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RESEARCH ARTICLE

Evaluation of cassava (*Manihot esculenta* Cranzt.) genotypes for resistance to mite and yield stability through AMMI analysis

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Abstract

The experiments were done during 2015 to 2018 in eight environments considering climate and soil chemistry factors. The evaluation of genotypes was carried out in early root bulking cassava to identify the promising ones for tuber yield stability based on Additive Effects and Multiplicative Interaction (AMMI () biplot analysis. Results showed that genotypes, CMR 51-61-1, CMR 51-48-17, CMR 51-48-16, OMR 51-20-5, OMM0806 - 57, UJ3 and UJ5 were most stable as compared to CMR 51-07-13 and CMR 51-06-16. The important environmental factors affecting yield stability of cassava promising genotypes based on tuber yield in seven months crop duration were N and P_2O_5 contents and pH on topsoil. Mean fresh tuber yield of OMR 51-20-5 was 25% significantly higher than UJ3 and the increasing value was equal to US $ 745/ha while of OMR 51-20-5, it was 15% higher than UJ5 and the increasing value was equal to US $ 482/ha. The genotype, OMR 51-20-5 has been released recently in 2020 as VAMAS 1 by the Indonesian Government.

Keywords: AMMI analysis, cassava, mite, resistance, yield stability

Introduction

Cassava (*Manihot esculenta* Cranzt.) is being grown in about 101 countries in the world. (FAOSTAT 2018). Nigeria produced the highest cassava (59.5 million ton) with productivity of 23 t/ha followed by Thailand, Democratic Republic of the Congo, Ghana, Brazil, and Indonesia with production 16.1-31.7 million ton with productivity of 8-23 t/ha in 2018. Cassava is used for food, feed and as raw material for industries. The productivity of cassava in the world is still low ranging from 8 to 23 t/ha. Mite *(Tetranychus bimaculatus)* is an important insect pest of cassava, which attack the plant and reduce the yield. Byrne et al. (1982) reported that mite attack can reduce yield from 15 to 73 %, depending on the resistance/susceptibility of varieties.

In some areas of cassava with humid climate, opportunity for cassava planting is relatively high as the farmers can plant cassava in November, December, January, March, April, May and June. Farmers prefer planting of the early root bulking varieties. Sree Jaya and Sree Vijaya are early root bulking variety released by ICAR-Central Tuber Crops Research Institute in India (Abraham et al. 2001). Productivity is an important parameter for farmer, government and businessmen. Many factors affect productivity, one of them is inherent genetic potential of a variety. Important step in producing a new variety is through the multi-environment testing in trials. There are many techniques used for multi-environments trial analysis. Several breeders have used regression method for a long period of time. Yasin et al. (2017), Pramudyawardani et al. (2015), and Sinaga et al. (2015) used this method for multi-environments trial analysis in corn and rice previously.

Gauch (1992) proposed AMMI model for data analysis of multi-environment trials. This model consist of two models i.e., additive model (grand mean, genotype mean, and environment mean), and multiplicative model (genotype x environment interaction). AMMI model for genotype x

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environment interaction analysis has earlier been used in chili, maize, sesame and cassava (Juharni et al. 2020; Amzeri et al. 2020; Basyir et al. 2020; Sholihin 2021). The accuracy of prediction of genotype x environment interaction of the AMMI model is higher than the traditional model such as Eberhart and Russel. There is no need of an assumption that there is linier relationship between genotype performance and environment factor for AMMI model, while traditional model need that assumption.

Some promising genotypes in cassava have been produced through breeding activities at the Institute from 2009 to 2014 following single plant, single row and single plot selections in different generations and tested the bulk material in preliminary yield trial and advanced yield trial. The objectives of the present study were to evaluate the early root bulking cassava promising genotypes for tuber yield stability based on AMMI biplot.

