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HYBRID PERFORMANCE TESTING OF CHILI PEPPER (*Capsicum annuum* L.) FOR RESISTANCE TO YELLOW LEAF CURL BEGOMOVIRUS GROWN IN LOWLAND ENVIRONMENTS

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SUMMARY

The attacks of Yellow Leaf Curl Begomovirus (YLCB) have brought about significant yield decreases in many Indonesian chili pepper production areas. Breeding program to develop resistant varieties since 2008 has produced five potential high yielding chili pepper hybrids that resistant to YCLB attacks. Series of adaptation testing to determine agronomical performances of respective hybrids have been conducted, including to evaluate its performance at the lowland environments. The objective of this research was to determine the performance of five chili pepper hybrids at three types of soil in lowland environments. Three separated experiments, in organosol, ultisol and regosol, were repeatedly conducted in 2013 and 2014. The experiments were arranged in Randomized Complete Block Design with four replications and was nested in the soil types. Plant materials were five genotypes of chili peppers (H13, H23, H43, H53, and H73) compared with an antecedent of P3 and two commercial varieties of IPBCH3 and Tilala. Results concluded that H23 hybrid have better fruit length, fruit diameter, fruit weight per fruit, fruit weight per plant than other comparing varieties. Chili pepper hybrids grown in organosol have higher yield performances compared to those grown in ultisol and regosol. Although H23 hybrid is suitable to organosol, ultisol and regosol, the best productivity of H23 takes place in organosol.

Key words: Performance testing, chili-peppers, yellow leaf curl begomovirus, lowland genotypes

Key findings: New hybrid of begomovirus's resistant chili pepper (H23) is documented to have good growth and yield in lowland agricultural lands.

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INTRODUCTION

During the period of 2000-2009, Indonesian vegetable production increased by almost 60%, from 6.7 to 10.7 metric tons (ACDIVOCA, 2011). Chili pepper (*Capsicum annuum* L.) is among the greatest growth followed by potatoes, head cabbages, shallots, and eggplants. This is a very important vegetable crop for Indonesian with average consumption of 2.9 kg capita^{-1} year^{-1} (Farid and Subekti, 2012) and its production area was the largest among other Indonesian vegetable productions (Anonim, 2007). However, Indonesian chili-pepper productivity was only 6.8 ton ha^{-1}, less than one third of Chinese productivity which has reached more than 22 ton ha^{-1} (FAO, 2014).

According to Hidayat *et al.* (1999), the attacks of Yellow Leaf Curl Begomovirus (YLCB) have brought about significant yield decreases in Indonesian chili pepper productions since fifteen years ago. YCLB is a devastative disease in a wide range of important crops causing significant yield losses (Lapidot and Friedmann, 2002). This disease has been observed in many Indonesian chili pepper production areas since 2000 (Sulandari *et al*., 2007). In Sumatera, YCLB attacks on chili pepper varied among provinces. According to Sudiono *et al*. (2005) the occurrence of disease accidents in the Province of Lampung, South Sumatera, Bengkulu, Jambi, West Sumatera and North Sumatera were 0-100, 20-60, 0-40 0-5, 0-5 and 0–80%, respectively. In other region, Central Java, it was also reported that sporadic YCLB's attacks on *Capsicum annuum* L acccounted for 10-35% (Sulandari *et al.*, 2001), while the intensity of YCLB attacked on *Capsicum frustesen* L. reached 100%. Recently, a study conducted in Bogor, Indonesia, reported that attacks of YCLB on the seedling growth brought about yield loss up to 84.6% (Ganefianti *et al*., 2017). This virus has been also reported to attack tobacco and caused harvest failure (Aidawati *et al*., 2002). In the other parts of the world, this disease have been widely reported to attack legumes crops (Morales and Niessen, 1988; Bianchini, 1999; Garrido-Ramirez *et al.*, 2000), cotton (Naveed and Zahid, 2007), cassava and tomato (Lapidot and Friedmann, 2002; Lapidot *et al.*, 1997; Vidavsky and Czosnek, 1998). In addition, YCLB is able to infect weeds (Salati *et al.*, 2002).

