Yield test of hybrid maize candidates with character of early maturity and high production

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Abstract. Developing hybrid maize varieties with early maturity and high productivity is one solution to increasing maize productivity in dryland areas. Plants with early maturity character will avoid stressful conditions on dry land, thus producing maximum maize production. The research was conducted in three districts on Madura Island, East Java Province, Indonesia: Bangkalan, Pamekasan, and Sumenep. Each research location used a non-factorial randomized block design with one treatment, namely genotype. The genetic material used in the research comprised 20 genotypes, including 18 hybrid maize candidates and two comparison varieties (Bisi-X and Pioneer-X). Each treatment was replicated three times, resulting in 60 experimental units. The results of the AAMI variance analysis for harvest age and production per hectare for 18 hybrid maize candidates and two comparison varieties showed that there were very significant effects of environment, genotype, and genotype by environment (GxE) interaction. Four candidate hybrid maize varieties had stable harvest ages in three locations (Bangkalan, Pamekasan, and Sumenep): G3, G14, G17, and G18. In contrast, five hybrid maize candidates had stable production per hectare in three locations: G2, G4, G5, G8, and G10. Three candidate hybrid maize varieties recommended for release were G2, G4, and G5. These three candidate hybrid maize varieties had early maturity (<95 days), high yield per hectare (exceeding those of the two comparison varieties), and high stability across all location

1 Introduction

Maize is the second most important food commodity in Indonesia, after rice [1]. Indonesia's maize production is the highest in Southeast Asia, at 19.98 million tons [2]. Maize production in Indonesia can be increased by utilizing suboptimal land. The area of suboptimal land in Indonesia is 137.00 million hectares, with peatland: 14.90 million hectares, dry acid land: 108.80 million hectares, and dry climate dry land: 13.30 million hectares. [3]. Indonesia's dry climate drylands are spread throughout Indonesia, including Madura Island. The drylands on Madura Island cover 360,000 hectares [4]. Penanaman jagung di Pulau Madura berdampak pada rendahnya produkstivitas jagung di Pulau Madura yaitu sebesar 2.15 ton ha^{-1} [5]. One solution to overcome the problem of low maize production in dry climates is to[1] develop early-maturing, high-yielding maize varieties [6]. Early maturity maize varieties are well suited for planting in dry climates because they have relatively short water requirements and shorter growing periods [7].

The stages of assembling superior maize varieties are germplasm characterization, assembly of maize varieties, and yield testing of candidate maize varieties [8]. Identification of potential maize germplasm has produced several lines with high yield, early maturity, and drought resistance [9], [10], [11]. The assembly of hybrid maize varieties using the diallel and line x tester methods produced several potential cross combinations to be developed into superior hybrid maize varieties [12][5], [13]. The next stage carried out is testing the stability of candidate maize varieties in the growing environment. This test is needed because the interaction between genotype and environment (GxE) can cause differences in the appearance of genotypes across locations, so an analysis method is needed that can separate and explain the interaction pattern [14][15].

Stability testing is required before releasing a variety, as the plants released as varieties must not only have superior characteristics but also be able to adapt and produce consistently across various environments [16]. One of the stability test methods used is the AMMI (Additive Main Effect and Multiplicative Interaction) model. The AMMI method can detect the adaptability of a genotype to various environments [17]. The AMMI method is very suitable for detecting genotype stability because it can analyze the effects of genotype, environment, and genotype by environment (GxE)

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interactions [18]. In addition, the AMMI method can precisely analyze and explain GxE interaction patterns. The AMMI method combines two statistical approaches, namely Analysis of Variance (ANOVA) to separate the main effects of genotype and environment, and Principal Component Analysis (PCA) to describe the GxE interaction pattern [19]. The use of the AMMI method can facilitate the selection and release of superior varieties by accurately describing a genotype adaptability and stability [20].

Determining the stability of candidate maize varieties is the final stage in the maize variety release process. The results of stability tests can provide recommendations to plant breeders for selecting genotypes with high, stable yield potential across several test locations [21]. The research aims to test the characteristics of harvest age and production per hectare of eighteen candidate hybrid maize varieties at three test locations (Bangkalan, Pamekasan, and Sumenep).