Materials and methods

Seven advance liners, namely, CMR 51-61-1, CMR 51-48-17, CMR 51-48-16, OMR 51-20-5, CMR 51-07-13, OMM0806 - 57 and CMR 51-06-16 along with checks, UJ3 and UJ5 were taken for study.

Experiments were conducted in eight environments using Randomized Complete Block Design in three replications with plot size 5.0 m x 4.8 m. The seedlings were planted with a distance 1.0 m x 0.8 m. Plants were fertilized 93 kg N+ 36 kg P_2O_5 + 60kg K_2O per hectare. Seven promising genotypes and two checks were used.

Soil of environmets had nitrogen (N) content (0.06 - 0.13%), phosphorus (P_2O_5) content (1.36-25.6 ppm), murate of potash (K) content (0.05-0.25 me(milli equivalent)/100 g), iron (Fe) content (2.48-15.1) ppm, pH of soil 3.9 to 5.1, CEC (6.82-23.9 me/100 g), Al-dd 0.00 – 0.88 Cmol+/kg, and organic carbon 0.46 - 1.12%. Number of rainy days/month of environments was 7-25 days and rainfall/month 31-633 mm. Excel, MSTAT (Michigan Statistic), version C and PBTools software was used for data analysis.

The AMMI stability value (ASV) was calculated as follows:

$$ASV = \sqrt{\left(\frac{IPCA1\ sum\ squares\ x\ IPCA1\ score}{IPCA2\ sums\ quares}\right) squares + (IPCA2\ score)\ squares}$$

Evaluation for resistance to mite was done in 2017 in the glass house of ILETRI. Nine genotypes were tested with a RCBD, 3 replications. Each plant was infested with 15 red spider mites at two months after planting. Scoring was done in 7 weeks after infestations of mites. The damage intensity of the mite attacks was calculated as follows:

$$I = \sum \frac{nxv}{NxV} \times 100\%$$

where

I = the damage intensity of the mite attack

N = number of leaves/plant

V = the highest score (5)

n = number of leaves in each score category

v = category score (from 0 to 5)

Method of scoring was determined following the scoring procedure as proposed by Bellotti and Schoonhoven (1978)

Score	Damage intensity
0	No symptoms
1	Initiation of yellowish spots on some of the lower and/or middle leaves
2	Fairly abundant yellowish spots on lower and/or middle leaves
3	Considerable damage: many spots; small necrotic zones and curling of leaves, especially the basal and middle leaves; yellowing and loss of some leaves
4	Severe damage: heavy defoliation in the lower and middle part of the plant; a large number of mites as well as webs can be observed
5	Total defoliation of the plant; shoot reduced in size with large number of webs; death of plant

Susceptibility class was determined as follows:

$$\text{Highly resistant (HR)} = I < (\bar{I} - 2\delta)$$
$$\text{Resistant (R)} = (\bar{I} - 2\delta) < I < (\bar{I} - \delta)$$
$$\text{Moderately resistant (MR)} = (\bar{I} - \delta) < I < (\bar{I} + \delta)$$
$$\text{Susceptible (S)} = I > (\bar{I} + \delta)$$

where:

$(\bar{I} + \delta)$ = mean of the damage intensity of the mite attack.

δ = standard deviation

Results and discussion

Variance analysis

Variance analysis showed factor genotypes having significant difference for tuber yield at seven months stage under every environment. Yield of OMR 51-20-5 was recorded highest at Lampung Timur 2015 and Lampung Selatan 2016. CMR 51-61-1 had the maximum tuber yield in Lampung Selatan 2015 and Lampung Tengah. CMR 51-07-13 produced the highest yield in Lampung Timur 2016 and 2017. The tuber yield of OMM0806 - 57 was highest in Lampung Selatan 2017, while check variety, UJ5 was the highest in Tulang Bawang Barat. OMR 51-20-5 also had similar yield with genotype which was highest in Lampung Selatan 2015, Lampung Timur 2016, Lampung Tengah, Lampung Selatan and Lampung Timur 2017 and Tulang Bawang Barat. Based on the mean yield over the environments of OMR 51-20-5 at 7 months was the highest and was significantly higher than UJ3 and UJ5 (Table 1). Yield of OMR 51-20-5 was 25% higher than UJ3. Yield of OMR 51-20-5 was 15% higher than UJ5.

