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THE GENOTYPES X ENVIRONMENT INTERACTION FOR STARCH YIELD IN NINE-MONTH OLD CASSAVA PROMISING CLONES

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ABSTRACT

Cassava (*Manihot esculenta*) is planted in dry areas with different environmental conditions, therefore the yield is varied. The aim of the study was to analyze the genotype x environment interaction for starch yield in 9-month old cassava promising clones. The experiment was conducted on mineral soils in four different locations, i.e. Lumajang-East Java (Inceptisols), Kediri-East Java (Entisols), Pati-Central Java (Alfisols), and Tulangbawang-Lampung (Ultisols) during 2004-2005. The experiment was arranged in split plot design with three replications. The main plots were cultivation techniques, i.e. simple technology and improved technology, whereas the subplots were 15 cassava promising clones. Starch yield of 9-month old cassava plants was analysed using the additive main effects and multiplicative interaction (AMMI). The results showed that environmental factors determined the stability of starch yield were soil bulk density on subsoil, the number of rainy days at fifth month, minimum air temperature at fourth month, and minimum air humidity at seventh month. CMM97002-183, Adira 4, CMM97007-145, CMM97007-235, Malang 2, CMM97002-36, and CMM97006-44 were identified as the stable cassava clones for starch yield in 9-month old. Average starch yield of Adira 4 was the third after MLG 10311 and CMM 97006-52. The CMM97006-52 was adapted to the soils having high P_2O_5 content on topsoil, high minimum air temperature at 4 and 5 months after planting, high mini-mum relative humidity at 7 months after planting, low total rainfall at 5 months after planting, and low number of rainy days at 5 and 8 months after planting. MLG 10311 was adapted to low soil bulk density. The average starch yield of MLG 10311 was the highest at 9 months after planting. The study implies that advanced trials for CMM 977006-52 and MLG 10311 clones are needed, so the clones can be released as new varieties of cassava. In selection and evaluation, the bulk density on subsoil is needed to be attained specifically to increase the probability to obtain new variety of cassava.

[***Keywords***: *Manihot esculenta*, selection, genotype x environment interaction, AMMI model, starch yield]

INTRODUCTION

Cassava in Indonesia is cultivated in dry areas with varied environmental conditions and yields. Therefore, cassava breeding is aimed to select superior clones specific for particular condition. If there are no clone x environment interaction, selection of superior clone will be based on the average yield. However, if there is clone x environment interaction, the selection of superior clone would be more difficult.

Starch yield of cassava is a multiplication between fresh tuber yield and starch content. Starch yield is determined by genetic and environmental factors, including plant maturity (Soenarjo and Hardono 1986). Generally, starch content increases till a certain point in line with the plant maturity. There is a positive correlation between starch content and total rainfall at 6-9 months after planting. However, at 1-2 months before harvest, the correlation is negative (Howeler 2001a). Sholihin and Sundari (2008) reported that the interaction effect between clones and locations was significant for starch yield of fresh tuber and starch content in 9-month old cassava plants.

Most plant breeders in Indonesia use regression method as proposed by Eberhart and Russell (1966) for interpreting the genotype and environment interaction. The method is based on the regression coefficient and mean square deviation from linear regression and can be used to determine the stability of genotype. The genotype is stable if the regression coefficient is not different from one and the mean square deviation is not different from zero. The regression method is called as descriptive model based on the data being analyzed, because the independent variable (environmental index) cannot be measured during the experiment. This is different to the prediction model where the independent variable can be measured before the experiment was conducted (Lin *et al*. 1986). In the regression method, variety performance and environmental factors were assumed having a strong linear relationship (McLaren and Chaudhary 1998). This is almost never happen in the case of wide area domains.

Gauch (1992) proposed the additive main effects and multiplicative interaction (AMMI) model for interpreting the genotype and environment interaction. The AMMI consists of two models, i.e. the additive model (the overall mean, genotype mean, and environmental mean), and the multiplicative model (the genotype and environment interaction). The AMMI model does not need an assumption that there is a strong linear relationship between variety performance and environmental factors (McLaren and Chaudhary 1996). Sutjihno (1996) determined genotype stability by drawing x-y graphic, where IPCA 1 for x-axes and IPCA 2 as y-axes. The genotype was stable if it was located around the origin. Mattjik and Sumertajaya (2002) stated that AMMI model increased the accuracy of the prediction of genotype and environment interaction response.