In the effort to increase Indonesian chili pepper, developing resistant varieties would be a reasonable option in easing the risk of harvest failures. Ganefianti *et al.* (2011) have conducted series of chili pepper breeding programs since 2008 and have produced five potential high yielding (>10 ton ha^{-1}) chili pepper hybrids (from 49 genotypes) that resistant to YCLB attacks. These significant initial results are very important because there have been no reports on chili pepper varieties that resistant to YCLB. These potential hybrids are not available to the markets yet, and have to go through series of adaptation testing to determine agronomical performances of respective hybrids. Performance testing can be done at various location (*e.g.* altitudes and soil types) and seasons (*e.g.* dry and raining seasons). It is very important to have resistant variety of chili pepper to begomovirus attacks since used of pesticides is not effective to control the vector of this virus.

Another important issue in Indonesian chili-pepper production is the fact that it generally takes place in highland areas. However, such practices could be no longer sustained since land uses and soil fertility at this altitude have drastically changed during the past decades (Sugino, 2008). Farmers produced other vegetable crops in the highland areas to meet consummer demands which might have decreased the chili pepper areas in highland areas. In the other hand, intensive application of chemicals in vegetable produced might have reduced land fertility and increased several weeds inwhich begomovirus hosted. It is therefore very urgent to find substituted areas at lower altitudes to compensate the declining highland production. At lower altitude, soil type might be the most influential environmental factor that determines the survival, growth and yield of chili-pepper. In the lower altitude of Bengkulu, Indonesia, organosol, ultisol and regosol mainly dominated its agricultural lands. These areas are not only available for the expansion of chili pepper production, but also abandoning the chili pepper from the begomovirus hosting-weeds. From chili pepper breeding point of view, developing a new variety that grows well in poor soil is very important to substitute the area of highland chili pepper production. Ultisol in Indonesia coveraged of 25% of agricultural lands and acccounted almost 48,000,000 ha (Subagyo *et al*., 2004). Ultisol is characterized by high soil acidity, high Al^+ and low nutrient availability, especially P (Kadir *et al*., 2001) that might suppress growth and development of chili pepper. Meanwhile organosol, a peatsoil, is resulted from the decomposition of plant/organic material in an area that is always waterlogged (swamps), characterized by high acidity, low nutrient and infertile. Regosol is mainly characterized by coarse grained, gray to yellow, low water holding capacity and low organic matter content. Such limitations could be overcome by developing new chili pepper hybrids that grow well and have high productivity.

The objectives of this two-year experiment were to determine hybrid performances of chili pepper resistant to yellow curl leaf begomovirus grown in organosol, ultisol and regosol of lowland areas.

MATERIALS AND METHODS

Three separated experiments were conducted at organosol, ultisol and regosol of lowland area of Bengkulu (15 m above sea level) from August to December 2013. Similar series of experiments were repeated in January to May 2014. The experiments were arranged in randomized complete block design with four replications nested in locations. Each experimental unit has 24 chili pepper plants. Soil and precipitation profiles during the experiments are presented in Table 1 and Table 2, respectively.

Plant materials consisted of eight chili pepper genotypes (H13, H23, H43, H53, H73, and P3 (one their ancestor) and two commercial hybrids of IPBCH3 and Tilala). Evaluation and preliminary selection to generate the hybrids used in these experiments were conducted in 2012 (Ganefianti *et al*., 2012). Plant materials used in this experiment were resulted from individual inoculation following methods proposed by (Ganefianti *et al*., 2008) using *Bemesia tabaci* as a vector to inoculate “Segunung” inoculum (Ganefianti *et al*., 2015). However, during these experiments, plants were not inoculated since all experimental sites were located in the areas of severe begomovirus attacks.

Standard cultural practiced were applied in all experimental sites. Four-week chili pepper seedlings of each genotypes were transplanted into the field at a spacing of 0.5 m x 0.5 m, on a 1 m x 6 m soil bed (24 plants per plot). A week before transplanting, each planting hole was fertilized with 1 kg cow manure and 5 g NPK (16:16:16). Upon transplanting, each plant was applied with 8 pieces of carbofuran and then mulched with dry rice straws. At four weeks after transplanting, all plants received 5 g NPK (16:16:16). The plots were manually irrigated when two consecutive days there was no raining. Weeds were manually controlled. Insect controls were conducted by applying profenos and imidaklorid (2 ml/l of water). Diseases were controlled by using mankozeb (2.5 ml/l of water).