Evaluation for mite resistance

Damage intensity of the mite attack ranged from 18.39 to 37.68% (Table 2). CMR 51-48-171 had the highest damage intensity of 37.68%, which was classified as susceptible. OMM0806 - 57 had the lowest damage intensity of 18.39%,

Table 1. Tuber yield (t/ha) of cassava genotypes over environments

S.No.	Genotype*	Lampung Selatan 2015 E1**	Lampung Timur 2015 E2**	Lampung Selatan 2016 E3**	Lampung Timur 2016 E4**	Lampung Tengah 2016 E5**	Lampung Selatan 2017 E6**	Lampung Timur 2017 E7**	Tulang Bawang Barat 2018 E8**	Mean
1	CMR 51-61-1	46.50 a	36.43 a	38.37 a	28.20 abc	26.25 a	24.61 a-d	28.23 abc	29.83 ab	32.30 a
2	CMR 51-48-17	33.86 de	24.30 cd	33.90 ab	24.07 cd	18.75 bc	21.28 cd	24.11 cd	24.67 bc	25.62 c
3	CMR 51-48-16	27.86 e	29.20 bc	26.03 c	17.50 e	16.50 c	20.08 d	17.55 e	18.67 cd	21.67 e
4	OMR 51-20-5	43.61 ab	37.80 a	39.73 a	28.00 abc	23.85 a	28.83 ab	28.04 abc	29.47 ab	32.42 a
5	CMR 51-07-13	41.00 abc	36.83 a	24.25 c	32.60 a	15.43 c	23.59 bcd	32.66 a	17.98 d	28.04 b
6	OMM0806 - 57	42.36 ab	34.17 ab	34.00 ab	30.03 ab	24.14 a	29.46 a	30.08 ab	30.30 ab	31.82 a
7	CMR 51-06-16	39.50 bcd	19.67 d	22.15 c	22.33 de	14.43 c	26.87 abc	22.37 de	21.67 cd	23.62 d
8	UJ3 (check)	34.86 cd	27.37 c	28.70 bc	29.25 ab	14.46 c	22.57 cd	29.28 ab	21.17 cd	25.96 c
9	UJ5 (check)	41.86 ab	29.80 bc	22.45 c	26.46 bcd	22.29 ab	25.31 a-d	26.68 bcd	31.09 a	28.24 b
Mean		39.05	30.62	29.95	26.49	19.57	24.73	26.56	24.98	27.74
C.V. (%)		10.1	12.1	13.7	10.7	13.5	13.1	10.6	14	12.2
LSD 5%		6.85	6.4	7.08	4.9	4.56	5.6	4.88	6.04	1.93

Values within a row followed by the different letters are significantly different at 5%; *= This number is the genotype ID in the figure; **= Indicating environment/location in figure

Table 2. Damage intensity caused by mite infestation

Genotypes	Reaction to mite	
	Damage intensity(%)	Susceptibility class
CMR 51-61-1	21, 75	MR
CMR 51-48-17	37, 68	S
CMR 51-48-16	34, 79	S
OMR 51-20-5	23, 91	MR
CMR 51-07-13	26, 67	MR
OMM0806 - 57	18, 39	R
CMR 51-06-16	22, 51	MR
UJ3 (Check)	28, 21	MR
UJ5 (Check)	19, 32	MR

Table 3. AMMI ANOVA for yield

Source	D.F	M.S
Environments €	7	877.188**
Error (a)	16	38.322
Genotype (G)	8	363.299**
GxE	56	42.145**
IPCA1	14	71.304**
IPCA2	12	56.904**
IPCA3	10	34.339**
IPCA4	8	22.432*
Residual	12	27.265
Error (b)	128	11.447
C.V (%)	12.	