Some promising cassava clones have been resulted from previous breeding activities (Sholihin *et al*. 2004). These clones need to be tested in various locations or environmental conditions before they are released as new varieties of cassava. The study is aimed to identify the adaptabilities of several cassava clones based on AMMI model.

MATERIALS AND METHODS

The experiment was conducted on mineral soils in Lumajang-East Java (Inceptisols), Kediri-East Java (Entisols), Pati-Central Java (Alfisols), and Tulangbawang-Lampung (Ultisols) during 2004-2005. The locations were considered as the cassava production centers in Indonesia.

The experiment was arranged in a split plot design with three replications. The plot size was 5 m x 5 m. The main plots were two cultivation technologies, i.e., simple technology (plant population of 12,500 plants ha^{-1} and N fertilizer rate of 93 kg N ha^{-1}) and improved technology (plant population of 12,500 plants ha^{-1} and fertilizer rate of 93 kg N + 36 kg P_2O_5 + 60 kg K_2O ha^{-1}). The subplots were 15 cassava promising clones as described in Table 1.

The locations had N content on topsoils of 0.06-0.14% and on subsoils 0.03-0.07%, or it was classified as low as the critical level of soil N was 0.17% (Howeler 1981). P_2O_5 contents on topsoils were 1.27-105 ppm and on subsoils 4.28-66.9 ppm or classified as very low to very high level. K contents on topsoils ranged from 0.08 to 0.58 me 100 g^{-1} and on subsoils were 0.05-0.81 me 100 g^{-1}, or classified as very low to high level. Soil pH of topsoils were 4.7-6.6 and on subsoils 4.9-6.15 or classified as medium based on the criteria proposed by Howeler (2001b). CEC on topsoils were 6.82-23.9 me 100 g^{-1} and on subsoils 8.41-34.4 me 100 g^{-1} or classified as low and medium based on the criterion proposed by Landon (1984). Bulk density on topsoils were 106.35-141.35 g and on subsoils 111.32-173.23. Percentages of sand on topsoils were 5.5-79% and on subsoils 5-85%, silt on topsoils were 14-44% and on subsoils 6-32%, and clay on topsoils were 5-50% and on subsoils 9-63%. These soils were classified as sandy loam, clay loam, sandy clay, and sandy based on the criterion proposed by Howeler (1995). Moisture contents of soils at 6 months after planting were 7.67-25.40% and at 9 months after planting were 1.97-16.47%. The minimum air temperature from planting till 5 months after planting (monthly mean) varied from 22.8°C to

Table 1. Fifteen cassava clones used in the evaluation of genotype and environment interaction.

Clone	Parent	Source	Remark
CMM97001-87	L.Tlekung x Malang 4	ILETRI	Promising clone
CMM97015-255	MLG 10.042 x Adira 4	ILETRI	Promising clone
CMM97011-191	MLG 10.038 x Adira 4	ILETRI	Promising clone
CMM97002-183	L.Tlekung x Adira 4	ILETRI	Promising clone
CMM97002-36	L.Tlekung x Adira 4	ILETRI	Promising clone
CMM97007-145	MLG 10.037 x Adira 4	ILETRI	Promising clone
CMM97007-235	MLG 10.037 x Adira 4	ILETRI	Promising clone
CMM97006-52	MLG 10.037 x Malang 4	ILETRI	Promising clone
Adira 1	Mangi x Ambon	ILETRI	Released variety
Malang 2	CM922-2 x CM507-37	ILETRI	Released variety
CMM97006-44	MLG 10.037 x Malang 4	ILETRI	Promising clone
CMM97001-12	L.Tlekung x Malang 4	ILETRI	Promising clone
UB 1-2	Unknown	BU	Promising clone
Adira4	BIC528 x Unkown	ILETRI	Released variety
MLG 10311	Germplasm collection	ILETRI	Promising clone

CMM = cross manihot Malang, MLG = Malang, ILETRI = Indonesian Legume and Tuber Crops Research Institute, BU = Brawijaya University

25.23°C, and the maximum air temperature were 31.53-34.27°C. The maximum relative humidity during growth period ranged from 72.23% to 100%, and the minimum relative humidity were 31.83-87%. Numbers of monthly rainy days were 0-21 days and total monthly rainfalls were 0-511 mm. The climate was classified as D1, D2, and C2 based on Oldeman.