2 Research methods

2.1 Genetic materials and experimental design

The research implementation flow starting from maize germplasm to determining the hybrid maize candidates recommended for release as maize varieties is presented in Figure 1. The planting material used comprised 20 maize genotypes, including 18 hybrid maize candidates from diallel crosses and line x tester crosses, and two comparison varieties (Bisi-X and Pioneer-X) (Table 1). Bisi-X and Pioneer-X are hybrid maize varieties widely planted by farmers in Indonesia. The research was conducted from April to September 2025. The research was conducted in three districts on Madura Island, East Java Province, Indonesia: Bangkalan, Pamekasan, and Sumenep (Table 2). Each research location used a non-factorial randomized block design with one treatment, namely genotype. The genetic material used in the study comprised 20 genotypes, including 18 hybrid maize candidates and two comparison varieties (Bisi-X and Pioneer-X). Each treatment was replicated three times, resulting in 60 experimental units. Fertilization is given in three stages, namely when the plants are 7 days after planting (200 kg ha^{-1} SP-36, 100 kg ha^{-1} Urea, and 50 kg ha^{-1} KCl), 25 days after planting (100 kg ha^{-1} Urea and 50 kg ha^{-1} KCl, and 40 days after planting (100 kg ha^{-1} Urea and 50 kg ha^{-1} KCl).

2.2 Observation parameters and data analysis

The parameters observed in this research were harvest age and production per hectare. At the time of maize harvest in the field, the moisture content of the seeds usually reaches less than 30%. Observations of maize grain yield were carried out on all plant samples for each experimental unit and converted into maize grain yield per hectare at a water content of 15% using the following formula:

$$Y = \frac{10000}{HA} x \frac{100 - MC}{100 - 15} xGW$$

where: Y : Grain yield (kg h^{-1}) HA : Harvested area per plot (m^2) MC : Moisture content at harvest time (%) GW : Harvested grain weight per plot (kg).

The character of harvest age and production per hectare were analyzed using the F test. f there was a significant effect, continued with the Honestly Significant Difference Test (HSD) ($p<0.05$) using the STAR 2.01 program. Genotype stability test calculations were performed using the PB tools 2.01 program.

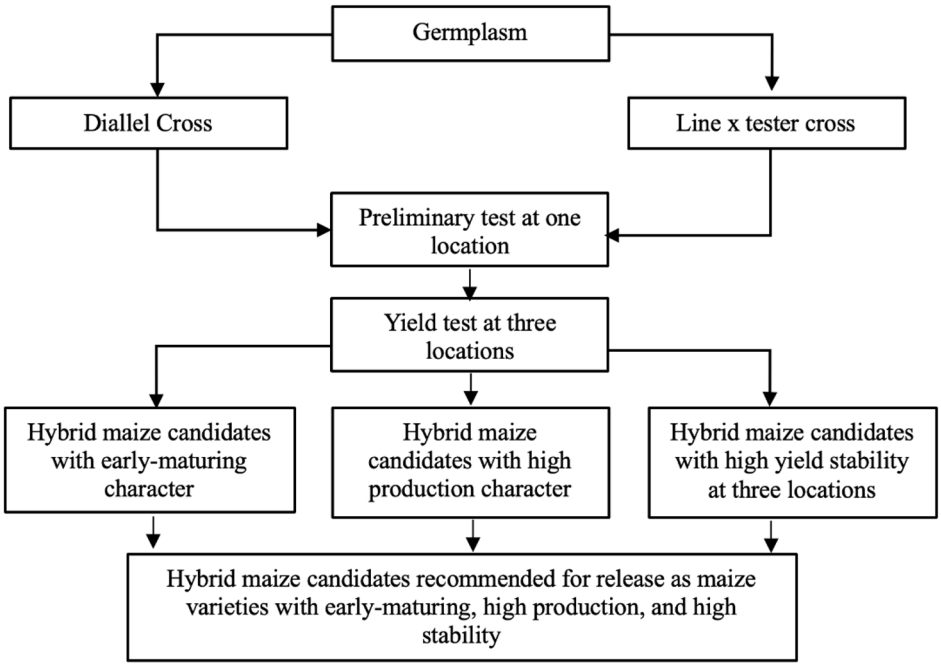

Fig. 1. Research workflow.

Table 1. 20 genotypes used in the research.

