Hindawi
International Journal of Agronomy
Volume 2022, Article ID 3599272, 11 pages
https://doi.org/10.1155/2022/3599272

Research Article

Morphological and Physiological Characterization of Cassava Genotypes on Dry Land of Ultisol Soil in Indonesia

Ridwan Diaguna,[1] **Suwarto**,[1] **Edi Santosa**,[1] **Arief Hartono**,[2] **Gatot Pramuhadi**,[3] **Nunung Nuryartono**,[4] **Roza Yusfiandayani**,[5] **and Tri Prartono**[5]

[1]*Bogor Agricultural University, Faculty of Agriculture, Department of Agronomy and Horticulture, Meranti Street IPB Darmaga Campus, Bogor 16680, Indonesia*
[2]*Bogor Agricultural University, Faculty of Agriculture, Department of Soil Science and Land Resoruces, Meranti Street IPB Darmaga Campus, Bogor 16680, Indonesia*
[3]*Bogor Agricultural University, Faculty of Agricultural Engineering and Technology, Department of Mechanical and Biosystem, Meranti Street IPB Darmaga Campus, Lingkar Akademik Street IPB Darmaga Campus, Bogor 16680, Indonesia*
[4]*Bogor Agricultural University, Faculty of Economics and Management, Department of Economics Science, Agatis Street IPB Darmaga Campus, Bogor 16680, Indonesia*
[5]*Bogor Agricultural University, Science and Techno Park, Taman Kencana Street IPB Darmaga Campus, Bogor 16128, Indonesia*

Correspondence should be addressed to Ridwan Diaguna; ridwandiaguna@apps.ipb.ac.id

Received 17 December 2021; Accepted 4 April 2022; Published 11 May 2022

Academic Editor: Magdi Abdelhamid

Indonesia has a large cassava diversity, but the tolerant cultivars on drought areas have not been well recorded. Candidate mapping can begin with morphological and physiological characterization. This study aimed to map cassava's genetic diversity, determining the key phenotype to distinguish genotypes, physiological adaptation, and high-yield candidates under environmental stress. A total of 29 genotypes were clustered into 5 groups. A specific group for genotype from same site was not found. The differences and relations among genotypes were very clear, demonstrating cassava's genetic diversity in Indonesia. The key group characteristics are upward petiole orientation (G1), nine lobes (G2), prominent foliar scars (G3), winding lobe (G4), and elliptic-lanceolate (G5). A total of 19 genotypes had a number of storage root >10 storage roots, 20 genotypes had a weight of storage root >2 kg/plant, and 3 genotypes had >4 kg/plant. Morphological and physiological trait determination is relevant to contribute to high-yield cassava breeding in dry areas. The morphological characteristics of well-adapted plants were plant height, lobe characteristics, and petiole orientation, while the physiological traits were chlorophyll index, transpiration rate, and photosynthesis rate.

1. Introduction

Cassava is an important food source in Indonesia. It is cultivated on over 1.3 million hectares, both on mono and mixed crops [1], gradually spreading into the less densely populated areas in Indonesia [2]. Cassava tubers have a high nutritional content, mostly from carbohydrates, which varies depending on the specific plant part (root or leaves), geographic location, variety, plant age, and environmental conditions [3]. Carbohydrates comprise about 32%–35% of its fresh weight and 80%–90% when dry. Starch is composed of 80% carbohydrates, 3% amylopectin, and about 17% amylose, although it also contains low quantities of sucrose, glucose, fructose, and maltose [4].

So far, cassava production is dominated by small farmers with low productivity because of the low use of improved cultivars and fertilization in areas which are not always environmentally apt. In addition, climatic changes such as water deficit present looming challenges to food production, even when cassava is considered tolerant to water deficits [5].

Adaptable cultivars are an opportunity to produce high-yield cassava despite these conditions. Indonesia has a large cassava diversity, both in farmer-cultivated land and research fields. However, this diversity has not been well explored to find high-yield cultivar candidates in dry areas. This mapping of potential candidate can begin with the morphological and physiological characterization of cassava genotypes, as already shown for genetic clustering [6–8]. Morphological characteristics are important attributes that contribute to gas exchange and plant metabolism, physiological characteristics, that can increase the yield. Therefore, morphological, physiological, and yield characteristics are important selection criteria in breeding programs [9].

The present study aimed to characterize the genetic diversity of cassava in Indonesia, pinpoint the key phenotype to distinguish among genotypes and physiological adaptation signal to environmental stress, and determine a high-yield candidate in environmental stress conditions.

2. Materials and Methods

2.1. Site and Climate. The research was conducted in Jonggol Teaching and Research Farm, Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University. The site is located at 6°28′12″S 107°01′47″E. Figure 1 shows the climatic conditions during the research. The monthly averages of temperature and relative humidity were 21.4°C and 86.3%, respectively.

2.2. Experimental Design. The field experiment was arranged in randomized complete block design with five replications, and the factor, i.e., cassava genotypes, consisted of 29 genotypes. Cassava genotypes were collected from both farmers and Indonesia Legumes and Tuber Crops Research Institute (ILETRI) (Table 1).

2.3. Agronomy Management. A stem cutting (20 cm) was planted at 1×0.5 m spacing. Organic manure (about 5 ton ha^{-1}) was laid down before planting. Chemical fertilizers, such as urea, SP-36, KCl, or NPK, were applied 2 weeks after planting, at 300 kg ha^{-1}, 200 kg ha^{-1}, 150 kg ha^{-1}, and 150 kg ha^{-1}, respectively.

