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Adaptation and Phenotype Varieties of Sweet Sorghum (*Sorghum bicolor* Linn. Moench) at Different Altitude

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***Abstract*—Sorghum is one of the main candidates for bioethanol feedstock. It is easy to cultivate and adapt to various land and altitude criteria but often developed in low land. The study aims to utilize land based on the altitude for the development of several varieties. An experiment was conducted on three different sites: dry land of a forest area with an elevation of 63 m above sea level (asl), on dry land with an elevation of 800 m asl, and on dry land with a height of 67 m asl. The interaction effect of both varieties and mycorrhizal towards adaptation and phenotypic appearance was evaluated. Factorial experiments were arranged in Randomized Complete Block Design, consisting of varieties and doses of biological fertilizers. The varieties used were Suri-3, Suri-4, Kawali, and Super-2, and doses of biofertilizer were (5, 10, 15) g per plant. In all research locations, the interaction between varieties and doses of biofertilizer only significantly affected the number of internodes. At 67 m asl, the interaction affects the plant height, stem FW, leaf FW, and panicle length. Suri-3 and Super-2 showed the best response on the doses of 5 g per plant, while Suri-4 did on 15 g per plant. Kawali adapts well at 800 m asl and 67 m asl. Kawali achieved the highest panicle length and seed FW at 800 m asl, respectively 34.39 cm and 81.17 g. Super-2 has the best adaptation and phenotype at 63 m asl, with the maximum plant height of 301.28 cm.**

***Keywords*—altitude; dryland; mycorrhiza; phenotype; sorghum.**

I. INTRODUCTION

The need for bioethanol has been increasing since the Indonesian government makes it mandatory to mix fossil fuels with bioethanol. Sweet sorghum – a crop consumed as food, made into liquid sugar, and fed to cattle – is used in ethanol production [1]-[3]. A candidate for renewable bioethanol source, it has been identified that the sugar content in its stem is high [4],[5]. Sugar content in sweet sorghum juice is ranged in (10 to 25) Brix [6], and it is feasible for producing ethanol as much as 6000 L ha^{-1} to 7000 L ha^{-1} [7], [8]. Most sorghum varieties in Indonesia can yield ethanol between 3000 L ha^{-1} to 6600 L ha^{-1} [9].

Sweet sorghum is a plant that is easy to cultivate and easy to adapt to a variety of land circumstances and altitude suitability classes. It can grow in low-quality soil – either in the tropics, in the sub-tropics, or in temperate regions – due to its vast adaptative quality, high productivity, relatively low input requirement, and resilience against the pest, disease, drought, salinity, and acidity [10]. It also adapts best in dry lowlands of (1 to 500) m above sea level (asl), while higher elevations tend to extend the age of harvesting [11]. Despite its potentials for commercial cultivation, the latter fact makes sweet sorghum less promising for commodity development in Indonesia; therefore, attempts on optimizing it is needed. One apparent effort is to uncover varieties befitting lands higher than 500 m asl with a satisfactory outcome, providing there is a significant assortment of sorghum genotypes [12]. These genetic varieties also indicate phenotypical differences agronomically [13].

Administering mycorrhizae in the early growth stage will improve the plant's adaptative ability. It should increase plant growth and productivity, especially on marginal land. The increase of root biomass enhances the plant size. As we are aware of, this series is often related to the absorption and mobilization of phosphorus nutrients [14]. In phosphorus-deficient soils, inoculation of mycorrhiza and Phosphate Solubilizing Bacteria (PSB) stimulates plant growth better.

This study is conducted to attest varieties of sweet sorghum fitting local agroecological conditions. The purpose is to evaluate the interaction effect of both varieties and mycorrhizae towards adaptation and phenotypic appearance of sweet sorghum on several altitudes in order to determine the most suitable sweet sorghum varieties as raw material for bioethanol.

II. Materials and Method

A. Field Location

This experiment had been performed in April to September 2016 at three different locations. The first in Trosono Village in Parang District of Magetan Regency, Indonesia, with an altitude of 800 m above sea level (asl). The second was in Banjarsari Wetan Village in Dagangan District of Madiun City, with an altitude of 67 m asl. The third was in the forest area in Kampung Baru Village of Saradan District, Madiun Regency, Indonesia, with an altitude of 63 m asl. The three sites have low soil organic carbon and pH (Table 1).

