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Selection Indicators of Yield Components and Yield for Improvement of Local Sweet Potato under Water Stress

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ABSTRACT

Genetic diversity is required for crop improvement against environmental stress. Astudy wasconducted to determine characters as selection indicators of water-stress tolerance, and of yield components and yield. The research method involved a one-factor experiment with 21 sweet potato clones, using a Completely Randomized Block design with three replicates. Water stress in this study mean that the bottom of plants was submerged in water at 2 and 3 months of age. Determination of selection indicators was conducted by estimating the coefficients of genetic and phenotypic variations, heritabilities, genetic advance and correlation test result. The characters of number of leaves, individual leaf area, leaf area per plant, leaf area index, stem length, internode length, number of tubers (storage root), individual tuber weight and yieldas selection indicators of water stress tolerance. Selection indicators of yield components consisted of less number of leaves, small leaf size, short stemsand number of branches, whereas selection indicators of yield were small leaf size, number of branches, number of tubers and individual tuber weight. Selection became effective and efficient when the selection indicators were influenced greatly by genetic factors.

INTRODUCTION

Sweet potato (*Ipomoea batatas* (L.) Lam) is a root/tuber crop that produces carbohydrate and other important nutrients, such as β-carotene, vitamin C and anthocyanin. The nutritional content of its tubers depends on the color of tuber flesh. The purple tuber flesh has become popular today because of a high anthocyanin content, which is known to be beneficial for human health. Maluku Province is one of the island provinces in Indonesia which people consume sweet potato to fulfill their daily staple food needs, in addition to sago, rice and cassava.

Global climate change cannot be predicted and extreme environment may affect food availability due to changes in the planting season, decrease in production and even harvest failure. Varieties that are tolerant to environmental stresses are needed to anticipate the global climate change. Crop varieties with such characterstics need to be produced through breeding activities which require sufficient genetic resources in the form of a genetic diversity of various characters corresponded to tolerance mechanism on environmental stresses.

One of the environmental conditions in areas with high levels of rainfall, such as in tropical monsoon regions in Indonesia, is waterlogging or flooding. Two crop conditions under water stress above normal that influence plant growth and production are waterlogging and flooding. Waterlogging occurs when root system of the crop is under anaerobic conditions but the canopy is in normal conditions; whereas flooding is when water is above the ground surface, which is grouped into (a) partial submergence, when the plants are partially submerged, and (b) full submergence, when the

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plants are entirely submerged (Striker, 2012). Crop improvement for tolerance to waterlogging and flooding is very important nowadays as theeffort to utilize marginal lands and to anticipate extreme weather on crop productivity. Sweet potato clones that are tolerant to such water stress are therefore needed for sustainable crop production, especially in the regions with many swamp areas.

The part of sweet potato plant that has economic value is the tubers which grow and develop in the soil. According to Wilson (1982), sweet potatoes is not tolerant to water stress, especially during tuber (storage root) initiation. The important characteristics related to the tolerance to water stress include crop ability to increase root porosity, roots ability to regrow, and crop ability to retain shoot nitrogen and chlorophyll in the leaves (Malik, Ailewe, & Erskine, 2015). Several studies indicated that the porosity in roots is higher by the formation of aerenchymes in legume plants which are tolerant to waterlogging stresses as compared to the sensitive plants, although adventitious roots are not found in legume plants. Whereas according to Hossain & Uddin (2011) the crop develop adventious roots to form aerenchymes as oxygen channels under water stress conditions. It is also said that the formation of aerenchymes is one of the important morphological adaptations underwaterlogging stresses. These characteristics support crops to maintain physiological growth under such water stress conditions.