Starch yield of 15 cassava clones at 9-month old was obtained by multiplying the fresh tuber yield and the starch content. The starch content was calculated by using the specific gravity (SG), where SG = (fresh tuber weight in the air)/(fresh tuber weight in the air - fresh tuber weight in the water), then the starch content = SG x 112.1-106.4 (CIAT 1976, unpubl.).

The environment data collected were soil moisture at 6 and 9 months after planting. The samples were taken during the dry season, three samples for each location, their each sample was measured separately. Total rainfall, number of rainy days, maximum and minimum air temperature, and maximum and minimum air relative humidity were taken from climate stations near the experimental sites during the growing period. Soil N, P_2O_5, K, CEC, bulk density, pH, and texture on top soils and subsoils were measured separately, three samples for each location. The average values were then used for calculating the correlation using IPCA score.

Starch yield was analysed using MSTATC program to obtain the combined analysis of variance. IRRISTAT program was used to analyse the variance based on the AMMI model and IPCA score. Correlation between IPCA score and environment were analysed using a MSTATC program. Biplot IPCA was constructed using Microsoft Office Excel Program.

The stability of cassava clones was determined based on biplot IPCA. Chaudhary and Ahn (1996) added ellipse around the point (0,0) of biplot IPCA and Sumertajaya (2005) proposed how to construct the ellipse. The radius (r) of ellipse was calculated as follows:

$$r_i = \pm \sqrt{[(n-1)p / (n-p)]\,[F(\alpha, p, n-p)]\,[\sqrt{\lambda_i e_i}]}$$

where: r_i = radius (r) of ellipse for i^{th} main component; n = number of genotype; and p = number of dimension of AMMI. $F(\alpha, p, n-p)$ = F table at a α level of 0.05. λ_i and e_i= the singular value and eigenvector for PCA axis i.

Clone located inside the ellipse was classified as the stable clone.

RESULTS AND DISCUSSION

Combined Analysis

The analyses of variance for 15 cassava clones, two cultivation technologies, and four experimental sites/locations for starch yield are presented in Table 2. The clone and location interaction effect was significant for starch yield due to the heterogeneity of clones and locations. Cassava is a cross pollinated crop (Poespodarsono 1992) and in heterozygote stage, so the opportunity to obtain the clone x location interaction for quantitative characters is high. However, the technology x location, and the technology x clone x location interaction effects were not significant.

Starch yields of cassava cultivated using simple and improved technologies in four locations were presented in Table 3. Starch yields of cassava clones fertilized with 93 kg N ha^{-1} were similar to those fertilized with 93 kg N + 36 kg P_2O_5 + 60 kg K_2O ha^{-1}.

Table 2. Combined ANOVA for 15 cassava clones, two cultivation technologies, and four locations for starch yield.

Source	Df	MS
Locations (L)	3	506829848**
Replication/L	8	1179815
Technology (T)	1	14571306*
T x L	3	5257094
Error (a)	8	1708884
Clones (C)	14	27432162**
C x L	42	4410850**
T x C	14	1558981
T x C x L	42	1844214
Error (b)	224	1327824
CV (%)		18.10

**, * = significantly different at 1% and 5%.

Table 3. Starch yield of is cassava clones cultivated with simple and improved technologies in four locations.

Location; technology	Starch yield (kg ha^{-1})
Lumajang; simple	8386 ab
Lumajang; improved	8877 a
Pati; simple	7207 ab
Pati; improved	7641 ab
Tulangbawang; simple	2641 c
Tulangbawang; improved	3568 c
Kediri; simple	6428 ab
Kediri; improved	6185 b
LSD 5%	2461

AMMI Analysis

Based on the clone x location interaction results, analysis of clone stability was conducted to know the stability and adaptability of the clones. The AMMI model was used to analyse the stability of the clones. The result showed that the technology x clone x location interaction effect was not significant starch yield (Table 2). As mentioned before, starch yields were similar for two cultivation technologies tested in each location. Thus, the technology factor in this experiment can be justified as replication. So for the AMMI model, there were 15 clones, four locations, and six replications.