2.4. Morphological Characterizations. Twenty-three agro-morphological characteristics including 14 qualitative and 9 quantitative characteristics were observed (Table 2) as described by [10].

2.5. Photosynthesis Rate Measurement. The photosynthetic rate was estimated using LI-COR (LI-6400XT Portable Photosynthesis System, LI-COR Inc., Lincoln, NE, USA). The estimation was conducted to the tenth leaf from shot, five plants per genotype, and measured between 10:00 and 12:00 am.

2.6. Chlorophyll Content Measurement. Chlorophyll content was estimated using the chlorophyll content meter (CCM-200 plus, Opti-Sciences Inc.). The measurement was conducted on the tenth leaf from shoot on the tagged plant, five plant per genotypes, and measured between 10:00 and 12:00 am.

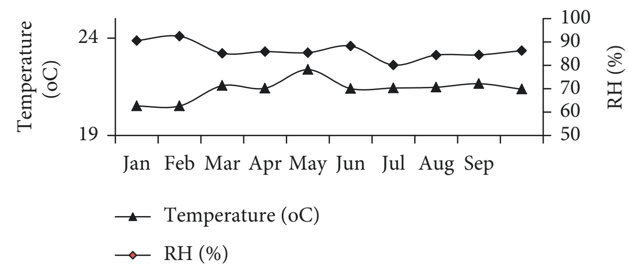

Figure 1: Climatic conditions during the research.

Table 1: Cassava genotyping materials.

Genotype	Source	Seed class
C5	Farmer, Jonggol	Not certified
IR	Farmer, Jonggol	Not certified
Vati 2	ILETRI, Malang	Breeder seed
UK 1	ILETRI, Malang	Breeder seed
Malang 4	ILETRI, Malang	Breeder seed
Adira 4	ILETRI, Malang	Breeder seed
Vati 1	ILETRI, Malang	Breeder seed
Darul Hidayah	ILETRI, Malang	Breeder seed
Adira 1	ILETRI, Malang	Breeder seed
Malang 1	ILETRI, Malang	Breeder seed
UJ 3	Farmer, Lampung	Not certified
Genjah Bayam	Farmer, Lampung	Not certified
Barokah	Farmer, Lampung	Not certified
Randu	Farmer, Lampung	Not certified
UJ 5	Farmer, Lampung	Not certified
Genjah Urang	Farmer, Lampung	Not certified
Ubi Ketan	Farmer, Lampung	Not certified
Daplang T	Farmer, Tuban	Not certified
Daplang Gureh	Farmer, Tuban	Not certified
Jegrek	Farmer, Tuban	Not certified
Kuning	Farmer, Tuban	Not certified
Ketan	Farmer, Tuban	Not certified
Manalagi	Farmer, Tuban	Not certified
Kunir	Farmer, Tuban	Not certified
Daplang G	Farmer, Gresik	Not certified
Mangu B	Farmer, Bogor	Not certified
Gajah	Farmer, Bogor	Not certified
Kubar	Farmer, Bogor	Not certified
Mangu L	Farmer, Bogor	Not certified

2.7. Data Analysis. Before data analysis, data were separated into a vegetative and a generative dataset and examined for outliers. Data are expressed as the mean ± standard error and were analyzed statistically using Minitab® Statistical Software Ver.18. Cluster analysis was performed using PBSTAT (http://www.pbstat.com/). The cluster analysis for plant genetic diversity used both quantitative and qualitative data. Clustering used Gower dissimilarity mode and neighbor joining clustering method. The correlation among characteristics was analyzed using the Pearson correlation using opensource R statistic (0.05).

Table 2: Quantitative and qualitative characteristics used to characterize cassava genotypes.

Character descriptor[1]	Score code	Sampling time
Qualitative characteristic		
Color of apical leaves	3 = light green, 5 = dark green, 7 = purplish green, 9 = purple	3 MAP[2]
Pubescence on apical leaves	0 = absent, 1 = present	3 MAP
Leaf retention	1 = very poor retention, 2 = less than average retention, 3 = average leaf retention, 4 = better than average retention, 5 = outstanding leaf retention	6 MAP
Shape of central leaflet	1 = ovoid, 2 = elliptic-lanceolate, 3 = obovate-lanceolate, 4 = oblong-lanceolate, 5 = lanceolate, 6 = straight or linear, 7 = pandurate, 8 = linear-pyramidal, 9 = linear-pandurate, 10 = linear-hostatilobalate	6 MAP
Petiole color	1 = yellowish green, 2 = green, 3 = reddish green, 5 = greenish red, 7 = red, 9 = purple	6 MAP
Leaf color	3 = light green, 5 = dark green, 7 = purple-green, 9 = purple	6 MAP
Lobe margins	3 = smooth, 7 = winding	6 MAP
Color of leaf vein	3 = green, 5 = reddish green in less than half of the lobe, 7 = reddish green in more than half of the lobe, 9 = all red	6 MAP
Petiole orientation	1 = inclined upwards, 3 = horizontal, 5 = inclined downwards, 7 = irregular	6 MAP
Prominence of foliar scars	3 = semiprominent, 5 = prominent	6 MAP
Color of stem exterior	3 = orange, 4 = greenish-yellowish, 5 = golden, 6 = light brown, 7 = silver, 8 = gray, 9 = dark brown	6 MAP
Distance between leaf scars	3 = short ≤8 cm, 5 = medium 8–15 cm, 7 = long ≥15 cm	6 MAP
Stem growth	1 = straight, 2 = zigzag	6 MAP
Number of leaf lobes	3 = three lobes, 5 = five lobes, 7 = seven lobes, 9 = nine lobes, 11 = eleven lobes	6 MAP
Quantitative characteristic		
Length of 2nd leaf lobe	Direct, meter rule	6 MAP
Width of 1st leaf lobe	Direct, meter rule	6 MAP
Width of 2nd leaf lobe	Direct, meter rule	6 MAP
Ratio of 1st leaf lobe	Direct, meter rule	6 MAP
Ratio of 2nd leaf lobe	Direct, meter rule	6 MAP
Petiole length of 1st leaf sample	Direct, meter rule	6 MAP
Petiole length of 2nd leaf sample	Direct, meter rule	6 MAP
Plant height	Direct, meter rule	Harvest
Height of first branching	Direct, meter rule	Harvest