Chili-pepper performances were measured on days to flowering (days), days to harvesting (days), fruit length (cm), fruit diameter (mm), fruit weight per fruit (g), fruit weight per plant (g). Variance analysis of 8 genotypes at three locations were analyzed by using PKBT Stat Software. This software was developed by Center Studies for Tropical Fruits, Bogor Agricultural University and designed to determine the superiority and purity of promising variety and licensed by Center for Plant Variety Protection and Agricultural Licensing, Ministry of Agriculture, Republic of Indonesia and aimed to support plant breeders in analyzing results of variety trials in the fields to release new cultivar. Means of treatments were compared using Least Significant Different Test at 5%. The additive main effect multiplicative interaction (AMMI) analysis as adopted by Sujiprihati *et al*. (2006) was performed to elucidate the nature of complex genotype x environment interaction (GEI) by partitioning GEI effect into a number of principal components (IPCAs). To provide a clear insight into the pattern of genotype performances across location, the AMMI biplot was constructed from the scores of IPCA1 and IPCA2 (Mattjik, 2005) using SAS v.9 as implemented by Littell *et al.* (2006).

RESULTS

Soil analysis revealed that organosol has high C-organic, followed by regosol and ultisol. Soil acidity of organosol, ultisol and regosol were 4.4, 4.4 and 5.0, respectively (Table 1). Although all soil types had low nutrient, organosol relatively had higher N-total and P_2O_5 compared to those of in ultisol and regosol. Average monthly precipitation in 2013 and 2014 were 248.8 and 321.5 mm, respectively, with 11 and 19 raining days, respectively (Table 2). Average air temperatures and relative humidity

Table 1. Characteristics of pH, N, P, K and organic- C in Regosol, Ultisol and Organosol

Soil traits	Soil types		
	Organosol	Ultisol	Regosol
pH (H_2O)	4.4 (acid)	5.0 (acid)	4.4 (acid)
C-organic (%)	12.41 (high)	1.50 (very low)	5.58 (low)
N-total (%)	0.33 (low)	0.12 (low)	0.20 (low)
P_2O_5 (ppm)	13.21 (low)	7.55 (low)	9.12 (low)
K (me/100 g)	0.18 (low)	0.19 (low)	0.21(low)

Analyzed at Soil Laboratory of University of Bengkulu

Table 2. Weather profiles during the experiments.

Soil type	Year	Weather
Ultisol	2013	248.8 mm month^{-1} (11 raining days month^{-1})
Organosol	2014	321.5 mm month^{-1} (19 raining days month^{-1}), 85% humidity, and average temperatures 26.5 ^{o}C
Regosol	2014	321.5 mm month^{-1} (19 raining days month^{-1}), 85% humidity, and average temperatures 26.5 ^{o}C

were 26.5 ^{o}C and 85%, respectively. Analysis of variances indicated that yield performances are significantly affected by genotypes, locations, years, interaction of location and year, interaction of genotypes and locations, as well as interaction of genotypes, location and years (Table 3). Among the promising hybrids, H13 had the shortest time to flowering (33.8 days), but it was longer than comparing varieties of IPBCH3 (31.5 days) (Table 4). Chili peppers grown in organosol had shorter days to flowering than those of grown in ultisol and regosol.

With respect to days to harvesting, it was revealed that H23 hybrid had the shortest time to flowering (69.3 days) compared to other tested hybrids (Table 5). However, all the promising hybrids took longer time to harvesting compared to IPBCH3 (65.7 days). In general, chili peppers grown in organosol had shorter days to harvesting compared to those grown in ultisol and regosol.

Fruit diameter of H23 hybrid was the highest among the tested hybrids (7.9 mm), and those of P3 dan Tilala (Table 6). However, its diameter was lower than of IPBCH3 (11.5 mm). In addition, H23 hybrid had the longest fruit length (average of 15.2 cm) compared to other tested hybrids and comparing varieties (Table 7). The average fruit weight per fruit of H23 hybrid (5.7 g) was heavier than other tested hybrids and comparing varieties P3 and Tilala, but it was lower than comparing variety of IPBCH3 (7.9 g) (Table 8). In general, chili peppers grown in organosol produced heavier fruit compared to those grown in ultisol and regosol. Total fruit weight per plant of H23 hybrid (471.7 g) was the heaviest among all tested hybrids and other comparing varieties (Table 9). The average total fruit weight per plant of organosol was higher than those of grown in ultisol and regosol.