Analysis of variance based on AMMI model for starch yield is presented at Table 4. The effects of clone x location interaction could be divided into three components, i.e. IPCA 1, IPCA 2, and IPCA 3 where IPCA 1 and IPCA 2 were significantly different, while IPCA 3 was not significantly different. The contributions of IPCA 1, IPCA 2, and IPCA 3 were 44%, 34%, and 22%, respectively.

Correlations between environmental data and IPCA scores are given in Table 5-7. The correlation can lead to the useful biological interpretation of the interaction effects. IPCA 1 was positively correlated with bulk density on subsoils. The bulk density increased if the IPCA 1 score improved. Such information would not come out when the additive model was used. IPCA 2 was positively correlated with P_2O_5 content on topsoils, minimum air temperature at 4 and 5 months after planting, and minimum relative humidity at 7 months after planting. P_2O_5 content, minimum air temperature at 4 and 5 months after planting, and minimum relative humidity at 7 months after planting increased when the IPCA 2 score improved. IPCA 2 were negatively correlated with the total rainfall at 5 months after planting, and number of rainy days at 5 and 8 months after planting. The total rainfall at 5 months after planting and the number of rainy days at 5 and 8 months after planting decreased when the IPCA 2 score increased. It is implied that to develop new cassava variety having stable starch yield, the important environmental factors, i.e bulk density on subsoils, P_2O_5 content on topsoils, minimum air temperature at 4 and 5 months after planting, minimum relative humidity at 7 months after planting, and number of rainy days at 5 and 8 months after planting

Table 4. Analyses of variance based on AMMI model for cassava starch yield.

Source of variance	Degree of freedom	Mean square
Location (L)	3	506829848**
Error	20	2672609
Clone (C)	14	27432162**
C x L	42	4410850**
IPCA 1	16	6219038**
IPCA 2	14	4462457**
IPCA 3	12	1939735
Error (b)	280	1416840

** = significant at 1%.

Table 5. Correlations between IPCA scores and soil chemical characteristics for cassava starch yield at 9 months after planting.

Soil chemical characteristics	IPCA 1	IPCA 2
N content on topsoil	-0.258	0.130
N content on subsoil	-0.168	-0.645
P_2O_5 content on topsoil	0.120	0.959*
P_2O_5 content on subsoil	-0.239	0.372
K content on topsoil	-0.608	-0.331
K content on subsoil	-0.419	-0.289
Soil pH on topsoil	-0.150	-0.561
Soil pH on subsoil	-0.770	0.022
CEC on topsoil	-0.431	0.151
CEC on subsoil	-0.653	0.536
Bulk density of topsoil	0.053	-0.485
Bulk density of subsoil	0.966**	-0.238
Soil moisture, 6 months after planting	-0.671	-0.681
Soil moisture, 9 months after planting	-0.427	-0.564

* and ** = significantly different at 5% and 1% level, respectively

Table 6. The selected correlations between IPCA scores and climate factors for cassava starch yield.

Climate factors	IPCA 1	IPCA 2
Number of rainy days		
5 months after planting	-0.160	-0.978**
8 months after planting	-0.142	-0.925*
Total rainfall at 5 months after planting	-0.095	-0.955*
Minimum air temperature at 4 months after planting	-0.058	0.984**
Minimum RH at 7 months after planting	0.233	0.972**

* and ** = significantly different at 5% and 1% level, respectively

Table 7. Correlations between IPCA scores and environmental factors for cassava starch yield.

Soil physical characteristics	IPCA 1	IPCA 2
Sand on topsoil (%)	0.471	0.152
Silt on topsoil (%)	-0.756	-0.060
Clay on topsoil (%)	-0.243	-0.204
Sand on subsoil (%)	0.572	0.307
Silt on subsoil (%)	-0.720	-0.659
Clay on subsoil (%)	-0.406	-0.083
Bulk density of topsoil	0.053	-0.485
Bulk density of subsoil	0.966**	-0238
Soil moisture, 6 months after planting	-0.671	-0.681
Soil moisture, 9 months after planting	-0.427	-0.564

* and ** = significantly different at 5% and 1% level, respectively

Table 8. IPCA scores for planting locations and average starch yield of cassava.