No	Genotypes	Code	No	Genotypes	Code
1	G1	Di.4*6	11	G11	LT.10*UTM08.5
2	G2	Di.4*7	12	G12	LT.16*UTM08.5
3	G3	Di.5*2	13	G13	LT.18*UTM08.5
4	G4	Di.5*4	14	G14	LT.2*UTM09.6
5	G5	Di.5*6	15	G15	LT.6*UTM09.6
6	G6	Di.6*1	16	G16	LT.9*UTM09.6
7	G7	Di.6*3	17	G17	LT.10*UTM09.6
8	G8	LT.2*UTM08.5	18	G18	LT.16*UTM09.6
9	G9	LT.4*UTM08.5	19	Check 1	Bisi-X
10	G10	LT.5*UTM08.5	20	Check 2	Pioneer-X

Table 2. Description of three test locations.

Location	Geographic position			Mean annual rainfall (mm)	Temperature (°C)		Soil type
	Longitude	Latitude	Altitude		Max	Min	
Kamal, Bangkalan	112°44 E	7°07 S	5 m	287	29	34	Grumusol
Pademawu, Pamekasan	113°31 E	7°10 S	7 m	1261	28	32	Aluvial
Lenteng, Sumenep	113°45 E	7°02 S	50 m	1824	27	31	Litosol

Table 3. Average harvest age in 20 maize genotypes at three test locations.

Genotypes	Locations			Mean
	BKL	PMK	SMP	
G1	90.00 f	87.00 gh	85.33 i	87.44 i
G2	103.00 bc	87.67 f-h	87.67 gh	92.78 g-i
G3	94.33 de	88.67 f-h	87.33 h	90.11 hi
G4	91.33 ef	87.00 gh	86.67 hi	88.33 i
G5	90.00 f	86.67 h	86.67 hi	87.78 i
G6	102.00 c	91.33 e-g	90.33 f	94.56 f-i
G7	102.00 c	98.00 cd	97.67 d	99.22 c-g
G8	102.33 bc	98.33 cd	97.67 d	99.44 c-g
G9	113.00 a	98.67 b-d	98.00 d	103.22 a-d
G10	103.33 bc	99.33 b-d	98.33 d	100.33 b-f
G11	98.00 d	96.33 d	95.33 e	96.56 d-h
G12	103.33 bc	101.33 a-c	101.67 c	102.11 a-e
G13	89.33 f	86.33 h	86.33 hi	87.33 i
G14	92.33 ef	90.00 f-h	89.33 fg	90.56 hi
G15	105.33 bc	103.00 ab	103.33 c	103.89 a-c
G16	106.00 b	104.00 a	103.33 c	104.44 a-c
G17	98.00 d	95.00 de	94.33 e	95.78 e-h
G18	95.00 de	91.67 ef	90.67 f	92.44 g-i
Bisi-X (G19)	111.00 a	104.67 a	108.67 a	108.11 a
Pioneer-X (G20)	111.00 a	104.67 a	105.33 b	107.00 a
Environment mean yield	100.03	94.98	94.70	96.57
CV (%)	5.27	5.47	5.65	7.43
HSD (0.05)	3.95	4.34	1.93	7.27

Note: BKL = Bangkalan; PMK = Pamekasan; SMP = Sumenep; CV = Coefficient of Variation; HSD = Honestly Significant Difference; The numbers followed by the same letter in the same column are not significantly different according to the 5% HSD test.

3 Result and discussion

3.1 Average harvest age and production per hectare

The average harvest age of 18 hybrid maize candidates ranged from 85.33 to 113.00 days (Table 3). At the Bangkalan location, G13 had the lowest harvest age (89.33 days) among the hybrid maize candidates. G9 had the highest harvest age (113.00 days) among hybrid maize candidates, exceeding the comparison varieties (Bisi-X and Pioneer-X). At the Pamekasan location, G5 had the lowest harvest age (86.67 days) among the hybrid maize candidates. G16 had the highest harvest age (104.00 days) among the hybrid maize candidates. The comparison varieties (Bisi-X and Pioneer-X) had a higher harvest age (104.67 days) compared to the 18 hybrid maize candidates but were not statistically significant different from G16. At the Sumenep location, G1 had the lowest harvest age (85.33 days) among the hybrid maize variety candidates. G15 and G16 had the highest harvest age (103.33 days) among the hybrid maize candidates. The comparison varieties (Bisi-X = 108.67 days and Pioneer-X = 105.33 days) had higher harvest ages than the 18 hybrid maize candidates tested. The average harvest age across three locations showed that G1, G4, G5, and G13 had the lowest harvest ages among the hybrid maize candidates, namely

87.44, 88.33, 87.78, and 87.33 days, respectively. G9 had the highest harvest age (103.22 days) among hybrid maize candidates across an average of three test locations. The comparison varieties (Bisi-X = 108.11 days and Pioneer-X = 107.00 days) had higher harvest ages than the 18 hybrid maize candidates across an average of three test locations.