Combining analysis of variances indicated that genotypes, locations, years, interaction between genotypes and year, interaction genotypes and locations as well as interaction between genotypes, locations and years significantly influenced the on fruit weight per plant (Table 10). Effects of genotypes gave the highest contribution to the fruit weight per plant, followed the effects of years, effects of interaction between genotypes, locations and years, effects of interaction genotypes and locations, and finally the effects of interaction between genotypes and years. Figure 1 shows the pattern of genotypic distribution across 3 locations as plotted on AMMI biplot. This approach will show the adaptability of certain genotypes to a particular growing environment. The coordinate of a wide-range genetic adaptability is located near to center of bi-plot graph. Meanwhile, genotypes that only adaptable to particular environment is located away from the biplot center.

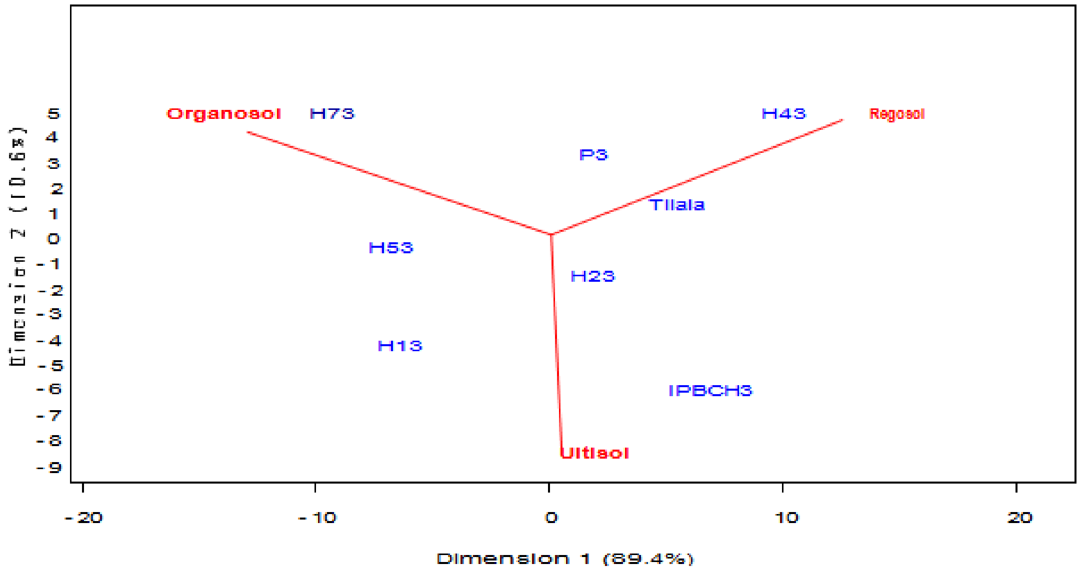

Figure 1. Biplot for effect of model interaction of AMMI2 for yield of 8 chili pepper hybrids in ultisol, organosol and regosol.

Table 3. Summary of combining analysis of variances for 8 genotypes at three locations for two consecutive years (2013 and 2014).

Source of variations	Days to flowering	Days to Harvest	Fruit weight	Fruit length	Fruit Diameter	Fruit weight plant^{-1}
Locations	68.0**	41.2**	179.1**	7.6**	5.0 *	13.9**
Years	144.5**	1444.0**	62.8**	6.37 *	68.6**	46.1**
Locations * Years	48.2**	88.1**	63.9**	14.2**	25.8**	38.3**
Replicates (Locations * Years)	1.5^{ns}	1.7 ^{ns}	0.9 ^{ns}	1.7^{ns}	0.8^{ns}	1.9^{ns}
Genotypes	73.8**	67.9**	292.3**	140.5**	358.4**	21.6**
Genotypes * Locations	9.8**	3.1**	6.4 **	3.3**	4.0**	3.2**
Genotypes * Years	38,2**	28.4**	12.9**	76.0**	7.9**	6.2**
Genotypes * Locations * Years	20.8**	17.0**	6.1**	3.1**	5.5**	4.4**

Table 4. Effects of genotypes on days to flowering in three different types of soils in 2013 and 2014 (days).