[1]CAL, color of apical leaves; PAL, pubescence on apical leaves; LR, leaf retention; SCL, shape of central leaflet; PC, petiole color; LC, leaf color; LM, lobe margins; CLV, color of leaf vein; OP, orientation of petiole; PFS, prominence of foliar scars; CSE, color of stem exterior; DLS, distance between leaf scars; GHS, growth habit of stem; NLL, number of leaf lobes; L2LL, length of second leaf lobe; W1LL, width of first leaf lobe; W2LL, width of second leaf lobe; R1LL, ratio of first leaf lobe; R2LL, ratio of second leaf lobe; PL1LS, petiole length of first leaf sample; PL2LS, petiole length of second leaf sample; HP, height of plant; H1B, height of first branching;[2]MAP, month after planting.

3. Results and Discussion

3.1. Morphological Characteristics. This morphological characterization aimed to highlight the variations and identify germplasms for plant breeding [11]. Table 3 provides the details of 14 morphological characteristics, including the color, pattern, and shape for leaf, petiole, lobe, and stem for 29 cassava genotypes. The corresponding data were interpreted on frequency (%; number genotypes/29 genotypes; Table 4). Generally, leaf characteristics were light green color apical leaves, absent pubescence on apical leaves, average leaf retention, lanceolate and elliptic-lanceolate shape of central leaflet, light green leaf color, and green color leaf vein. Color of apical leaves was recorded light green (65.5%), purplish (6.9%), and dark green (27.6%). No genotype showed pubescence on apical leaves. The leaf retentions were average (72.4%) and better than average (27.6%). The shapes of central leaflet were elliptic-lanceolate (37.9%), obovate-lanceolate (13.8%), and lanceolate (48.3%), while the leaf colors were light green (65.5%), dark green (17.3%), and purple-green (17.2%), and color of leaf vein was green (93.1%), reddish green in less than half of the lobe (3.4%), and all red (3.4%).

Almost all genotypes had purple petiole color and horizontal orientation, smooth lobe margin, and seven lobes. The petiole color distribution was purple (65.5%), yellowish green (17.2%), greenish red (13.8%), and red (3.4%), while the orientation of petiole is both horizontal (72.4%) and inclined upwards (27.6%). The lobe margin was smooth (65.5%) and winding (34.5%), while the number of leaf lobes was seven lobes (58.6%) and nine lobes (41.4%). Stem phenotypes are large, prominent of foliar scars, silver and green-yellowish stem exterior, medium-long distance between leaf scars, and straight kinds of growth habit.

Table 3: Phenotype of cassava genotype in Indonesia.

Genotypes	Characteristics[1]													
	CAL	PAL	LR	SCL	PC	LC	LM	CLV	OP	PFS	CSE	DLS	GHS	NLL
Genjah Bayam	3	1	3	5	9	5	3	9	1	5	7	5	1	7
Malang 1	3	1	3	5	2	3	3	3	1	5	7	5	1	7
Adira 4	3	1	3	5	5	3	3	3	3	5	7	5	1	9
UJ 3	3	1	3	5	9	5	3	3	3	5	7	5	1	9
UK 1	3	1	3	5	9	3	7	3	3	5	7	3	1	9
Mangu L	7	1	3	2	9	3	3	3	3	5	4	3	1	7
Darul Hidayah	3	1	3	2	9	3	3	3	1	5	7	3	1	9
Daplang Gureh	3	1	3	2	9	3	3	3	1	3	7	5	1	9
Malang 4	3	1	3	5	9	3	3	3	1	5	7	5	1	9
Daplang Tuban	5	1	3	2	9	3	3	3	3	5	7	5	1	9
Mangu B	3	1	3	2	9	3	3	3	1	5	4	3	1	9
Gajah	3	1	3	2	9	3	3	5	3	5	4	3	1	9
Kuning	5	1	3	5	9	3	3	3	3	3	6	5	1	7
Barokah	3	1	4	5	9	3	3	3	3	3	5	5	1	7
Manalagi	5	1	4	5	5	3	7	3	3	5	4	5	1	7
Adira 1	5	1	4	5	9	5	3	3	3	5	3	5	1	7
Daplang G	7	1	4	3	9	5	7	3	3	5	4	5	1	7
Kunir	3	1	3	5	9	5	7	3	3	3	4	5	1	7
Vati 1	3	1	4	5	9	7	7	3	3	5	7	3	2	7
Jegrek	5	1	3	5	5	7	7	3	3	5	4	5	1	9
IR Jonggol	3	1	3	3	2	7	7	3	3	5	4	3	1	7
C5 Jonggol	3	1	3	3	2	7	7	3	3	5	4	3	1	9
UJ 5	3	1	4	3	2	7	7	3	3	3	7	3	1	9
Vati 2	3	1	4	5	2	3	3	3	1	5	4	3	1	7
Randu	5	1	4	2	7	3	3	3	3	5	7	7	1	7
Genjah Urang	3	1	3	2	9	3	7	3	1	5	6	3	1	7
Ubi Ketan	5	1	3	2	9	3	3	3	3	5	7	7	2	7
Ketan	3	1	3	2	5	3	3	3	3	3	9	5	1	7
Kubar	5	1	3	2	9	3	3	3	3	5	4	3	1	7

[1]CAL, color of apical leaves; PAL, pubescence on apical leaves; LR, leaf retention; SCL, shape of central leaflet; PC, petiole color; LC, leaf color; LM, lobe margins; CLV, color of leaf vein; OP, orientation of petiole; PFS, prominence of foliar scars; CSE, color of stem exterior; DLS, distance between leaf scars; GHS, growth habit of stem; NLL, number of leaf lobes.