TABLE I
Soil Characteristic of The Three Location

Location	**63 m asl (forest land)**	**800 m asl**	**67 m asl**
Texture	sandy loam	sandy loam	Sandy loam
pH salt	5.37	5.08	4.79
C org (%)	1.59	1.13	1.43
CEC [meq (100 g)$^{-1}$]	82.32	42.67	58.59
Total N (%)	1.15	1.35	1.59
Total P (ppm)	269.64	1120.59	1103.13
Olsen-Available P (ppm)	86.75	110.74	42.60
C/N Ratio	1.50	0.84	0.92

B. Experimental design

A factorial experiment consisting of two factors was used based on randomized complete block design. The two-factors were repeated three times. The four varieties of sorghum tested were Suri-3, Kawali, Super-2, and Suri-4; they are labeled V1, V2, V3, and V4. Three levels of biofertilizer dosage were (5, 10, and 15) g per plant, labeled D1, D2, and D3. Biofertilizers contain *Trichoderma* sp, *Pseudomonas fluorescents*, *Bacillus subtilis*, and indigenous mycorrhizae. In each replication, 12 plots – each was (3.50 x 1.50) m in size – were used. Planting spaces of 70 cm between rows and 20 cm within a row were applied. Five plants in every plot were randomly chosen to be measured.

C. Parameter Observed

Plant height, stem diameter, and the number of internodes of those five plants were measured. Plant height was measured as the height to the neck node of the ear. Stem diameter was measured at (10 to 15) cm from the base, including the leaf sheath. The stem sugar content (Brix) was measured using a refractometer. Before juice extraction, the leaves were stripped, and the panicles and the peduncles were removed from each plant. The stems were squeezed once using a three-roller machine miller without imbibition water to extract the juice. The juice was collected into bottles, and then the volume was measured.

D. Statistical Analysis

The SPSS version 25 software was employed to analyze the variance ($p < 0.05$) and to calculate the significant differences among the varieties and mycorrhizal. The statistical significance of the differences between the means was estimated by Duncan's Multiple Range Test (DMRT) at the 5 % level.

III. Result and Discussion

At three locations, there was the effect of significant interaction between varieties and doses of biofertilizer for the number of internodes. In two of the locations, the interaction between varieties and doses of biofertilizer had significant differences on some growth variables. The effect of varieties was significant on some variables measured (Table 2 – 4), while different doses of biofertilizer given did not significantly affect variables measured (data not shown).

TABLE II
Effect of Interaction Between Varieties and Dosage of Biofertilizer on Plant Growth Characters in Sorghum

Variable	**63 m asl (forest)**	**800 m asl**	**67 m asl**
Plant heights (cm)	ns	**	**
Stem diameter (cm)	ns	ns	ns
Number of internodes	*	**	**
Sugar content (brix)	ns	ns	ns
Panicle length (cm)	ns	ns	**
Leaf Fresh Weight (g)	ns	ns	**
Stem FW per stem (g)	ns	ns	**
Seed FW per stem (g)	ns	ns	ns
Seed Dry Weight per stem (g)	ns	ns	ns
Juice production ($L \cdot ha^{-1}$)	ns	ns	ns

*significant difference at 5%.
ns: non-significant
** significant difference at 1%.

Table 2 shows that biofertilizers in some varieties affected the growth of sorghum plants on the dry land of 67 m asl, including plant heights, panicle length, leaf FW, and stem FW. The characteristic of the dry land is low pH, which means it has low available P content and high total P content (Table 1). The mycorrhiza can enhance the availability of P in soils by deteriorating high P-fixation [15]. It was added in the biofertilizers applied on sweet sorghum – the compositions were indigenous mycorrhizae, *Trichoderma* sp, *Pseudomonas fluorescent,* and Bacillus *subtilis.* Several studies have shown that inoculation of mycorrhiza can increase the ability of plants in water and nutrient absorptions, especially P, by expanding their absorption areas. Association between mycorrhiza and *Pseudomonas fluorescence* increases the amount of nutrition uptake. *Pseudomonas fluorescence* as Phosphate Solubilizing Bacteria (PSB) is one of the soil microorganisms that can improve the supply of P on acid mineral soils [16]–[18]. *Bacillus subtilis* increases plant growth and can act as a stimulator in the absorption of several nutrients. The uptake of P affects the physiological and morphological of the plant.