Genotypes	Ultisol		Organosol		Regosol		Average (2013-2014)
	2013	2014	2013	2014	2013	2014	
H13	32.8^{b}	36.5^{b}	32.8^{bc}	31.0^{c}	33.0^{c}	36.5^{d}	33.8^{e}
H23	34.0^{b}	38.0^{ab}	38.5^{a}	32.0^{bc}	36.8^{b}	38.0^{bcd}	36.1^{bc}
H43	40.3^{a}	36.5^{b}	39.0^{a}	34.0^{b}	40.0^{a}	44.3^{a}	39.0^{a}
H53	34.3^{b}	37.0^{b}	35.5^{b}	33.0^{bc}	35.3^{bc}	39.8^{bc}	35.8^{c}
H73	35.0^{b}	37.3^{b}	32.3^{c}	32.0^{bc}	34.0^{bc}	37.3^{cd}	34.6^{de}
P3	35.0^{b}	40.5^{a}	34.8^{bc}	37.0^{a}	35.3^{bc}	39.3^{bcd}	36.9^{b}
IPBCH3	27.8^{c}	39.3^{ab}	27.0^{d}	30.5^{c}	27.8^{d}	36.5^{d}	31.6^{f}
Tilala	40.8^{a}	37.3^{b}	29.3^{d}	39.0^{a}	27.5^{d}	40.5^{b}	35.7^{cd}
Average (2013-2014)	36,4		33,6		36,4		

Means in the same column followed with the same letter are not significantly different according Least Significant Different Test at 5%.

Table 5. Effects of genotypes on days to harvest at three different types of soils in 2013 and 2014 (days).

Genotypes	Ultisol		Organosol		Regosol		Average (2013-2014)
	2013	2014	2013	2014	2013	2014	
H13	76.8^{b}	68.0^{a}	75.5^{c}	61.0^{bc}	79.0^{b}	68.0^{b}	71.4^{bc}
H23	73.3^{c}	66.5^{ab}	79.0^{ab}	58.5^{c}	71.8^{de}	66.5^{bc}	69.3^{d}
H43	82.8^{a}	64.5^{b}	76.8^{bc}	65.3^{a}	74.3^{cd}	72.3^{a}	72.6^{b}
H53	75.5^{bc}	68.0^{a}	78.0^{bc}	61.0^{bc}	76.8^{bc}	68.0^{b}	71.2^{bc}
H73	75.0^{bc}	69.0^{a}	79.8^{ab}	60.3^{bc}	75.8^{bc}	67.3^{bc}	71.2^{c}
P3	84.0^{a}	69.3^{a}	81.5^{a}	61.0^{bc}	83.5^{a}	68.0^{b}	74.5^{a}
IPBCH3	64.5^{d}	68.0^{a}	69.5^{d}	58.0^{c}	69.5^{e}	64.5^{c}	65.7^{e}
Tilala	81.3^{a}	67.3^{ab}	79.3^{ab}	62.3^{ab}	74.8^{cd}	69.3^{ab}	72.3^{bc}
Average (2013-2014)	72.1		69.2		71.8		

Means in the same column followed with the same letter are not significantly different according Least Significant Different Test at 5%.

Table 6. Effects of genotypes on fruit diameter at three different types of soils in 2013 and 2014 (mm).

Genotypes	Ultisol		Organosol		Regosol		Average (2013-2014)
	2013	2014	2013	2014	2013	2014	
H13	5.8^{ef}	5.6^{bc}	5.9^{cde}	5.9^{cd}	6.3^{cde}	5.6^{bcd}	5.8^{e}
H23	8.8^{b}	6.6^{b}	8.1^{b}	8.6^{b}	8.8^{b}	6.8^{b}	8.0^{b}
H43	6.8^{cde}	5.5^{bcd}	6.9^{bc}	6.2^{cd}	6.8^{cd}	5.5^{cde}	6.3^{de}
H53	7.2^{c}	5.9^{b}	6.6^{cd}	6.5^{c}	6.9^{cd}	5.8^{bc}	6.5^{cd}
H73	7.1^{cd}	6.0^{b}	6.5^{cd}	8.9^{b}	7.2^{c}	6.1^{bc}	7.0^{c}
P3	5.4^{f}	4.6^{cd}	5.2^{e}	4.6^{e}	5.2^{e}	4.6^{de}	5.0^{f}
IPBCH3	12.6^{a}	12.1^{a}	11.0^{a}	11.0^{a}	10.2^{a}	12.1^{a}	11.5^{a}
Tilala	5.9^{def}	4.4^{d}	5.5^{de}	5.0^{de}	5.8^{de}	4.4^{e}	5.2^{f}
Average (2013-2014)	6.9		7.0		6.7		

Means in the same column followed with the same letter are not significantly different according Least Significant Different Test at 5%.

Table 7. Effects of genotypes on fruit length at three different types of soils in 2013 and 2014 (cm).