Prominence of foliar scars was both prominent (79.3%) and semiprominent (20.7%). The color of stem exterior was silver (44.8%), green-yellowish (37.9%), and others. The distribution of distance between leaf scars was short (41.4%), medium (51.7%), and long (6.9%), while the kinds of growth habit were straight (93.1%) and zigzag (6.9%).

Table 5 provides the quantitative evaluation of the characteristics of the 29 genotypes. Malang 1 and UJ 5 were the tallest that are about 280 and 270 cm, respectively. In contrast, the smallest, about 160 cm, was identified on Barokah. Twenty genotypes have a plant height of more than 2 m, while about 9 genotypes have height of less than 2 m. Ten genotypes were recorded with no branching, while 19 genotypes were recorded to have branching. The height of first branching range about 0.2–2 m, whereas the highest first branching was recorded on Adira 1 about 2 m, followed by Kubar about 1.1 m, and other genotypes height of first branching mostly were obtained about 0.2–0.6 m. The shortest petiole length was recorded on Kunir, Genjah Urang, and Vati 2 (about 27 cm). In contrast, the longest petiole length was recorded on Malang 4, Daplang Gureh, and Mangu (about 44 cm). Leaf lobe characteristics including length, width, and ratio were recorded as about 17–25 cm, 4–7 cm, and 3–5 cm, respectively.

3.2. Genotype Clustering. Morphological classification is important in plant breeding to emphasize the variability and relationships between genetic lines. Accessions sharing many similarities are closely related [11]. Conversely, accessions showing many differences show distant relationships [12]. The characterization of genetic diversity by morphological characteristic is a cheap and proven method [6,7] that also shows a significant correlation to agronomic traits that could be used to evaluate the potential production and can be used in plant breeding [8].

Similarity analysis showed that the genotypes were clustered on five groups (Figure 2, Table 6). G1 consists of two genotypes, i.e., Genjah Bayam and Malang 1, while G2 consists of ten genotypes, i.e., Adira 4, UJ 3, UK 1, Mangu L, Darul Hidayah, Daplang Gureh, Malang 4, Daplang Tuban, Mangu B, and Gajah. G3 consists of two genotypes, i.e., Kuning and Barokah. G4 clusters nine genotypes, namely, Manalagi, Adira 1, Daplang Gresik, Kunir, Vati 1, Jegrek, IR Jonggol, C5 Jonggol, and UJ 5. G5 consists of six genotypes, namely, Ubi Ketan, Kubar, Genjah Urang, Vati 2, Ketan, and Randu.

Group 1 showed similarity on most qualitative characteristics, except for PC, LC, and CLV. Similarly, group 2 showed similarity on most qualitative characteristics, except

Table 4: Genotypic frequency of cassava in Indonesia.

Characteristics[1]	Phenotypes	Number	Frequency (%)
CAL	Light green	19	65.5
	Dark green	8	27.6
	Purplish	2	6.9
	Purple	0	0.0
PAL	Absent	29	100.0
	Present	0	0.0
LR	Very poor retention	0	0.0
	Less than average retention	0	0.0
	Average leaf retention	21	72.4
	Better than average retention	8	27.6
	Outstanding leaf retention	0	0.0
SCL	Ovoid	0	0.0
	Elliptic-lanceolate	11	37.9
	Obovate-lanceolate	4	13.8
	Oblong-lanceolate	0	0.0
	Lanceolate	14	48.3
	Straight or linear	0	0.0
	Pandurate	0	0.0
	Linear-pyramidal	0	0.0
	Linear-pandurate	0	0.0
	Linear-hostatilobalate	0	0.0
PC	Yellowish green	0	0.0
	Green	5	17.2
	Reddish green	0	0.0
	Greenish red	4	13.8
	Red	1	3.4
	Purple	19	65.5
LC	Light green	19	65.5
	Dark green	5	17.3
	Purple-green	5	17.2
	Purple	0	0.0
LM	Smooth	19	65.5
	Winding	10	34.5
CLV	Green	27	93.1
	Reddish green in less than half of the lobe	1	3.4
	Reddish green in more than half of the lobe	0	0.0
	All red	1	3.4
OP	Inclined upwards	8	27.6
	Horizontal	21	72.4
	Inclined downwards	0	0.0
	Irregular	0	0.0
PFS	Semiprominent	6	20.7
	Prominent	23	79.3
CSE	Orange	1	3.4
	Greenish-yellowish	11	37.9
	Golden	1	3.4
	Light brown	2	6.9
	Silver	13	44.8
	Gray	0	0.0
	Dark brown	1	3.4
DLS	Short	12	41.4
	Medium	15	51.7
	Long	2	6.9
GHS	Straight	27	93.1
	Zigzag	2	6.9

Table 4: Continued.