The average production per hectare of 18 hybrid maize candidates ranged from 5217.25 kg to 11997.70 kg (Table 4). At the Bangkalan location, G15 had the lowest production per hectare (5,657.57 kg) among the hybrid maize candidates. G2 had higher production per hectare than 18 other hybrid maize candidates and two comparison varieties (Bisi-X and Pioneer-X). At the Pamekasan location, G15 had the lowest production per hectare (5,217.25 kg) among the hybrid maize candidates. G2, G3, and G4 had the highest production per hectare among the hybrid maize candidates and two comparison varieties, namely 11460.07 kg, 11420.38 kg, and 11420.38 kg, respectively. At the Sumenep location, G15 had the lowest production per hectare (5497.55 kg) among the hybrid maize candidates. G3 and G4 had the highest production per hectare among the hybrid maize candidates and two comparison varieties, namely 11997.70 kg and 11986.07 kg, respectively. Average production per hectare at three locations showed that G15 had the lowest production per hectare (5,457.46 kg) among the hybrid maize candidates. G2 and G3 had the highest production per hectare among the hybrid maize candidates, averaging 11,425.62 kg and 11,480.53 kg, respectively.

Table 4. Average production per hectare in 20 maize genotypes at three test locations.

Genotypes	Locations			Mean
	BKL	PMK	SMP	
G1	11014.42 a-d	10825.16 a-c	11006.76 bc	10948.78 ab
G2	11667.41 a	11460.07 a	11149.40 a-c	11425.62 a
G3	11023.51 a-c	11420.38 a	11997.70 a	11480.53 a
G4	10098.63 b-f	11420.38 a	11986.07 a	11168.36 ab
G5	9698.21 d-f	10198.19 a-c	10932.09 bc	10276.17 a-c
G6	11149.79 a-c	9404.56 b-d	9147.57 e	9900.64 a-c
G7	7972.42 gh	10975.95 ab	11235.80 a-c	10061.39 a-c
G8	9445.64 ef	8031.57 de	7876.05 fg	8451.09 c-e
G9	10042.89 b-f	9325.19 b-d	8665.54 ef	9344.54 a-c
G10	9843.81 c-f	9880.74 a-c	9459.82 de	9728.12 a-c
G11	10760.21 a-e	10397.60 a-c	10624.08 bc	10593.96 a-c
G12	7535.76 hi	7008.21 ef	7014.49 g	7186.16 d-f
G13	6468.40 ij	6010.20 fg	6966.40 g	6481.67 ef
G14	10725.90 a-e	9442.00 b-d	9247.50 e	9805.13 a-c
G15	5657.57 j	5217.25 g	5497.55 h	5457.46 f
G16	11276.97 ab	10417.73 a-c	10647.79 bc	10780.83 ab
G17	9142.15 fg	9228.40 cd	9173.52 e	9181.36 b-d
G18	10108.61 b-f	9631.57 b-d	10408.43 c	10049.54 a-c
Bisi-X (G19)	10405.12 a-f	10125.17 a-c	11367.77 ab	10632.69 ab
Pioneer-X (G20)	9921.75 d-f	9412.50 b-d	10361.84 cd	9898.70 a-c
Environment mean yield	9697.96	9491.64	9738.31	9642.64
CV (%)	9.40	10.69	8.11	12.18
HSD (0.05)	1323.62	165.99	941.25	2147.89

Note: BKL = Bangkalan; PMK = Pamekasan; SMP = Sumenep; CV = Coefficient of Variation; HSD = Honestly Significant Difference; The numbers followed by the same letter in the same column are not significantly different according to the 5% HSD test

3.2 Analysis of variance

The results of the AAMI variance analysis for harvest age and production per hectare on 18 candidate hybrid maize varieties and two comparison varieties showed that there was a very significant influence on the environment, genotype, and genotype by environment interaction (GxE) (Tables 5 and 6). These results showed that harvest age is influenced by genotype and environmental factors. In addition, the genotypes tested had different harvest ages in several locations, caused by genotype and environment (GxE) interactions [22]. In the characters of harvest age and production per hectare, Interaction Component Analysis (IPC) showed that IPC1 made a very significant contribution to the interaction between genotype and environment (GxE), while IPC2 had no significant effect. This condition indicated that most of the variation in GxE interactions can be explained by IPC1.