Diversity genepool in a germplasm collection becomes very important for the genetic improvement to deal with tolerance mechanism to water stresses. Sweet potato is a crop species that has a high morphological diversity. Genetically, the diversity in sweet potato is supported by the high number of genomes and a large number of its chromosomes ($2n = 6x = 90$), and the fact that sweet potato belongs to cross-pollinating plants due to incompatibility in the sex organs. Genetic diversity can be measured by estimating genotypic variance, phenotypic variance, genotypic diversity coefficient, broad heritability and genetic progress (Agrawal & Kumar, 2017). Based on the estimated value of these genetic parameters, characters can also be determined as selection indicators from the best parents in the population according to the purpose of breeding. According to Segherloo, Mohammadi, Sadeghzadeh, & Kamrani (2016), the progress of the characters that become the selection indicators can be predicted genetically in the offsprings through the analysis of average genetic progress. High heritability and genetic progress are useful tools for predicting the resultant effect for selecting the best genotypes based on yield components and yield.

A character can be a selection indicator of other characters based on a correlation test so that the selection program can be more effective. Correlations between yield, yield components, and other economic properties, are important for selection in breeding programs. If genotypic variance and heritability are low for tuber yields then plant improvement might be done more efficiently by selecting non-tuber characters that are positively correlated with yield (Wera, Yalu, Ramakrishna, & Deros, 2015; Yahaya, Saad, Mohammed, & Afuape, 2015). The objectives of the paper was to determine characters that can be used for selection indicators of yield components and yield in sweet potato tolerance improvement in water stress.

MATERIALS AND METHODS

This research was conducted in Ambon, Maluku Province, in 2017, involving 21 sweet potato clones, from 6 districts in Maluku Province, namely Western Ceram, Central Maluku, North Buru, Southeast Maluku, Western Southeast Maluku, and Ambon, and 2 national superior varieties, i.e. Antin 2 and Cilembu that were obtained from the Indonesian Legumes and Tubers Crops Research Institute (ILETRI), Malang, East Java, Indonesia. The experiment was a single-factor experiment using a Completely Randomized Block Design with three replicates. Planting material consisted of stem cuttings with 3 nodes and 2 leaves. Planting spacing was 75 cm x 40 cm, and there were 16 plants per plot consisting of 4 middle plants and 12 side plants. Before planting, 300 g of manure was added into each planting hole. Additional fertilizers in the form of 9 g NPK fertilizer and 3 g each of Urea and KCl were given per plant at 2 weeks and 2 months after planting, respectively.

Planting was done in April and harvesting period was in September 2017. The highest rainfall period occurred in May, June and July, with an average rainfall of 1,076 mm, average 28 rain days per month, and a relatively high humidity of 92% (Table 1). Under this condition, the plot surface and plant parts near the soil surface were submerged with water in the range of 2 to 3 months after planting.

Table 1. Climatology data during the experiment

Month	Rainfall (mm)	Number of rainy days	Solar radiation (%)	Average humidity (%)
March	143	23	57	83
April	129	26	65	85
May	753	29	40	91
June	1,430	29	2	93
July	1,046	27	32	92
August	452	29	28	88
September	501	25	33	87

Remarks: Source: Meteorology Climatology and Geophysic Board - Pattimura Meteorology Station, 2017

The water level began to decrease in line with the decrease of rainfall. Observations of vegetative characters were done involving four sided plants at 4 months after planting involving number of green leaves, individual leaf area (cm^2), leaf area per plant (cm^2), leaf area index (LAI), stem length (cm), internode length (cm) and number of primary branches. The observations of yield components and yield of four middle plants number of rumbers per plant, tuber length (cm), tuber diameter (cm), individual tuber weight (g), and tuber weight per plant or yield (g). Yield component and yield data were transformed with square root (SQRT data + 0.5) before the analyses of variance. The estimation of the genetic parameters included: (a) genotypic coefficient of variation (CVg) and phenotypic coefficient of variation (CVp), (b) heritability (h^2) that was categorized as low when h^2 was <20%, moderate when h^2 was 20-50% and high when h^2 was >50% (Singh & Chaudhary, 1977), (c) genetic advance (GA) and the percentage of genetic advance based on average (GAM), as used by Agrawal & Kumar (2017) and Badu, Ashok, Kiran Patro, & Sasikala (2017) at k= selection diferential 5%=2.06, that was categoried as low (<10%), moderate (10-20%) and high (>20%), and (d) genotypic correlation coefficient ($r_{g(xy)}$) and phenotypic correlation coefficients ($r_{p(xy)}$) with t test for the significance of the correlation test (Singh & Chaudhary, 1977).