Location	Starch yield (kg ha^{-1})	IPCA1	IPCA2
Lumajang, Inceptisols	8632	-24.24	-27.22
Pati, Alfisols	7424	-32.37	1.49
Tulangbawang, Ultisols	6307	48.73	-19.94
Kediri, Entisols	3104	7.89	45.67

should be considered in the selection and evaluation of cassava clones.

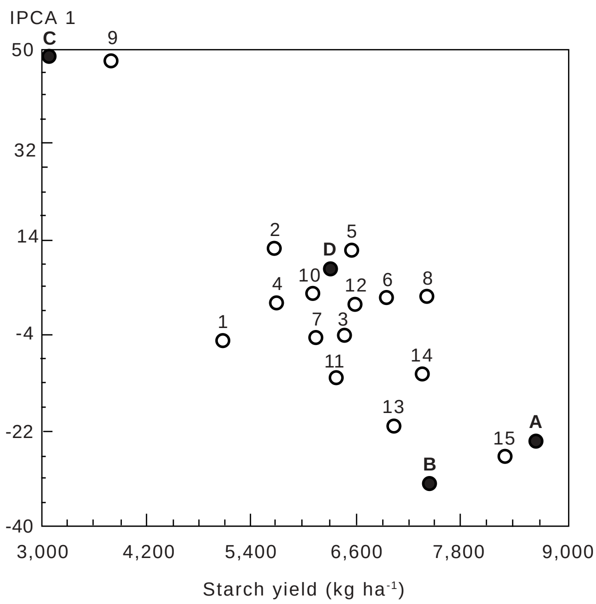
IPCA scores for four locations (Lumajang, Kediri, Pati, and Tulangbawang) and average starch yields are given in Table 8. IPCA 1 score for Lumajang was -24.24 and positively correlated with bulk density on subsoils which was 1.3 g cm^{-3}. It meant that Lumajang soils had relatively low bulk density on subsoils or the soils were relatively loose. It was different from that in Tulangbawang that had the IPCA 1 score of 48.73. It meant that Tulangbawang soils had high bulk density on subsoils or the soils were relatively compact. Bulk density of subsoil in Tulangbawang was 1.8 g cm^{-3}.

IPCA 2 score for Lumajang was -27.22, which was positively correlated with P_2O_5 content on topsoil, minimum air temperature at 4 and 5 months after planting, and minimum relative humidity at 7 months after planting. It meant that Lumajang had relatively low P_2O_5 content on topsoil, low minimum air temperature at 4 and 5 months after planting, and low minimum relative humidity at 7 months after planting. Based on the soil analysis results, P_2O_5 content of topsoil in Lumajang was 1.27 ppm. The minimum air temperature at 4 and 5 months after planting were 22.95°C and 22.97°C, respectively. The minimum relative humidity at 7 months after planting in Lumajang was 76.23% which was different to that in Kediri.

The IPCA 2 score for Kediri was 45.67. It meant that Kediri had relatively high P_2O_5 content on topsoil, high minimum air temperature at 4 and 5 months after planting, and high minimum relative humidity at 7 months after planting. Based on the soil analysis results, P_2O_5 content of topsoil in Kediri was 105 ppm. The minimum air temperature at 4 and 5 months after planting were 25.23°C and 24.37°C, respectively, and the minimum relative humidity at 7 months after planting was 46.63%.

The IPCA 2 score for Lumajang of -27.22 was negatively correlated with the total rainfall at 5 months after planting and the number of rainy days at 5 and 8 months after planting. It meant that Lumajang had relatively high total rainfall at 5 months after planting and high number of rainy days at 5 and 8 months after planting. The total rainfall at 5 months after planting in Lumajang was 181 mm, and the numbers of rainy days at 5 and 8 months after planting were 14 and 12 days, respectively. It was different from that in Kediri. IPCA 2 score for Kediri was 45.67. It meant that Kediri had relatively low total rainfall at 5 months after planting and low numbers of rainy days at 5 and 8 months after planting. The total rainfall at 5 months after planting in Kediri was 5 mm, and the numbers of rainy days at 5 and 8 months after planting were 1 and 0 days, respectively.