Characteristics[1]	Phenotypes	Number	Frequency (%)
NLL	Three lobes	0	0.0
	Five lobes	0	0.0
	Seven lobes	17	58.6
	Nine lobes	12	41.4
	Eleven lobes	0	0.0

[1]CAL, color of apical leaves; PAL, pubescence on apical leaves; LR, leaf retention; SCL, shape of central leaflet; PC, petiole color; LC, leaf color; LM, lobe margins; CLV, color of leaf vein; OP, orientation of petiole; PFS, prominence of foliar scars; CSE, color of stem exterior; DLS, distance between leaf scars; GHS, growth habit of stem; NLL, number of leaf lobes.

Table 5: Quantitative characteristics of 29 cassava genotypes in Indonesia at 6 months after planting.

Genotypes	Height of plant (cm)	Height of first branching (m)	Petiole length (cm)	Length of leaf lobe (cm)	Width of leaf lobe (cm)	Ratio of leaf lobe
C5	200	0.40	31.16	24.07	5.09	4.73
IR	200	0.25	34.98	17.87	5.82	3.07
Vati 2	230	0.54	27.83	16.29	4.37	3.73
UK 1	200	0.00	43.85	21.71	5.93	3.66
Malang 4	200	0.00	44.44	22.42	5.98	3.75
Adira 4	200	0.00	37.53	22.48	5.34	4.21
Vati 1	250	0.20	38.97	21.48	5.52	3.89
Darul Hidayah	200	0.25	40.61	21.61	5.75	3.76
Adira 1	210	2.00	29.21	21.02	5.52	3.81
Malang 1	280	0.25	40.32	24.96	6.74	3.70
UJ 3	230	0.00	35.53	20.39	5.94	3.44
Genjah Bayam	170	0.00	36.03	22.24	5.23	4.26
Barokah	160	0.00	43.52	25.41	4.94	5.15
Randu	200	0.00	33.36	23.05	6.55	3.52
UJ 5	270	0.30	39.74	25.80	6.17	4.18
Genjah Urang	180	0.25	27.26	18.71	5.15	3.64
Ubi Ketan	170	0.60	30.16	17.70	5.01	3.53
Daplang Tuban	200	0.00	39.12	21.35	5.95	3.59
Daplang Gureh	220	0.00	44.06	27.02	7.17	3.77
Jegrek	210	0.25	36.71	21.86	5.72	3.82
Kuning	200	0.35	42.07	27.96	6.04	4.64
Ketan	190	0.16	32.02	19.15	6.11	3.14
Manalagi	200	0.25	35.31	23.02	5.93	3.88
Kunir	180	0.00	27.03	20.11	4.95	4.07
Daplang G	170	0.23	29.15	20.90	4.92	4.25
Mangu B	190	0.10	43.06	20.32	5.87	3.46
Gajah	240	0.10	43.17	21.10	6.08	3.47
Kubar	190	1.10	28.82	19.85	5.35	3.71
Mangu L	220	0.43	44.09	20.16	6.04	3.34

CSE, DLS, CAL, SCL, and OP. Group 3 shared all qualitative characteristics, except CAL, LR, and CSE. In contrast, in group 4, similarities were found only for PAL, CLV, and OP characteristics and in group 5 on PAL, LC, CLV, GHS, and NLL. To distinguish among groups, ≥1 characteristics need to be used. However, the number of leaf lobes could be a specific characteristic to differentiate for group 2, prominence of foliar scars for group 3, petiole orientation for group 1, lobe margin for group 4, and shape of central leaflet for group 5.

Despite the lack of specific groups in same site genotypes, differences and relationships among genotypes were clear, indicating the genetic diversity of cassava germplasm in Indonesia. Nevertheless, lobe characteristics, prominence of stem, and petiole orientation can distinguish the genotypes in each group. The key characteristics of groups include inclined upward orientation of petiole (G1), nine lobes (G2), prominent foliar scars (G3), winding lobe (G4), and elliptic-lanceolate (G5). The large variations of quantitative characteristics were evaluated among the genotypes. The