$$CV_g = \frac{\sqrt{\sigma^2 g}}{\bar{x}} \quad \text{.......... 1)}$$

$$CV_p = \frac{\sqrt{\sigma^2 p}}{\bar{x}} \quad \text{.......... 2)}$$

$$h^2 = \frac{\sigma^2 g}{\sigma^2 p} \times 100\% \quad \text{.......... 3)}$$

$$GA = k \cdot \sigma_p \cdot h^2 \quad \text{.......... 4)}$$

$$GAM = \frac{GA}{\bar{x}} \times 100\% \quad \text{.......... 5)}$$

$$r_{g.(xy)} = \frac{Cov_{g(xy)}}{\sqrt{(\sigma^2_{gx})(\sigma^2_{gy})}} \quad \text{.......... 6)}$$

$$r_{p(xy)} = \frac{Cov_{p(xy)}}{\sqrt{(\sigma^2_{px})(\sigma^2_{py})}} \quad \text{.......... 7)}$$

$$t = r\sqrt{\frac{n-2}{1-r^2}} \quad \text{.......... 8)}$$

Where:

σ^2_g: genotypic variance; σ^2_p:phenotypic variance; $\bar{x}$: all treatment mean; k: diferensial seleksi; $\sigma_{p:}$ standar phenotypic standard error; $r_{p(xy)}$: phenotypic correlation coefficient of character x and character y; $r_{g(xy):}$ genotypic correlation coefficient of character x and character y; Cov_p: phenotypic covariance; Cov_g: peragam genotypic covariance; t: value of correlation significant test (t_{table} n, α=5% and 1%); r: number of replicates, n: number of treatments.

RESULTS AND DISCUSSION

Genetic Performance Based on Vegetative Characters under Water Stress

The tested sweet potato clones showed high genetic diversity based on the genotypic coefficient of variation (CVg) as well as the phenotypic coeficient of variation (CVp). The criteria for CVg values of vegetative characters and yield component and yield were determined based on the coefficient value of the absolute genotypic variation of 32.85 as the 100% relative value (Febrianto, Wahyu, & Wirnas, 2015). The CVg values in this study were categorized into: high (24.64 ≤ x ≤ 32.85), moderately high (16.43 ≤ x ≤ 24.64), slightly low (8.21 ≤ x ≤ 16.43) and low (0 ≤ x ≤ 16.43). This method was also performed on CVp with an absolute value of 36.89 as 100% relative value. Similar basis was also used for the CVp of the vegetative characters as well as yield component and yield characters with an absolute value of 36.89 as the 100% relative value. The categories of CVp were high (27.67 ≤ x ≤ 36.89), moderately high (18.45 ≤ x ≤ 27.67), slightly low (9.23 ≤ x ≤ 18.45), and low (0 ≤ x ≤ 8.21).

All the vegetative characters showed CVg in the categories of moderately to high, except for the number of branches per plant. The CVp in all observed characters were falled into categories of moderate high to high (Table 2). The characters with high CVg and CVp can used as indicators for parental selection, in that reflected variations in response to water stress. Studied in sugarcane, Agrawal & Kumar (2017) observed number of shoot at the plant age of 120 days and plant height at 240 and 360 days of age representing high CVg and CVp. These indicated that the features were important in evaluating sugarcane clones tolerance to waterlogging.

The results of this study also showed that CVp values of all vegetative characters were higher than the CVg values. The value of phenotypic coefficient variation (CVp) that were greatly different from CVg indicated that environmental conditions affected the diversity of sweet potato clones,as also reported by Baafi et al. (2016) and Denton & Nwangburuka (2011). Other reports also confirmed higher CVp values than CVg values (Baafi et al., 2016; Denton & Nwangburuka, 2011; El Gendy & Samaa-Abd Khalik, 2014; Wera, Yalu, Ramakrishna, & Deros, 2015). However, El Gendy & Samaa-Abd Khalik (2014) obtained a small difference between CVg and CVp in several characters of sweetpotato indicating that the environment had a limited effect on the characters. Based on the description, the improvement of sweet potato in this research should be done on vegetative characters that have CVg at moderately high to high categories (Table 2), due to genetic factors affecting the variations of these characters.The vegetative characters included in this category were number of green leaves, individual leaf area, leaf area per plant, leaf area index, stem length, and stem internode length (Table 2).