TABLE III

ADAPTATION AND PHENOTYPE OF SORGHUM VARIETIES ON GROWTH CHARACTER AND YIELD ON DIFFERENT ALTITUDE

Variable	Varieties					
	63 m asl (forest)		800 m asl		67 m asl	
	Sig.	The highest Value	Sig.	The highest Value	Sig.	The highest Value
Plant heights (cm)	**	Super-2	*	Kawali	**	Kawali
Stem diameter (cm)	ns	Kawali	*	Kawali	ns	Super-2
Number of internodes	*	Super-2	**	Suri-4	*	Suri-3
Sugar content (brix)	**	Suri-3	*	Suri-4	*	Super-2
Panicle length (cm)	ns	Super-2	*	Kawali	**	Kawali
Leaf Fresh Weight (g)	*	Kawali	*	Super-2	*	Kawali
Stem FW per stem (g)	*	Super-2	ns	Super-2	ns	Kawali
Seed FW per stem (g)	*	Super-2	**	Kawali	**	Kawali
Seed Dry Weight per stem (g)	**	Super-2	**	Kawali	*	Kawali
Juice production ($L \cdot ha^{-1}$)	ns	Suri-4	*	Kawali	**	Kawali

* significant difference at 5%. ** significant difference at 1%. ns: non-significant

TABLE IV

THE SINGLE EFFECT OF SORGHUM VARIETIES ON GROWTH CHARACTER AND YIELD ON DIFFERENT ALTITUDE

Varieties	Plant height (cm)			Panicle length (cm)			Seed FW per stem (g)		
	63 m asl	800 m asl	67 m asl	63 m asl	800 m asl	67 m asl	63 m asl	800 m asl	67 m asl
Suri-3	268.03 b	165,73 a	160.70 a	33.94	29.68 ab	18.07 a	43.98 ab	31.19 a	23.07 a
Kawali	192.38 a	198.35 c	199.17 b	29.27	34.39 b	23.62 b	40.62 ab	81.17 b	40.88 b
Super-2	301.28 b	173.29 ab	158.48 a	34.32	31.73 b	21.04 ab	51.99 b	53.24 a	26.44 a
Suri-4	181.29 a	190.10 bc	193.31 b	27.67	25.20 a	19.39 a	38.85 a	40.44 a	18.98 a

Means with the same letter at the same column are not significantly different at 5% Duncan test

Table 3 presents the overall mean performance of the four varieties evaluated for their agronomic traits – specifically on adaptation and phenotype – at three different places of different altitudes. Current findings show that while Kawali has the highest average of plant growth and the yield on 800 m asl and 67 m asl, Super-2 does on altitude 63 m asl.

Data presented in Table 4 indicates that plant height, panicle length, and seed FW have significant differences in all four varieties of sweet sorghum at all different altitudes, with an exception on the panicle length on 63 m asl. Of all sweet sorghum varieties tested, Kawali attains the highest values on 800 m asl and 67 m asl. It shows that Kawali has the best adaptation and phenotype in two locations (testing sites). Meanwhile, on 63 m asl, Super-2 variety is the champion. Similar results were achieved by studies in [19], [20], which indicated that Super-2 varieties were highly suitable and significant to develop in dry areas.

Moreover, the Super-2 variety has better adaptation and phenotype performance than Kawali. It is visible from the plant height that Super-2 (301.28 cm) is higher than Kawali (198.35 cm and 199.17 cm). In adaptation testing, the growth and yield components are a combination of genetic, environmental, and genotype x environmental influences [21],[22]. Variation in the results shows different responses from each variety to the environment, as it is known that high productivity is due to the excellent adapting capability of the variety with its environment [23].

Adaptation tests of four varieties of sorghum at all three trial sites show that the plant height of Super-2 is the best. (Table 4). The number of sweet sorghum's internodes planted in 67 m asl dryland were varied from 10.44 to 24.11 with a mean of 17.85 – the highest of all lands. Suri-4 (V4) adapted well at 63 m asl and 67 m asl, whereas Suri-3 (V1) at 800 m asl. However, at 67 m asl, there were significant interaction differences in varieties and biofertilizer dosage as shown in plant height, stem FW, leaf FW, and panicle length (Table 5).

TABLE V

EFFECT OF INTERACTION BETWEEN VARIETIES AND DOSAGE OF BIOFERTILIZER ON NUMBER OF INTERNODES

Treatment	63 m asl (forest land)	800 m asl	67 m asl
V1D1	8.67 abc	14.56 ef	21.56 cd
V1D2	8.00 ab	11.44 abcde	22.11 d
V1D3	7.11 a	9.22 abc	19.22 bcd
V2D1	10.78 bc	9.22 abc	19.44 bcd
V2D2	8.66 abc	10.89 abcd	14.00 abc
V2D3	8.00 ab	12.33 cdef	13.56 ab
V3D1	11.44 c	11.67 bcde	23.56 d
V3D2	10.67 bc	8.11 a	17.67 abcd
V3D3	9.00 abc	8.22 a	16.44 abcd
V4D1	7.67 ab	8.78 ab	12.11 ab
V4D2	9.44 abc	15.56 f	10.44 a
V4D3	11.78 c	13.67 def	24.11 d