Genotypes	Ultisol		Organosol		Regosol		Average (2013-2014)
	2013	2014	2013	2014	2013	2014	
H13	12.7^{bc}	15.3^{bc}	13.3^{bc}	14.9^{a}	13.3^{c}	15.3^{bc}	14.1^{c}
H23	13.1^{bc}	17.1^{a}	14.6^{b}	14.5^{a}	15.0^{ab}	17.1^{a}	15.2^{a}
H43	9.9^{d}	10.8^{f}	9.5^{e}	8.2^{c}	10.0^{d}	10.8^{f}	9.8^{e}
H53	13.0^{bc}	14.9^{cd}	13.2^{bcd}	16.1^{a}	13.1^{c}	14.9^{cd}	14.2^{c}
H73	13.8^{b}	16.8^{ab}	13.5^{bc}	14.6^{a}	14.1^{bc}	16.8^{ab}	14.9^{ab}
P3	17.4^{a}	12.1^{ef}	18.0^{a}	10.4^{b}	16.2^{a}	12.2^{ef}	14.4^{bc}
IPBCH3	11.8^{c}	13.3^{de}	11.8^{d}	11.5^{b}	10.6^{d}	13.3^{de}	12.0^{d}
Tilala	13.2^{bc}	11.8^{ef}	12.7^{cd}	11.0^{b}	12.6^{c}	11.8^{ef}	12.2^{d}
Average (2013-2014)	13.6		13.0		13.6		

Means in the same column followed with the same letter are not significantly different according Least Significant Different Test at 5%.

Table 8. Effects of genotypes on fruit weight per fruit at three different types of soils in 2013 and 2014 (gram).

Genotypes	Ultisol		Organosol		Regosol		Average (2013-2014)
	2013	2014	2013	2014	2013	2014	
H13	3.6^{cd}	2.7^{cde}	4.2^{c}	4.6^{c}	3.3^{cd}	4.6^{c}	3.5^{d}
H23	5.6^{b}	4.4^{b}	6.7^{b}	7.4^{b}	5.8^{b}	7.4^{b}	5.7^{b}
H43	3.7^{cd}	2.3^{de}	3.4^{c}	3.1^{d}	2.9^{d}	3.1^{d}	2.9^{e}
H53	3.8^{cd}	3.0^{cd}	3.7^{c}	5.2^{c}	3.5^{cd}	5.2^{c}	3.7^{d}
H73	4.5^{bc}	3.9^{bc}	4.4^{c}	8.2^{b}	4.1^{c}	8.2^{b}	4.8^{c}
P3	3.1^{d}	1.7^{e}	3.9^{c}	2.5^{d}	3.0^{d}	2.5^{d}	2.7^{e}
IPBCH3	8.8^{a}	5.7^{a}	9.3^{a}	10.2^{a}	7.8^{a}	10.2^{a}	7.9^{a}
Tilala	2.9^{d}	1.8^{e}	3.6^{c}	2.8^{d}	3.1^{cd}	2.8^{d}	2.7^{e}
Average (2013-2014)	3.9		5.2		3.7		

Means in the same column followed with the same letter are not significantly different according Least Significant Different Test at 5%.

Table 9. Effects of genotypes on fruit per plant at three different types of soils in 2013 and 2014 (gram).

Genotypes	Ultisol		Organosol		Regosol		Average (2013-2014)
	2013	2014	2013	2014	2013	2014	
H13	317.7^{ab}	528.1^{ab}	236.9^{ab}	727.2^{ab}	333.8^{bc}	255.7^{abc}	399.9^{ab}
H23	358.0^{ab}	566.3^{a}	250.0^{ab}	689.8^{ab}	536.3^{a}	429.7^{a}	471.7^{a}
H43	304.5^{ab}	292.6^{cd}	304.6^{a}	394.9^{d}	256.6^{c}	333.25^{ab}	314.4^{cd}
H53	430.6^{a}	369.0^{bcd}	364.2^{a}	606.7^{abc}	291.9^{c}	157.8^{bc}	370.0^{bc}
H73	356.6^{ab}	442.3^{abc}	266.0^{ab}	799.7^{a}	360.1^{abc}	252.2^{abc}	412.8^{ab}
P3	313.5^{ab}	210.6^{d}	215.8^{ab}	381.4^{d}	225.6^{c}	131.2^{c}	246.4^{d}
IPBCH3	278.4^{ab}	557.2^{ab}	399.2^{a}	568.4^{bcd}	514.3^{ab}	411.1^{a}	454.876^{a}
Tilala	204.8^{b}	370.4^{bcd}	104.0^{b}	474.0^{cd}	206.3^{c}	300.8^{abc}	276.7^{d}
Average (2013-2014)	368.8		423.9		312.3		

Means in the same column followed with the same letter are not significantly different according Least Significant Different Test at 5%.