which was classified as resistant. It is suggested that OMR 51-20-5 having damage intensity of 23.91 % could be improved with respect to resistance to mite attacks through conventional and non-conventional breeding methodologies. Chalwe et al. (2015) reported additive and non-additive gene effects that play an important role in the expression of cassava green mite density and cassava green mite leaf damage. Marker assisted selection can also be used as an alternative method to improve the accuracy of selection in development of a new variety for resistance to mite (Wolfe et al. 2017). Ezenwaka et al. (2018) reported that there are 35 single-nucleotide polymorphism (SNPs) which are significantly associated with cassava green mite severity, leaf pubescence, leaf retention, stay green, shoot tip compactness, and shoot tip size could be utilized in MAS.

The combined variance

Combined variance analysis showed genotypes interacted with environments significantly for tuber yield at seven months age (Table 3). Some environments can be predicted, and some other environments cannot be predicted. A few researchers have previously reported that genotypes interacted with environment for tuber yield, starch yield, and starch content in cassava (Noerwijati and Budiono 2015; Noerwijati 1 et al. 2017).

AMMI analysis

Analysis of variance for tuber yield showed environment component explained the largest proportion of variations (46%), followed by genotypes (22%) and G x E interactions (18%) (Table 3). IPCA 1, IPCA 2, IPCA 3 and IPCA 4 were significantly different contributing 42%, 29%, 15% and 8%, respectively. Adiebeng-Danquah et al. (2017) reported that they found two IPCA with an accumulation of 96.67% variation with 4 environments. Peprah et al. (2020) found two IPCA with cumulative variation of 70%.

Sara et al. (2019) stated that AMMI model does not make provision for a quantitative stability measure. However, Purchase et al. (2000) developed AMMI stability value (ASV) based on AMMI model's IPCA 1 and IPCA 2. Genotype OMM0806 - 57, UJ3, CMR 51-61-1, CMR 51-48-16, CMR 51-48-17, OMR 51-20-5), UJ5, and UJ3 had ASV lower than the average of ASV (Table 4), means these genotype were more stable than CMR 51-06-16 and CMR 51-07-13. Stability based on AMMI biplot (Fig. 1) showed the same result with those based on ASV.

IPCA 1 was positively correlated with N content (Table 4). It means N content of soil was important factor in determining the stability of genotype although all N content of environments were classified as low level based on the criterion reported by Howeler (1981). Range of N content of the environments used was 0.06% - 0.13 %. However, Sholihin 1 (2009; 2011_a; 2011_b) reported N content 0.06-0.14% of soil did not affect stability of genotypes related to starch yield at 6 and 9 months and tuber yield at 9 months

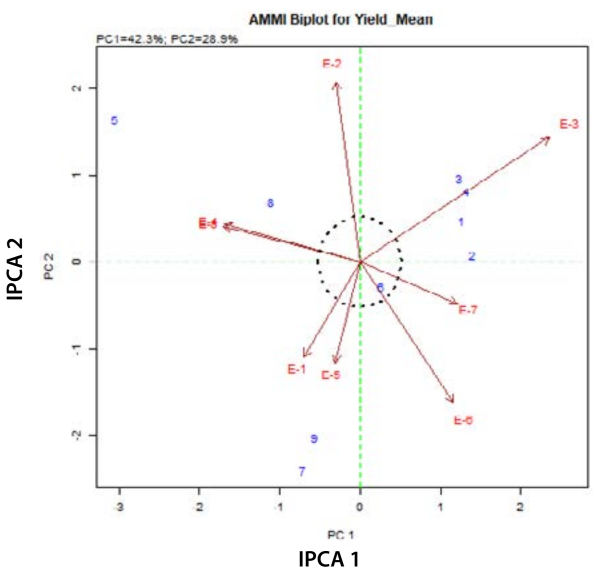

Fig. 1. Biplot of IPCA 1 and IPCA 2 for genotype

Table 4. Correlations between IPCA and soil chemistry for yield

Soil chemistry factors on top soil	IPCA 1	IPCA 2
Content of C-organic	-0.155	-0.487
CEC of soil	0.652	-0.498
Content of Fe	0.326	0.580
Soil pH	0.133	-0.793**
AL-dd	0.224	0.466
See level	0.485	-0.315
N content	0.885**	0.358
P_2O_5 content	-0.814**	-0.296
K content	-0.342	-0.197