Means with the same letter at the same column are not significantly different at 5% Duncan test

The highest achievements went to V1D1 (236.67 cm), V4D3 (323.78 g), V2D1 (96.17 g), and V2D2 (24.33 cm). The interaction of varieties x dosage of biofertilizer indicated between one factor with another factor the effect is not is free, or there is mutual influence. The interaction of varieties x dosage of biofertilizer indicated between one factor with another factor the effect is not accessible, or there is mutual influence. Colonization of *Glomus etanicatum* mycorrhizae with sorghum enhances the field-grown sorghum's drought tolerance, nutrient content, and yield. The higher the drought stress of underfield conditions, the better the mycorrhizae's colonization process will be

[24]. The research location at 67 m asl has the lowest water status compared to the other two places. Consequently, plants colonized by mycorrhizal are much more efficient in taking up P nutrients than plants without mycorrhizal, which influences sorghum's quality [15]. The effects of interaction between varieties and biofertilizer dosage on plant growth characters at 67 m asl are given in Fig. 1– 4.

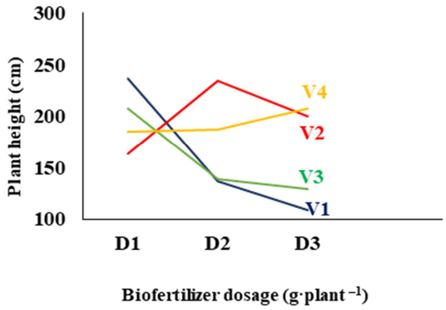

Fig. 1 Plant height of sweet sorghum varieties in three biofertilizer dosages

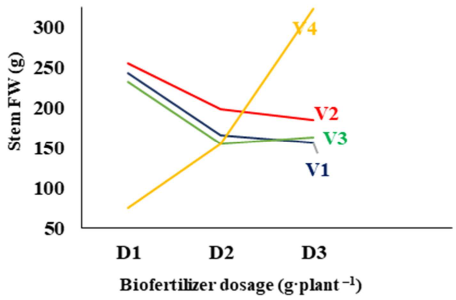

Fig. 2 Stem FW of sweet sorghum varieties in three biofertilizer dosages

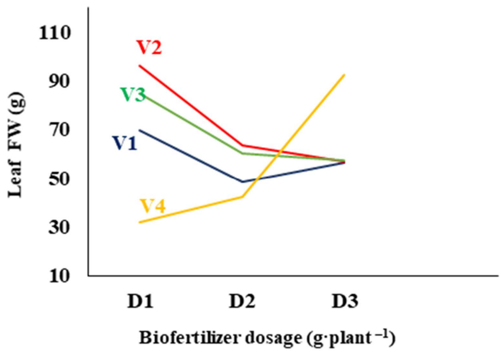

Fig. 3 Leaf FW of sweet sorghum varieties in three biofertilizer dosages

Figure 1-4 shows that Suri-3 (V1) has excellent responses on 5 g per plant (D1) as shown in plant height, stem FW, leaf FW, and panicle length, yet Super-2 (V3) has the same reactions as Suri-3 except on panicle length. Meanwhile, Suri-4 (V4) best performs to 15 g per plant (D3). Different results appear in Kawali (V2), for the variables of plant height and panicle length are good on 10 g per plant (D2) while stem FW and leaf FW on 5 g per plant (D1). It is positive that the four varieties have different response rates on different dosages of biofertilizer. In agreement with this result, [25] reported that grain yield harvests are significantly different from one variety of sorghum from another. Also, a significant variation on the above-ground dry biomass exists because of variety and fertilizers [26].

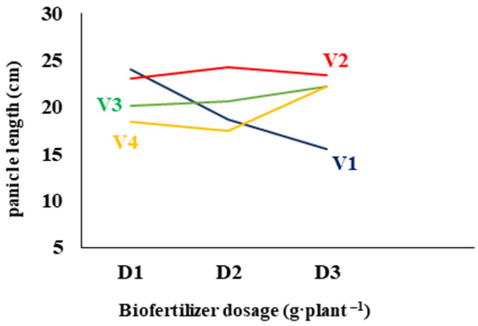

Fig. 4 Panicle length of sweet sorghum varieties in three biofertilizer dosages

All varieties significantly differ in sugar contents in three study sites, whereas juice production has significant effects on 800 m asl and 67 m asl drylands (Fig. 5 and Fig. 6).