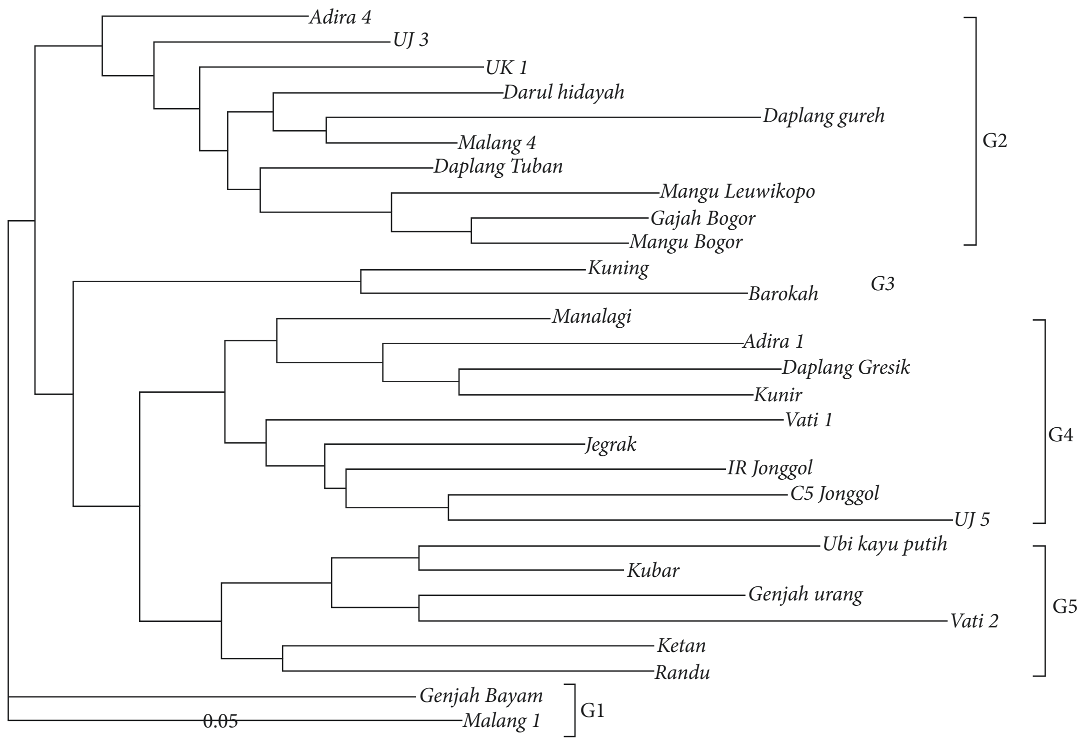

Figure 2: A dendrogram cluster of 29 cassava genotypes.

Table 6: Genotype groups of cassava based on 24 qualitative and quantitative characteristics.

Group	Total	Genotypes
G1	2	Genjah Bayam and Malang 1
G2	10	Adira 4, UJ 3, UK 1, Mangu L, Darul Hidayah, Daplang Gureh, Malang 4, Daplang Tuban, Mangu B, and Gajah
G3	2	Kuning and Barokah
G4	9	Manalagi, Adira 1, Daplang Gresik, Kunir, Vati 1, Jegrek, IR Jonggol, C5 Jonggol, and UJ 5
G5	6	Ubi kayu Putih (Ubi Ketan), Kubar, Genjah Urang, Vati 2, Ketan, and Randu

environmental and genetic effect was suspected to lead their variations. The effect of both interactions was important to cassava traits [13].

3.3. Physiological Characteristics: Chlorophyll Index and Photosynthetic Rate. Chlorophyll index (CI), photosynthesis rate, and transpiration rate (TR) among genotypes were varied (Figure 3, Table 7). Adira 1 had the highest CI (46.5), whereas Mangu L had the lowest (10.0). Among the groups, the highest CI was recorded in G5 and the lowest in G3, whereas CI in groups G1, G2, and G4 was 36.2, 27.7, and 27.0, respectively. Gas exchange activity was identified by photosynthetic and transpiration rates. G5 also showed the highest photosynthetic rate (33.4), while G2 was the lowest (27.8), whereas photosynthetic rate of groups G1, G3, and G4 was 31.7, 28.1, and 28.1, respectively. Mangu L had the lowest photosynthetic rate (22.6), while Genjah Bayam (32.6) had the highest. TR did not differ much among groups, i.e., G1 (6.4), G2 (6.2), G3 (5.7), G4 (5.8), and G5 (5.7). Daplang Gureh and Vati 2 showed the highest transpiration rate and Ubi Ketan the lowest.

Physiological changes follow morphological changes in plants responding to environmental stress [14]. As reported by [15], CI can serve as adaptation indicator to environmental stress. CI is involved in gas exchange functions such as photosynthesis and transpiration, and [16] considered it as a possible indirect indicator of photosynthetic capacity. Environmental stress could significantly decrease CI, indicating impaired photosynthesis [17]. It is difficult for plant to escape the environment in which they are currently growing, so they must passively adapt to changing or even adverse conditions; therefore, evolution can occur in the process of their long-term adaptation [18].

3.4. Yield Characteristics. Yield characteristics consider both storage units and storage root weight. Figure 4 shows both characteristics for all genotypes. The highest weight corresponded to UK 1 (5 kg) and the lowest to Manalagi (1.1 kg), while Darul Hidayah (14) had the highest number of storage roots and Daplang G (6) the lowest. Eight genotypes had a storage root weight >3.5 kg plant^{-1}, namely, Ketan, IR, Kunir, Mangu B, UK 1, UJ 3, Malang 1, and Genjah Bayam.