Other genetic parameters that also play an important role to facilitate selection work in plant improvement are heritability and genetic advance mean (GAM). In this study, the six vegetative characters including number of leaves, individual leaf area, leaf area per plant, leaf area index, stem length and internode length, had moderate to high heritability high GAM and CVg, which could become selection indicators for resistance to water stress (Table 2). Characters with high heritability and GAM indicate the great influence of genetic factors and the magnitude of genetic progress on the characters that can be derived into their offsprings. The estimated heritabilities mean the heritabilities in a broad sense, so that the genes that controled the characters could not be determined specifically. However, since the characters studied were quantitative characters, it could be assumed that there was an effect of the additive genes (Denton & Nwangburuka, 2011). According to Wera, Yalu, Ramakrishna, & Deros (2015), heritability and genetic progress that are categorized as high are important as predicting tools for individual selection. Agrawal & Kumar (2017) obtained the number of sugarcane shoots at 120 days, the height of plants at 240 and 360 days and the single cane weights had high heritability and GAM, so direct selection could be made to these characters.

Genetic Performance Based on Yield Component and Yield under Water Stress

The results of CVg and CVp analysis showed that the sweet potato clones had a moderately high to high variation on the two characters of the yield components, namely number of tubers and individual tuber weight, and yield or tuber fresh weight per plant (Table 3). Sweet potato clones under water stress conditions showed high phenotypic and genetic variation in these three quantitative characters. Characters with high phenotypic variation followed by high genetic variation will be more efficient and effective in selection work for plant improvement, including in sweet potato.

It was also found that there was a large difference between CVp and CVg values on all yield and yield component characters. The large difference between these two genetic parameters showed the contribution of environmental influences to phenotypic variation, as found also in the character of corn ear weight and yield (Ogunniyan & Olakojo, 2014). In the case like this, CVg in a high category will be more appropriately used as a genetic criterion to determine the variation of a character for crop improvement. The genetic coefficient of variation (CVg) in the category of quite high to high was obtained in the character of number of tubers and the individual tuber weight (Table 3). Baafi et al. (2016) found a high coefficient of variation on tuber weight and some other characters in sweet potatoes. According to them, characters with high variations would be suitable for accession selection for desirable characteristics.

Table 2. Genetic paramaters of vegetative characters of sweet potato clones

Vegetative characters	CV_g (%) CV_p	Category of CV_g CV_p	Heritability (h^2)	Category of h^2	GAM (%)	Category of GAM
Green leaf number	22.77	Moderately high	0.69	High	47.39	High
	33.79	High				
Individual leaf area	28.53	High	0.84	High	53.86	High
	31.12	High				
Leaf area per plant	22.78	Moderately high	0.45	Moderate	31.96	High
	33.73	High				
Leaf area index	27.76	High	0.45	Moderate	31.32	High
	33.34	High				
Stem length	32.85	High	0.79	High	60.03	High
	36.89	High				
Internode length	20.31	Moderately high	0.80	High	37.45	High
	22.72	Moderately high				
Branch number	15.55	Slightly low	0.40	Moderate	21.26	High
	23.46	Moderately high				

Remarks: CV_g: genotypic coeficient of variation, CV_p: fenotypic coeficient of variation, GAM: genetic advance mean

Table 3. Genetic paramaters of yield component and yield characters of sweet potato clones

Yield component characters	CV_g (%) CV_p	Category of CV_g CV_p	Heritability (h^2)	Category of h^2	GAM (%)	Category of GAM
Tuber number per plant	25.50	High	0.67	High	42.96	High
	31.12	High				
Tuber length	8.05	Low	0.42	Moderate	10.79	Moderate
	12.47	Slightly low				
Tuber diameter	7.94	Low	0.29	Moderate	8.83	Low
	14.79	Slightly low				
Individual tuber weight	19.42	Moderately high	0.43	Moderate	26.33	High
	29.72	High				
Tuber fresh weight per plant	24.67	High	0.47	Moderate	34.89	High
	36.04	High				