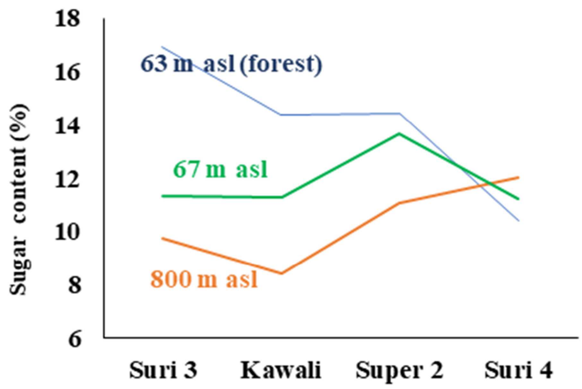

Fig. 5 Sugar contents of four varieties of sorghum at different altitudes

The sugar content of four sweet sorghum varieties is in a range of (8.44 to 16.93) % with a mean of 12.07 %, which is higher than the average sugar content of the varieties at 67 m asl dan 800 m asl. Sugar content in this study is like one reported by [27]. In the same review, 19 cultivars of sweet sorghum are reported to have sucrose content between (6 to 16) %; according to [28], the content of sugar in juice is at variance between (9 to 20) %.

Fig 5 illustrates the content of sugar in four varieties at each elevation. Apparently, the phenotype of sweet sorghum with the highest sugar content could be found at the altitudes of 63 m asl, 800 m asl, and 67 m asl were Suri-3, Suri-4, and Super-2, respectively. The sugar content of Super-2 (13.64 %) is proven like research report [19], with recorded sugar content of 13.90 %.

Maturity of stem affects the sugar content in juice. Sugar content will increase with maturity and decrease before seed development [29]. Besides, [28] reported that varieties with high sucrose content has higher percentage of TSS and lower sugar reduction levels. Varied test results of sorghum varieties may rely on genotypes. The content of sugar in stem juice of sweet sorghum varies depending on the variety, likewise the time of sucrose accumulation in the stem [30]).

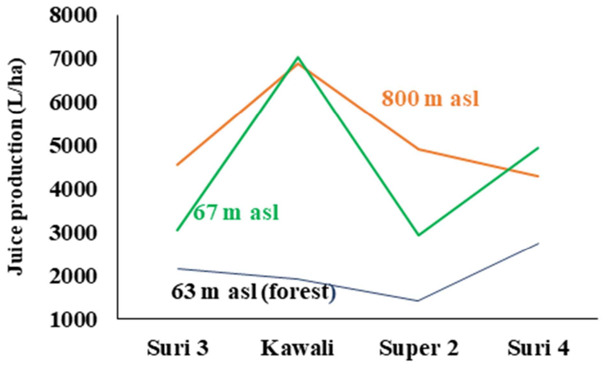

Fig. 6 Production of juice the varieties of sweet sorghum at a different altitude

As shown in Figure 6, a wide range of variability for juice production has been observed among the four varieties at three different altitudes. The juice is extracted from the stalks considered green stem, as it gives a higher amount of juice [31]. The juice production range is between 1415.44 L ha^{-1} to 7034.91 L ha^{-1} by mean of 3904.73 L ha^{-1}. All varieties that have been studied at 800 m asl have juice production above average, with the highest content found in Kawali (6888.91 L ha^{-1}). At altitude 67 m, the richest juice is also generated by Kawali (7034.91 L ha^{-1}). But, at 63 m asl, the variety with the most stem extract is Suri-4. The ideal genotype is defined as a genotype that has the highest average yield in all test sites as well as having high stability (having the highest ranking in all test sites) [21]. Data of juice production shows that there are significant differences between the four sweet sorghum varieties at 800 m asl and 67 m asl, but at 63 m asl there is no significant difference. The highest juice production in those three varieties has the lowest sugar content (Fig. 5 & Fig. 6). It is conclusive that juice production and sugar content are affected by variety. The present study is consistent with data reported in [8].

IV. Conclusions

The four varieties of sweet sorghum can grow and adapt well at altitudes of 63 m asl, 67 m asl, and 800 m asl, and each has its own phenotypic characters. The interaction between varieties and dosage of biofertilizer significantly affects the number of internodes at three locations. The effects of variety are highly significant, whereas the impacts of dosage biofertilizer are not. Varieties of Kawali adapt the best at altitudes of 800 m and 67 m asl. Super-2 variety is the most remarkable in both adaptation and phenotype performance at 63 m asl. The four varieties can yield above-average juice quantity at 800 m asl, and the highest producer is Kawali.

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