Table 5. AMMI analysis of variance for harvest age.

Source of variance	d.f	SS	MS	F-value	% SS_{GEI}
Environment (E)	2	1080.54	540.27	89.88**	
Replications (Environ.)	6	36.07	6.01	4.55**	
Genotypes (G)	19	8007.17	421.47	319.01**	
G x E	38	625.68	16.46	12.46**	
IPC1	20	195.58	9.78	7.40**	93.80
IPC2	18	12.97	0.72	0.54^{ns}	6.20
Error	114	150.60	1.32		
Total	179	9900.06			

Note: E = Envinronment (location); df = degrees of freedom; SS = sum of squares; MS = mean squares; IPC = Interaction Principal Component Analysis; ** = significant at the α level of < 0.01

Table 6. AMMI analysis of variance for production per hectare.

Source of variance	d.f	SS	MS	F-value	% SS_{GEI}
Environment (E)	2	21000783.58	1050391.79	14.97**	
Replications (Environ.)	6	421122.03	70187.01	0.37^{ns}	
Genotypes (G)	19	449485063.33	23657108.60	125.52**	
G x E	38	54592503.08	1436644.82	7.62**	
IPC1	20	16279617.00	813980.80	4.32*	89.50
IPC2	18	1917884.00	106549.10	0.57^{ns}	10.50
Error	114	21485140.92	188466.15		
Total	179	528084612.94			

Note: E = Envinronment (location); df = degrees of freedom; SS = sum of squares; MS = mean squares; IPC = Interaction Principal Component Analysis; ** = significant at the α level of < 0.01; ns = non significant.

The level of genotypic diversity tested varied across three locations (Figure 2). In terms of harvest age character, the Bangkalan location showed a narrower range of harvest ages, while the Sumenep location showed a broader range. In terms of production per hectare character, the narrowest diversity is found in the Pamekasan location, while the largest is found in the Sumenep location. Differences in genotypic diversity across locations are caused by genotype and environment interactions [23]. Significant differences in location caused genotype responses to the environment to differ as well [24]. Certain environmental conditions can caused genetic expression to be prominent or lost, resulting in differences in the appearance of a genotype in different environments [25].

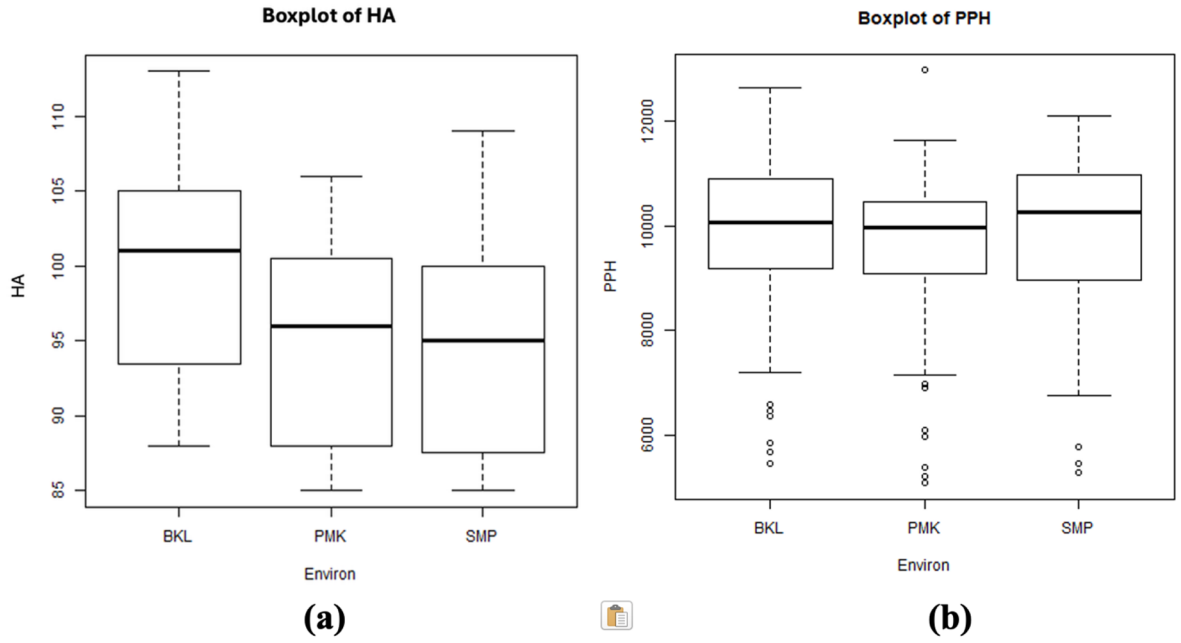

Fig. 2. (a) harvest age, (b) production per hectare of 20 genotypes tested at three locations.