[a]IPCA = Interaction Principle Component Analysis
** = robability = 0.01

stage. IPCA 1 was negatively correlated with P_2O_5 content, It means IPCA 1 will increase if P_2O_5 content of soil decrease. P_2O_5 content of environments ranged 1.36 ppm-29.9 ppm. These were classified as very low to medium level based on the criterion reported by Howeler 1 (2001). Sholihin (2009) reported that P_2O_5 content ranged (1.27-105) ppm of soil was positively correlated to IPCA 2 which was related to starch yield. However, Sholihin 2 (2011a; 2011b) reported that P_2O_5 content of environments ranged 1.27-105 ppm did not affect the stability of genotypes related to starch yield at six months and tuber yield at 9 months.

IPCA 2 were negatively correlated with the soil pH. If the soil pH decreases, IPCA 2 will increase. Its implication is that to develop a new variety which is stable for tuber yield, tolerance to low pH should be considered in the process of genotype selection and evaluation. Range of pH of soil of the environments was 3.9 - 5.2 . These were classified as low to medium level based on the criteria reported by Howeler (2001). Sholihin (2011_b) reported that pH on subsoil was correlated with IPCA 1 in relation to yield under the humid and dry environments at the time of crop. Contrastingly, Sholihin (2009; 2011a) reported that there was no correlation between IPCA value and pH on topsoil.

Genotypes, OMR 51-20-5, CMR 51-48-17, CMR 51-61-1 and CMR 51-48-16 showed high IPCA 1 (Table 5), indicating their adaptation to low P_2O_5 because IPCA 1 was negatively correlated with that character. CMR 51-07-13 have low IPCA 1 (-3.055) indicating its adaptation to low N because IPCA 1 was positively correlated with N content. OMR 51-20-5, CMR 51-48-17, and CMR 51-48-16 have high IPCA 2, indicating their adaptation to low pH because IPCA 2 was negatively correlated with that character.

Number of rainy days/month and rainfall/month of trial environments were not correlated with any IPCA. This was assumed because of the rainfall was recorded during at least 6 days in each month. Besides this reason, the climate of all environments prevailed were classified as humid. Sholihin (2011a) reported that there was no correlation between number of rain/month and rainfall/months with IPCA related

Table 5. AMMI Stable Value for yield

Genotype	IPCA 1	IPCA 2	ASV
CMR 51-61-1	1.266	0.482	1.913
CMR 51-48-17	1.391	0.083	2.035
CMR 51-48-16	1.222	0.974	2.035
OMR 51-20-5	1.315	0.826	2.093
CMR 51-07-13	-3.055	1.651	4.762
OMM0806 - 57	0.263	-0.279	0.475
CMR 51-06-16	-0.723	-2.410	2.632
UJ3	-1.111	0.701	1.769
UJ5	-0.568	-2.028	2.191

IPCA = Interaction Principle Component Analysis;
ASV= AMMI stability value

to starch yield in six months. However Sholihin (2009) also reported that number of rainy days/month and total rainfall/ month in 5 months after planting were correlated with IPCA-2 in relation to starch yield in nine months.

Authors' contributions

Conceptualization of research (S); Designing of the experiments (S, KN); Contribution of experimental materials (S, SWI); Execution of field/lab experiments and data collection (S, SWI); Analysis of data and interpretation (S, KN, SWI)); Preparation of the manuscript (S, MJM, HK).

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