Table 10. Analysis of variances of fruit weight per plant for 8 genotypes at three locations for two consecutive years (2013 and 2014).

Source of variations	df	SS	MS	F cal.	F Table		Prob. > F
					5%	1 %	
Locations	1	663,035.3	663,035.3	46.1**	4.4	8.3	0.0001
Years	2	398,824.6	199,412.3	13.9**	3.6	6.0	0.0002
Locations * Years	2	1,101,662.7	550,831.3	38.3**	3.6	6.0	0.0001
Replicates (Locations * Years)	18	258,836.9	14,379.8	1.9*	1.7	2.1	0.0201
Genotypes	7	1,135,309.1	162,187.0	21.6**	2.1	2.8	0.0001
Genotypes * Locations	7	327,351.3	46,764.5	6.2**	2.1	2.8	0.0001
Genotypes * Years	14	339,932.3	24,280.9	3.2**	1.8	2.8	0.0002
Genotypes * Locations * Years	14	946,647.1	7,513.1				
Error	126	5,628,813.5					
Total	191						

Coefficient of variations = 23.5%.

DISCUSSION

Soil acidity in our experimental sites ranged from 4.4 to 5.0 (Table 1). This was below optimum range for chili pepper *i.e.* 5.5 to 6.8 (Sundstrom, 1992). We did not apply dolomits to increase soil pH to allow the promising hybrids grew in natural condition of lowland soils. However, NPK were supplied at minimum doses to ensure chili pepper grew well. Both average air temperatures and relative humidity during the experiments are considered favorable for chili pepper growth. So did the average monthly precipitation and raining days.

Results indicated that days to flowering of H13 hybrid (33.8 days) was earlier than other tested hybrids. However, all the promising hybrids took longer time to flowering compared to IPBCH3 (31.5 days). Differences among varieties were presumably due to genetic reasons. Fitriani *et al.* (2013) found that heritability estimates of days to flowering for hot pepper was 44.5% and is considered fair. Syukur *et al.* (2010a) suggested that earlier flowering is considered as one of superior character of chili peppers breeding. Research conducted by Tesfaw *et al*. (2013) also confirmed that each hot pepper variety required particular days to flowering. Our findings also confirmed that chili peppers grown in organosol had shorter days to flowering than those of grown in ultisol and regosol. This different response could have been related to the fact that P_2O_5 available in organosol was much higher than that in ultisol and regosol (Table 1). Phosphor is responsible to accelarate flowering in many plants. Similar response between locations was also reported by Fitriani *et al.* (2013). Tesfaw *et al*. (2013) also confirmed that both nutrient availability in the soil and location significantly affected number of days required for flowering day of hot pepper.

Research conducted by Fitriani *et al.* (2013) concluded that heritability estimates of days to harvesting for hot pepper was 49.4% and is considered fair. This implied that days to harvesting is somehow controlled by genetic factor. Our results indicated that although H13 (33.8 days) had the earliest flowering time, this hybrid was not the earliest hybrid for harvesting. The hybrid of H23 (69.3 days) had shorter days to harvesting compared to H13 (71.4 days) (Table 5). This was unlikely suitable to popular believe that earlier flowering leads to earlier harvesting time. It means that fruit development in H13 took longer time reach maturity compared to H23. Importantly, H23 hybrid had shorter days to harvesting compared to Tilala, a variety that widely used in lowland chili pepper production. This could be a significant consideration to recommend the use of H23 hybrid for lowland production.

H23 hybrid had the highest fruit diameter of (7.9 mm) among the promising hybrids, but lower than of IPBCH3 (11.5 mm) (Table 6). Differences among genotypes were likely due to differences in genetic materials that composed individual hybrid. For example, hybrid of H23 was a crossing product of P2 (big chili pepper) and P3 (curly chili pepper) that produced semi-curly hybrid. According to Widyawati *et al.,* (2014) and Syukur *et al.*, (2010b) fruit diameter trait had high heritability estimate, indicating that this trait was genetically rather than environmentally controlled. Fitriani *et al.* (2013) recently concluded that heritability estimates for fruit diameter was 90.6% (high). It is clear that fruit diameter was mainly controlled by genetic factor, not a soil type. Our findings are also in accordance with previously reported by Wahyudi (2012) that in ultisol, H23 hybrid had the highest fruit diameter compared to other hybrids.