3.3 Genotype stability at three locations

AMMI analysis is used to evaluate genotype by environment (GxE) interactions in multi-location trials [26]. This analysis helps determine the genotypes with the best, stable performance across various environmental conditions [27]. AMMI analysis showed that the GxE interaction effect on the harvest age character was as follows: the contributions of the IPC1 and IPC2 components were 93.80% and 6.20%, respectively (Table 5). AMMI analysis on production character per hectare showed that the GxE interaction effect was as follows: the contribution of the interaction effect of IPC1 and IPC2 components was 89.50% and 10.50% respectively (Table 6). Based on the IPC values for both characters (harvest age and production per hectare), the GxE interaction pattern was relatively simple and can be well explained by two main axes so that the AMMI analysis was effective in describing the stability and adaptation of genotypes to the environment.

AMMI biplot is used to interpret the AMMI model. The comparison of PC1 and PC2 shows stable genotypes that perform well at all locations or at specific locations [28]. The genotype closest to the center point (coordinate 0.0) had high stability or appeared stable at the test location. Furthermore, genotypes near a particular test location (environment) showed a close relationship between the genotype and the environment [29]. In terms of harvest age character, four candidate hybrid maize varieties (G3, G14, G17, and G18) exhibited broad stability and adaptation, as they were close to the ordinate (Figure 3). In terms of production per hectare, the five hybrid maize candidates (G2, G4, G5, G8, and G10) demonstrated stability and broad adaptation.

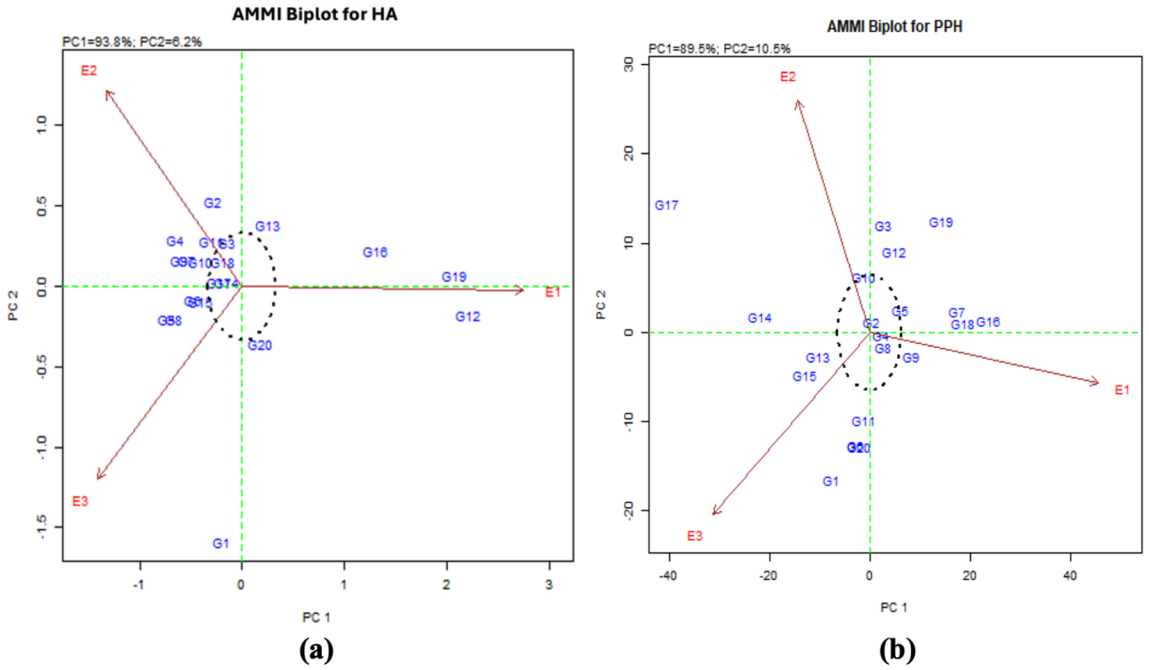

Fig. 3. Biplot of the interaction of PC1 and PC2 for (a) harvest age, (b) production per hectare. E1 = Bangkalan; E2 = Pamekasan; E3 = Sumenep.

