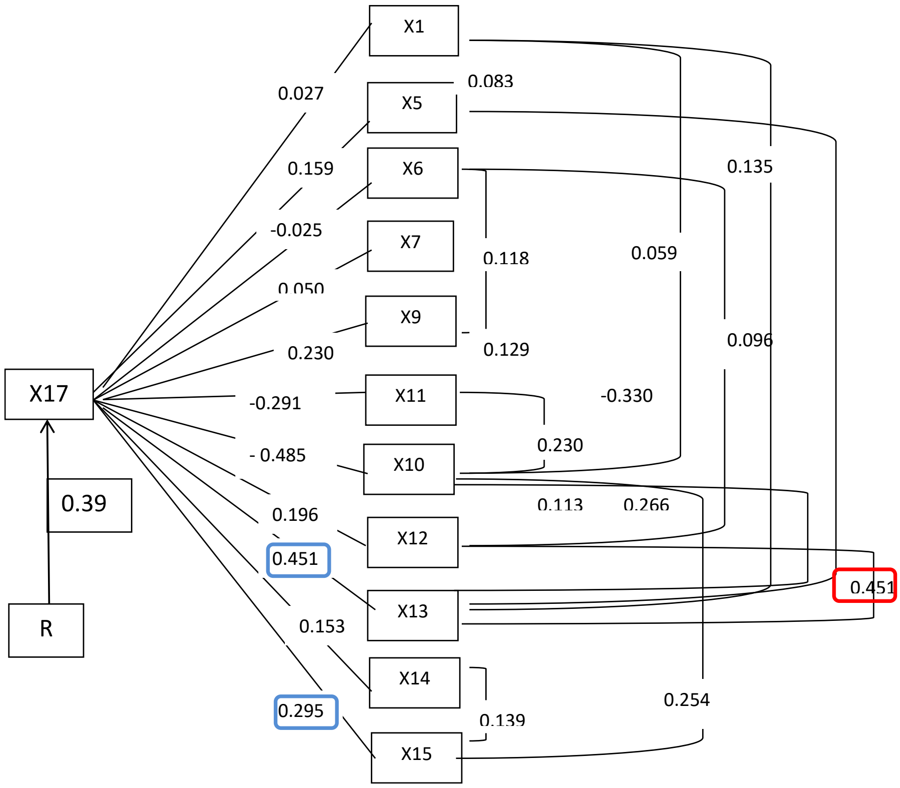

Figure 3. Path diagram of F_2 Ja/Se Population. Note: X1 = days to plant height, X5 = number of productive tillers, X6 = spike length, X7 = number of spikelet per spike, X9 = number of floret of main spike, X10 = number of grain of main spike, X11 = the percentage of unfilled grain, X12 = number of grain of non-main spike, X13 = number of grain per plant, X14 = 100 grains weight , X15 = grain weight of main spike, X16 = grain weight of non-main spike, X17 = grain weight per plant

Spike density of F_2 Ja/Se population had null broad-sense heritability (Table 7). It indicated that its character was influenced mostly by the environment. Otherwise, two others populations had a high broad-sense heritability for spike density character. In these population, its character was controlled genetically, so perhaps it will be inherited to next generations. Sohail et al. (2018) said that characters whose high heritability values could be selected by single plant selection for the next generation.

The number of grain per plant always had positive and significant direct factor in all F_2 populations (Figure 1, 2, 3). Its character also had a high broad-sense heritability (Table 7). It means that it can be a direct selection character for yield improvement in the wheat breeding program. Based on its path analysis and broad-sense heritability, the number of a grain of non-main spike character could be indirect selection character in all populations (Table 4,5,6,7). In this research, we concluded that we could use the number of grain per plant and number of a grain of non-main spike to select plants in each population to improve grain yield for the next generation.

ACKNOWLEDGEMENTS

This research was funded by IPB's Higher Education Primary Research (PDUPT) 2018 Fiscal Year Number: 1801/IT3.11/PN/2018 chaired by Yudiwanti Wahyu EK.

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