Remarks: CV_g: genotypic coeficient of variation, CV_p: fenotypic coeficient of variation, GAM: genetic advance mean

The result of heritability analysis on five yield component characters revealed four characters with medium heritability, and only tuber number per plant had a high heritability (Table 3). Based on these results, number of tubersper plant is a good indicator for selecting sweet potato clones that are tolerant to water stress, which is shown through the high heritability and GAM values compared to other characters. Similar findings was also reported by Lestari, Hapsari, & Sutoyo (2012). Jindal, Arora, & Ghai (2010) obtained high heritability and GAM value on number of branchesper plant, total yield per plant and fruit yield in okra, which indicated that there was an additive gene effect, and selection could be effective for those characters. In this study, besides number of tubersper plant, the other tuber characters that could be used as selection indicators under water stress were individual tuber weight and tuber fresh weight per plant, because of their high GAM and high CVg, and moderate heritability (Table 3). These characters will experience great genetic progress during their selection and genetic inheritance as compared to characters with a low to moderate GAM percentage, such as tuber diameter and tuber length. Yani, Khumaida, Ardie, & Syukur (2018) obtained moderate heritability in some cassava characters such as number of fresh tubers with economic value and plant height up to the first branch, but they had a high direct influence on tuber fresh weight per plant, so it was recommended as a character for selection in later generation.

Correlation between Characters in Sweet Potatoes under Water Stress

The results of the correlation analysis of the investigated sweet potato clones showed that number of green leaves had a high negative genotypic correlation and very significant effects to individual leaf area, but positively correlated with number of branches (Table 4). This indicated that the more leaves would contribute to the smaller the individual leaf area under water stress. Under normal conditions, the higher number of leaves per plant would increase leaf area per plant detected from high correlation with significant effects.

It was also found that the increases in individual leaf area and leaf area index (LAI) positively induced the increase of leaf area per plant, with significant to very significant effects. Individual leaf area could be used as a selection indicator in the early generation of these two characters because it was supported by a high heritability. However, what is more important to accelerate plant improvement through selection method is when the vegetative characters correlate with important characters, such as yield and yield component characters. Yani, Khumaida, Ardie, & Syukur (2018) found that plant height and stem diameter had a direct correlation with tuber fresh weight in cassava; whereas number of branchesper plant correlated with yield in *Solanum anguivi* (Denton & Nwangburuka, 2011).

Four vegetative characters that were related to yield and yield components in this study were number of leaves, individual leaf area, stem length and number of branches. Leaf number was positively, highly and very significantly correlated with the tuber diameter, so that selection of sweet potato with high number of leaves would result in greater tuber diameter. Individual leaf area was negatively, high and significantly to very significantly correlated with tuber diameter, tuber length and individual tuber weight (Table 4). These results indicated that the wider the individual leaves, the lower the values of three yield components under water stress. Stem length was also negatively and significantly correlated with tuber diameter, suggesting that selection of sweet potato clones with long stems would contribute to the decrease in tuber diameter. It was also suggested that selection of sweet potato clones with smaller individual leaves would give effects on the increases of tuber length, tuber diameter, individual tuber weight, whereas selection of sweet potato clones with short stems would increase tuber diameter. Number of primary branches positively, significantly and very significantly correlated with tuber diameter and tuber yield. Bassey, Effiong, & Aniezi (2019) found that number of branches was positively correlated with tuber diameter but it did not correlate with tuber yield. A vegetative character may not be an unimportant character but can be an indicator of selection for yield components and yield if both have a high and significant correlation coefficient. In this study, sweet potato vegetative characters, including high number of leaves, small individual leaf size, short stems and high number of primary branches might be recommended as selection indicators for increasing tuber diameter, tuber length, individual tuber weight and yield under water stress. The characters that became the selection indicators for this yield components needed to be supported also by moderate to high heritability and high GAM. Of the four vegetative characters, individual leaf area with narrow leaf size phenotype were more effective to be used as a selection indicator because it would increase simultaneously three characters of yield components, namely tuber diameter, tuber length and individual tuber weight.