3.4 Determination of hybrid maize candidates that are released as hybrid maize varieties

This research aims to select hybrid maize candidates that had early maturity age and production per hectare. Early maturity maize varieties with high yield potential can be used to address low maize productivity in dryland. Maize varieties with early maturity character complete their life cycle in a short time, thus avoiding drought stress during the critical growth period [30]. In addition, if maize varieties with early maturity characteristics are also high yielding, maize productivity in dryland will increase even under less than ideal environmental conditions.

The harvest age of maize plants is classified into three categories: early maturity (75 - 95 days), medium maturity (95 - 120 days), and long maturity (>120 days) [31]. The test results showed that 10 hybrid maize candidates had an early maturity (<95 days), namely G1, G2, G3, G4, G5, G6, G7, G13, G14, and G18 (Figure 4a). In terms of production per hectare, five hybrid maize candidates exceeded the comparison variety-1 (Bisi-X), namely G1, G2, G3, G4, and G16 (Figure 4b). However, the hybrid maize candidates that exceeded the comparison variety-2 (Pioneer-X) were obtained from 9 hybrid maize candidate varieties: G1, G2, G3, G4, G5, G7, G11, G16, and G18. The determination of hybrid maize candidates recommended for release as hybrid varieties is based on three considerations: harvest age, production, and genotype stability. Based on these categories, three recommended hybrid maize varieties were released, namely G2, G4, and G5. The three hybrid maize candidates had early harvesting times (<95 days), high production per hectare (exceeded the two comparison varieties), and high stability at all locations.

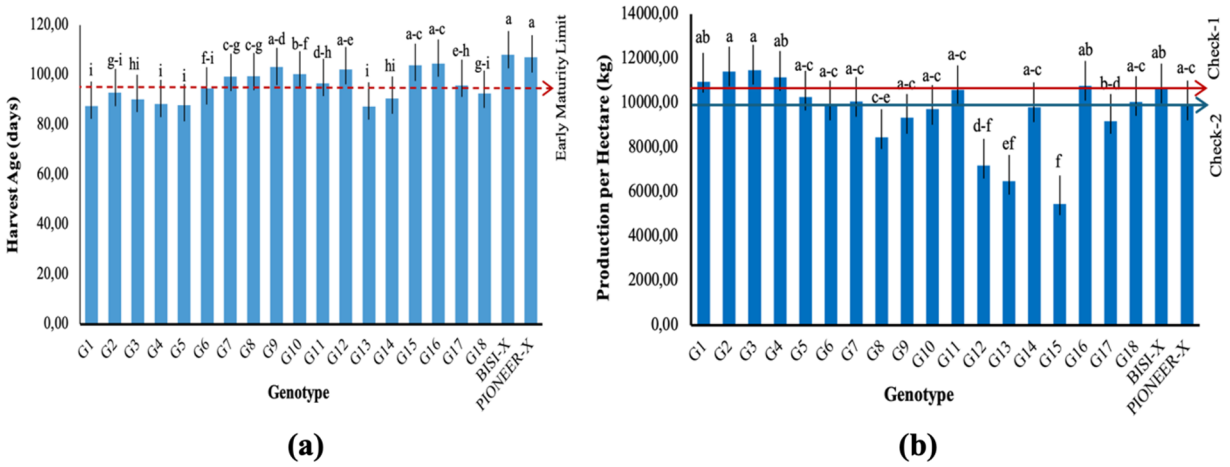

Fig. 4. Average performance of 20 genotypes at three test locations. (a) harvest age, (b) production per hectare.

4

Conclussion

Analysis of AAMI variance for harvest age and production per hectare across 18 hybrid maize candidates and two comparison varieties showed that environment, genotype, and the genotype by environment (GxE) interaction were highly significant. Four hybrid maize candidates had stable harvest ages across three locations (Bangkalan, Pamekasan, and Sumenep): G3, G14, G17, and G18, while five hybrid maize candidates had stable production per hectare across three locations: G2, G4, G5, G8, and G10. Three hybrid miaze candidates recommended for release as varieties were G2, G4, and G5.

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