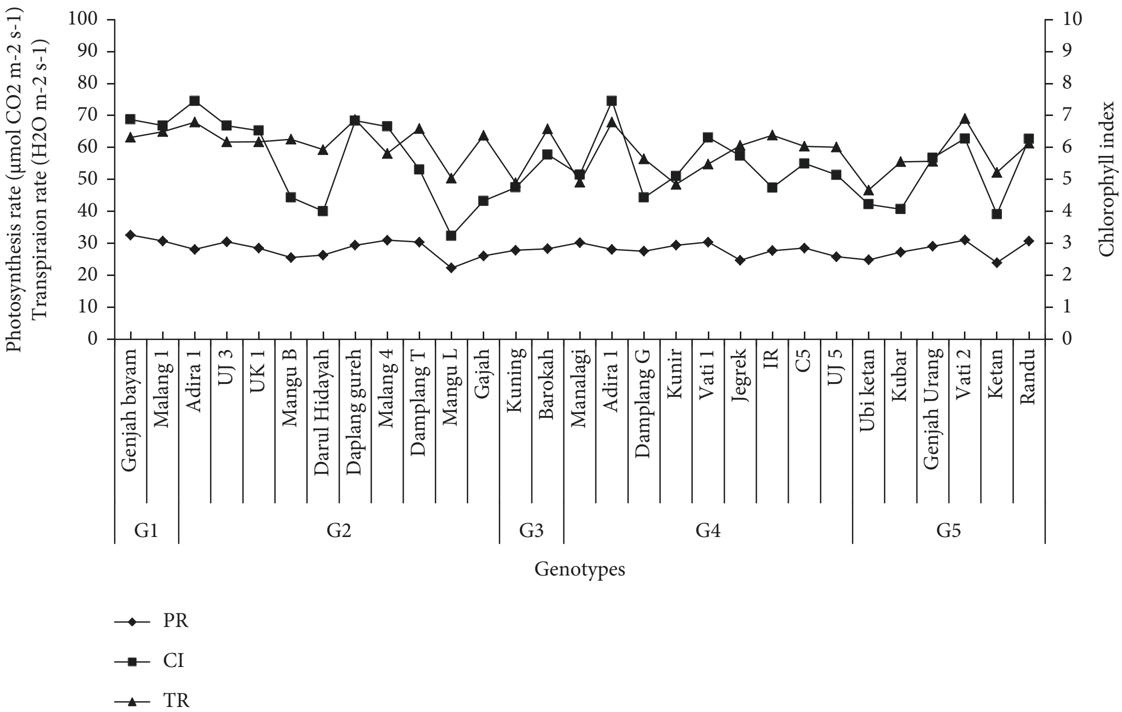

Figure 3: Photosynthesis rate and chlorophyll index of 29 cassava genotypes in Indonesia. PR, photosynthetic rate; CI, chlorophyll index; TR, transpiration rate.

Table 7: Photosynthetic rate and chlorophyll index pattern of cassava groups.

Group	*N*		Chlorophyll index	Photosynthesis rate (μmol m^{-2} s^{-1})	Transpiration rate (mmol H_2Om^{-2} s^{-1})
		Min	30.9	29.2	4.9
G1	2	Max	46	33.5	7.1
		Average	36.2 ± 5.12	31.7 ± 1.6	6.4 ± 0.7
		Min	6.5	17.5	3.7
G2	10	Max	67.7	34.8	7.4
		Average	27.7 ± 13.2	27.8 ± 4.5	6.2 ± 0.8
		Min	8.7	23	3.7
G3	2	Max	33.6	30	7.2
		Average	24.6 ± 8.2	28.1 ± 2.0	5.7 ± 1.2
		Min	9.7	17.3	3.6
G4	9	Max	67.7	33.5	7.4
		Average	27.0 ± 11.0	28.1 ± 3.9	5.8 ± 1.0
		Min	4	20.6	3.3
G5	6	Max	48.1	33.4	7.4
		Average	48.1 ± 11.2	33.4 ± 3.8	5.7 ± 0.9

More than half of all genotypes (19) had >10 storage roots (Table 8). G2 showed the highest weight and biggest number of storage roots, i.e., 3.1 kg plant^{-1} and 11.5 storage root plant^{-1}, respectively. G4 showed the lowest weight of storage root (1.1 kg plant^{-1}) and G3 the lowest number of storage roots (8.5 plant^{-1}). NSR/P did not significantly differ among groups.

The number and weight of storage root yield attributes regulate the sink capacity. Nineteen genotypes had >10 storage roots. This indicates that some genotypes can be potential candidates for dry land conditions. Under water deficit conditions, almost all cassava genotypes resulted in <10 storage roots and about 5–8 root storage plant^{-1} [19]. In addition, 20 genotypes had >2 kg plant^{-1} storage root, with 3 having >4 kg plant^{-1}. Since, the weight of storage root of cassava in dry land is usually 1–1.8 kg plant^{-1} [19]. This result shows the characteristic candidates of high production in dry land.

3.5. Correlation among Characteristics. The correlation among characteristics was analyzed to determine relationships between characteristics. Two signs are positively correlated if one increases quantitatively and other decreases quantitatively or if both decrease [12]. The correlation among characteristics was low to moderate (Figure 5).