The average fruit length of H23 hybrid was longer than other hybrids and varieties, but it was lower than IPBCH3 (Table 7). Previous research conducted Alfian *et al*. (2013) concluded that fruit length had high heritability estimates, implying that genetic factor controlled fruit length more than environmental factors. Among the promising hybrids, H23 generally had the longest fruit in all types of soils (organosol, ultisol and regosol). However, previous research conducted by Wahyudi (2012) the longest fruit of chili pepper hybrids grown in Ultisol was H73, followed by H23, H53, H13 and H43.

Among all promising hybrids, H23 hybrid had the highest fruit weight per fruit (5.71 g), but it was lower than of IPBCH3 (7.9 g) (Table 8). Differences in average fruit weight per fruit was definitely due to genetic factors. Fitriani *et al*. (2013) reported that heritability estimates for fruit weight per fruit was 86.1% (high), implying that genetic controlled fruit weight per fruit more than environmental factors. Chili peppers grown in organosol generally had heavier fruit weight per fruit compared to those grown in ultisol and regosol. This was probably attributed to higher P_2O_5 and N-organic in organosol compared to ultisol and regosol (Table 1).

Higher total fruit weight per plant of H23 hybrid (471.7 g) than other comparing hybrids and varieties (Table 9) might be related to the fact that H23 hybrid have bigger fruits than others as suggested by fruit diameter (7.9 mm, Table 6) and fruit length (15.2 cm, Table 7). Ganefianti (2006) reported that fruit weight per plant was proportional to the number of fruit number per plant. It is likely that fruit weight per plant is not dominantly controlled by the genetic factor. Fitriani *et al.* (2013) recently reported that heritability estimates for fruit weight per plant was only 14.5% (low), implying that environmental factors controlled fruit weight per fruit more than genetic factor.

Higher fruit weight per plant of chili pepper grown in organosol than those of grown in ultisol and regosol might have attributed to the higher N-organic and P_2O_5 in organosol than those in ultisol and regosol. It was previously reported that nutrient availability in the soil and growing location significantly affected total fruit weight per plant of hot pepper (Tesfaw *et al*., 2013). Using a plant spacing of 50 cm x 50 cm in 1 m width of soil bed, total population per hectare will be approximately 26,670 plants (Berke and Gniffke, 2006). Assuming there are only 80% plants grow well, H23 hybrid grown in organosol will have a productivity of 10.1 ton ha^{-1}. This figure is fair enough for lowland chili pepper production, although its potential productivity ranges from 20–30 ton ha^{-1}.

Those above results suggested that the yields of chili peppers are strongly determined by genotypes, years and locations. Similar results were previously demonstrated by Sujiprihati *et al.* (2007), Syukur e*t al.* (2010b) and Ganefianti *et al.* (2009). The locations used in these experiments representing the marginal lands where it is rarely used for chili pepper productions. Since its productivity in this experiment reached 10 ton ha^{-1}, the use of marginal lands (*i.e*., organosol, ultisol, and regosol) might be suitable for chili pepper production in the lower altitude.

By using AMMI2 analysis it is indicated that H23 hybrid is adaptable to all types of soils in lower altitude, *i.e*., organosol, ultisol, and regosol (Figure 1). Meanwhile, H73 and H43 hybrids are most suitable to organosol and regosol, respectively. It is important to note that

H23 hybrid is crossing product of P2 and P3 that belong to local germplasms of IPB's collections. Organosol is likely a promising marginal land in the lower altitude to be used for chili pepper production. However, its productivity could be further increased with intensive chili pepper productions.

In conclusion, H23 hybrid has higher fruit length, fruit diameter, fruit weight per fruit, fruit weight per plant than other comparing varieties. Chili pepper hybrids grown in organosol have higher yield performances compared to those grown in ultisol and regosol. Although H23 hybrid is suitable to organosol, ultisol and regosol, its best productivity took place in organosol. These experiments provided information that begomovirus's resistant variety (H23) grow well in lowland agricultural soils. Chili pepper breeders might be able to use this genotype to develop other new cultivated varieties that resistant to begomovirus.

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