Biplot of IPCA 1 score and mean starch yield is presented in Figure 1. Starch yield of MLG 10311 was the highest, while Adira 1 was the lowest. The figure shows that cassava clone having the same value for the horizontal axis had the same main effect (starch yield), while that having the same value for the vertical axis had the same interaction effect. The starch yields of CMM97002-183 and CMM97015-255 were similar, but the interaction effects with locations were different. CMM97015-255 had a positive interaction with D location (Kediri), while CMM97002-183 was negatively interacted with D location (Kediri). The same pattern was seen for CMM97002-36 and CMM97001-12 clones.



1 = CMM97001-87 | 6 = CMM97007-145 | 11 = CMM97006-44
2 = CMM97015-255 | 7 = CMM97007-235 | 12 = CMM97001-12
3 = CMM97011-191 | 8 = CMM97006-52 | 13 = UB 1-2
4 = CMM97002-183 | 9 = Adira 1 | 14 = Adira 4
5 = CMM97002-36 | 10 = Malang 2 | 15 = MLG 10311

A = Lumajang, B = Pati, C = Tulangbawang, D = Kediri

Fig. 1. Biplots of IPCA 1 score and means of starch yield of 15 cassava clones at 9 months after planting in four locations.

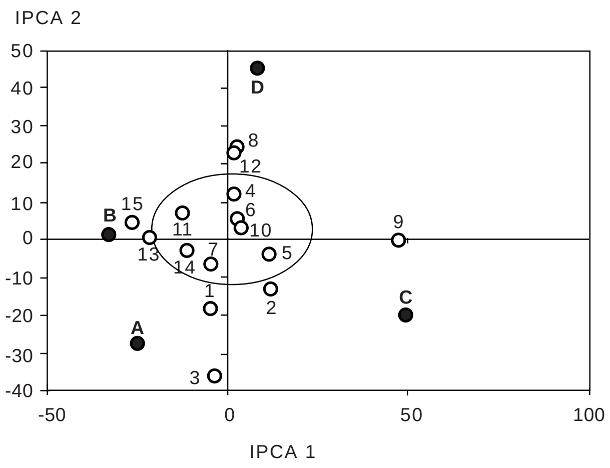
Biplots of IPCA 1 and IPCA 2 scores for locations based on the starch yields are given in Figure 2. The figure showed that the locations had a large variability. The position of A (Lumajang) was far from B (Pati), C (Tulangbawang), and D (Kediri) in Figure 1, and the position of B was far from C and D and the position of C was far from D. These mean that these locations were varied.

IPCA scores for 15 cassava clones and starch yields are presented in Table 9. The average starch yield of MLG 10311 was the highest, followed by CMM97006-52. MLG 10311 had a low IPCA 1 score (-26.795). This indicates that the clone is adapted to low bulk density on subsoils, because the IPCA 1 score was positively correlated with the bulk density on subsoils. In addition, MLG 10311 tubers were 7% more efficient in producing bioethanol compared to Adira 4 (Ginting *et al*. 2006). The starch content is an important characteristic for ethanol production. Ginting *et al*. (2006) reported that starch content was negatively correlated with the conversion value of tubers to ethanol (r = -0.68*). It means that cassava tubers having high starch are more efficient in producing bioethanol than those with low starch content .

CMM97006-52 had a high IPCA 2 score (24.406) indicating that the clone is adapted to high P_2O_5 content on topsoil, high minimum air temperature at 4 and 5 months after planting, and high minimum relative humidity at 7 months after planting because the IPCA 2 score was positively correlated with the P_2O_5 content on topsoil, minimum air temperature at 4 and 5 months after planting, and minimum relative humidity at 7 months after planting. CMM97006-52 was also adaptive to low total rainfall at 5 months after planting and low number of rainy days at 5 and 8 months after planting because the IPCA 2 score was negatively correlated with the total rainfall at 5 months after planting and the number of rainy days at 5 and 8 months after planting.

Table 9. IPCA scores and starch yield of cassava clones at 9 months after planting.