The results of the correlation analyses on the characters of yield components and yield showed that tuber diameter could become a selection indicator to increase tuber length, individual tuber weight and tuber weight per plant (yield) because of it has positive, high and very significant correlation (Table 4). Also, selection for tuber length had effects on the increase of individual tuber weight and yield. The two characters, however, had GAM with low and moderate categories (Table 3), so that they were not useful as a selection indicator. Individual tuber weight character could be used as a selection indicator for tuber diameter and tuber length, because of it has positive, high and very significant correlation (Table 4) and also high GAM yet with moderate heritability. Syukur, Sujiprihati, Yunianti, & Nida (2010) determined the number of chili fruits per plant as one of the selection criteria based on the genetic variation, correlation analysis and path analysis, despite the heritability in a medium category.

The results of this study showed that tuber fresh weight per plant (yield) was strongly and positively correlated, and significantly to very significantly influenced number of tubers per plant, tuber diameter, tuber length and weight per tuber (Table 4).

Table 4. Genotypic coeficient corelation of vegetative and yield characters of sweet potato clones

Characters	GLN	ILA	LAP	LAI	SL	INL	PBN	TN	TD	TL	ITW	FTYP
GLN	1	-0.73**	0.06	0.06	-0.40	-0.38	0.50*	0.10	0.60**	0.21	0.42	0.38
ILA		1	0.59**	0.58**	0.32	0.25	-0.37	-0.08	-0.67**	-0.47*	-0.59**	-0.39
LAP			1	1.00**	0.13	0.12	-0.06	0.14	-0.12	-0.29	-0.21	0.06
LAI				1	0.13	0.12	-0.06	0.14	-0.12	-0.29	-0.22	0.07
SL					1	0.85**	-0.83**	-0.27	-0.46*	-0.19	-0.26	-0.40
INL						1	-0.68**	-0.13	-0.12	-0.07	-0.03	-0.16
PBN							1	0.4	0.54*	0.34	0.39	0.59**
TN								1	0.37	-0.03	-0.03	0.81**
TD									1	1.05**	1.08**	0.91**
TL										1	0.93**	0.51*
ITW											1	0.60**
FTYP												1

Remarks: *:significant, α 5%, **: very significant, α 1%. GLN: green leaf number per plant, ILA: individual leaf area, LAP: leaf area per plant, LAI: leaf area index, SL: stem length, INL: internode length, PBN: primary branch number, TN: tuber number, TD: tuber diameter, TL: tuber length, ITW: individual tuber weight, FTYP: tuber fresh weight per plant or yield

However, only number of tubers and individual tuber weight that could be used as an selection indicator of yield as indicated by positive and very high correlation, and very significant effect (Table 4), which was also supported by moderate to high heritability and high GAM. Bassey, Effiong, & Aniezi (2019) found that number of tubers, tuber diameter and individual tuber weight correlated with fresh tuber yield, so that the improvement of these three sweet potato characters would simultaneously improved tuber yield. There were sweet potato characters that are positively, highly and significantly correlated with total tuber yield (Yahaya, Saad, Mohammed, & Afuape, 2015), and therefore, improvement of one character might directly lead to an improvement of total tuber yield.

Our current studies only characterized relations among morphological and agronomic traits with yield, under water stress. To accelerate breeding for resistance or tolerance to environmental stresses, it is necessary to include the use of molecular genetic traits as indicators. The combination of these two different approaches was very effective in differentiating or clustering the different clonal genotypes (Palumbo, Galvao, Nicoletto, Sambo, & Barcaccia, 2019), and therefore, this can be expected to be useful in a breeding program for sweet potato.

CONCLUSION

Leaf number, individual leaf area, leaf area per plant, LAI, stem length, internode length, number of tubers, individual tuber weight and yield could become indicators selecting for improvement sweet potato under water stress, based on CVg, heritabilities and GAM.The selection indicators of yield components included leaf number, small leaf size, short stems and number of branches, and the selection indicators of yield were small leaf size, higher number of branches and tubers and individual tuber weight based on correlation coefficients, heritabilities and GAM.

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