Clone	Starch yield (kg ha^{-1})	IPCA1	IPCA2
CMM97001-87	5080	-4.934	-18.097
CMM97015-255	5663	12.151	-13.310
CMM97011-191	6484	-3.934	-35.735
CMM97002-183	5690	1.852	12.009
CMM97002-36	6538	11.864	-4.124
CMM97007-145	6935	2.925	5.773
CMM97007-235	6133	-4.343	-6.383
CMM97006-52	7415	2.909	24.406
Adira 1	3799	47.447	-0.030
Malang 2	6119	3.781	2.798
CMM97006-44	6367	-11.952	6.879
CMM97001-12	6592	1.506	22.910
UB 1-2	7035	-21.181	0.842
Adira 4	7348	-11.296	-2.928
MLG 10311	8305	-26.795	4.990



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2 = CMM97015-255 7 = CMM97007-235 12 = CMM97001-12
3 = CMM97011-191 8 = CMM97006-52 13 = UB 1-2
4 = CMM97002-183 9 = Adira 1 14 = Adira 4
5 = CMM97002-36 10 = Malang 2 15 = MLG 10311

A = Lumajang, B = Pati, C = Tulangbawang, D = Kediri

Fig. 2. Biplots of IPCA 1 and IPCA 2 scores for 15 cassava clones in four locations based on starch yield at 9 months after planting; r_1 = radius of ellipse for IPCA 1 which was 19.7 and r_2 = radius of ellipse for IPCA 2 which was 17.0.

Biplots of IPCA 1 and IPCA 2 based on starch yield as given in Figure 2 determined that the clones had wide or specific adaptation. Sutjihno (1996) reported that genotype located near the origin or point (0,0) was classified as stable. Chaudhary and Ahn (1996) added ellipse around the origin or point (0,0), but there was no information about how to add those ellipses. They stated that genotype located inside the ellipse was classified as the stable genotype, and the one at the opposite side for genotype which is out of the ellipse. Sumertajaya (2005) reported how to determine the ellipse by calculating the radius (r) of the ellipse.

Based on Figure 2, Adira 4, CMM97007-145, CMM 97007-235, Malang 2, CMM97002-183, CMM97002-36, and CMM97006-44 were classified as stable cassava clones, while CMM97006-52, CMM97001-12, UB 1-2, CMM97011-191, Adira 1, CMM97001-87, CMM97015-255, and MLG 10311 were as unstable clones. There are two possible reasons in which cassava clone can adapt to varied location conditions, those are the clone is a hybrid or it has a genetic potential to perform well irrespective of the location where it is grown.

MLG 10311 and UB 1-2 were more adaptive compared to Adira 1 on the location having low bulk density on subsoil. CMM97006-52 and CMM97001-12 were more adaptive than CMM97011-191 on environment having low number of rainy days at 5 and 8 months after planting, low total of rainfall at 8 months after planting, and high minimum air temperature at 4 and 5 months after planting (Fig. 2).

On IPCA 1 axis, Lumajang and Pati locations were separated from Tulangbawang, thus the bulk density of subsoils in Lumajang and Pati were lower than that in Tulangbawang. High soil bulk density showed the low air in the soil. On IPCA 2, Kediri that was separated from Lumajang and Tulangbawang had higher P_2O_5 content in topsoil, minimum air temperature at 4 and 5 months after planting, minimum relative humidity at 7 months after planting than those of Lumajang and Tulangbawang. The numbers of rainy days at 5 and 8 months after planting and the total rainfall in Kediri were lower than those in Lumajang and Tulangbawang (Fig. 2).

CONCLUSION

The important environmental factors determined the stability of cassava starch yield at 9-month old were bulk density on subsoil, number of rainy days at 5 months after planting, minimum air temperature at 4 months after planting, and minimum relative humidity at 7 months after planting. CMM97002-183, Adira 4, CMM97007-145, CMM97007-235, Malang 2, CMM 97002-36, and CMM97006-44 were the stable cassava clones for starch yield based on AMMI model. MLG 10311 clone produced the highest starch yield and was adaptive to low bulk density on subsoil. CMM 97006-52 was adaptive to high P_2O_5 content on topsoil, high minimum air temperature at 4 and 5 months after planting, high minimum relative humidity at 7 months after planting, low total rainfall at 5 months after planting, and low number of rainy days at 5 and 8 months after planting.

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