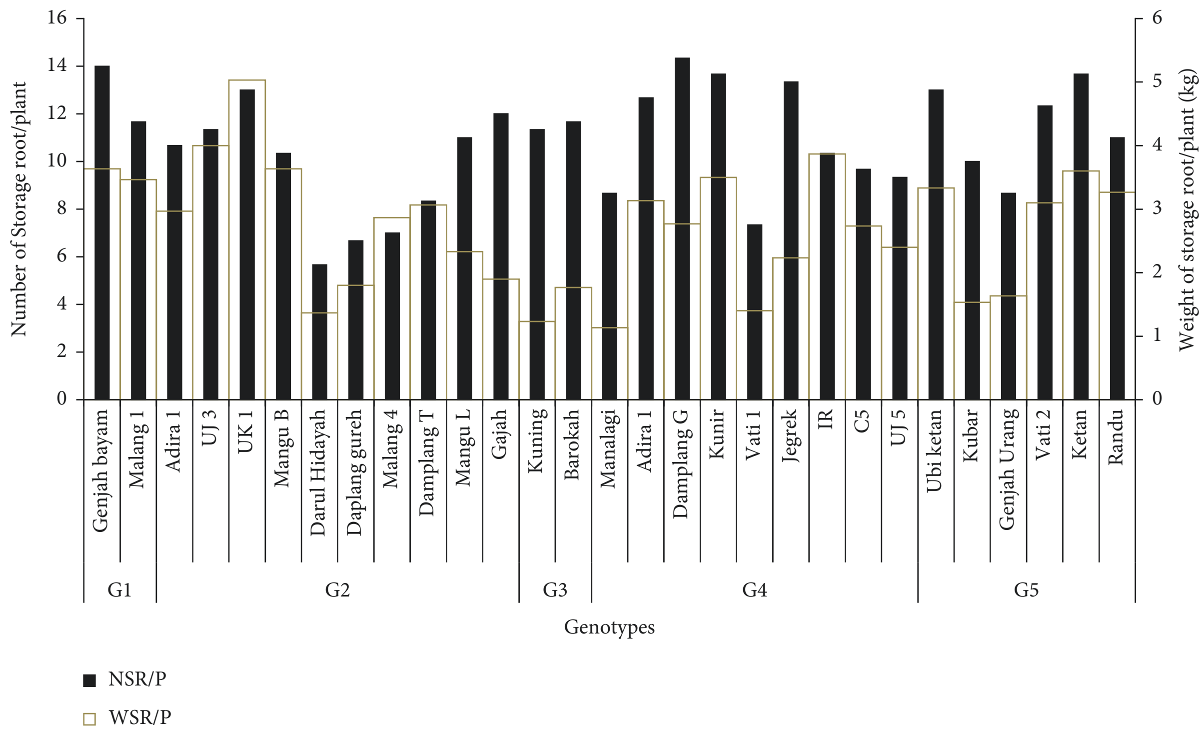

Figure 4: Yield characteristics of genotypes cassava in Indonesia. NSR/P, number of storage root/plant; WSR/P, weight of storage root/plant.

Table 8: Yield characteristics of genotype groups.

Group	N	WSR/P		NSR/P	
		Range	Average	Range	Average
G1	2	3.5 – 3.6	2.1 ± 0.1	11.7 – 14.0	11.0 ± 1.6
G2	10	1.4 – 5.0	3.1 ± 1.1	5.7 – 13.0	11.5 ± 2.5
G3	2	1.2 – 1.8	2.2 ± 0.4	11.3 – 11.7	8.5 ± 0.2
G4	9	1.1 – 3.9	2.5 ± 0.9	7.3 – 14.3	10.2 ± 2.5
G5	6	1.5 – 3.6	2.8 ± 0.9	8.7 – 13.7	11.0 ± 1.9

NSR/P, number of storage root/plant; WSR/P, weight of storage root/plant.

Moderate correlations were found for HP ∗ PL, HP ∗ PR, CI ∗ PR, CI ∗ WSR/P, and NSR/P ∗ WSR/P, while low correlations were identified for HP ∗ TR, PL ∗ TR, PL ∗ CI, PL ∗ NSR/P, PL ∗ WSR/P, CI ∗ TR, and CI ∗ WSR/P. Vegetative growth as indicated by both HP and PL affects photosynthesis and transpiration, whereas higher plant will increase photosynthesis, and a longer petiole would increase transpiration. Since CI affects photosynthetic, TRs further support to increase the weight of storage root. Negative correlations between transpiration rate and yield and photosynthesis rate and NSR/P were found as well.

Positive and moderate correlations among CI, photosynthesis rate, transpiration rate, and storage root weight could be considered storage root accumulations. The correlation of plant growth to physiological activities [20], plant growth to yield characteristics [21], and physiological

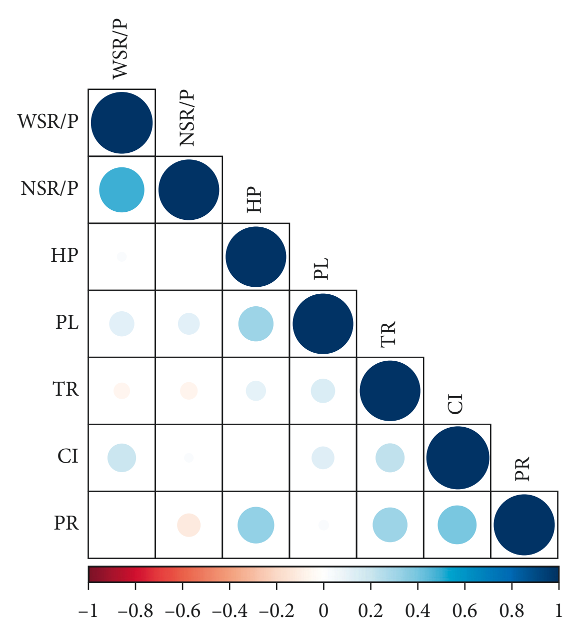

Figure 5: Correlation among characteristics of cassava genotypes in Indonesia. Positive correlations are displayed in blue, and negative correlations are displayed in red. Color intensity and circle size are proportional to the correlation coefficients. PR, photosynthetic rate; CI, chlorophyll index; TR, transpiration rates; HP, height of plant; PL, petiole length; NSR/P, number of storage root/plant; WSR/P, weight of storage root/plant.

activities to yield [22], among yield characteristics [23], had been reported. Morphological and physiological description is an important first step for successful high-yield cassava breeding for dry areas. The morphological characteristics of well-adapted plants were plant height, lobe characteristics, and petiole orientation, and the physiological traits were CI, TR, and photosynthesis rate.

4. Conclusions

The initial 29 genotypes were clustered in 5 groups. A specific group for genotype from same site was not found. The differences and relations among genotypes were very clear. It indicates the presence the genetic diversity of cassava germplasm in Indonesia. The key characteristics of groups were upward petiole orientation (G1), nine lobes (G2), prominent foliar scars (G3), winding lobe (G4), and elliptic-lanceolate (G5). Nineteen genotypes had >10 storage roots, and 20 genotypes had >2 kg/plant of storage root, of which 3 had >4 kg/plant. The morphological and physiological traits finding was very important to early data to contribute to the successful high-yield cassava breeding for dry areas. The morphological characteristics were plant height, lobe characteristics, and petiole orientation, while the physiological traits include CI and photosynthesis rate.

Data Availability

All the data used to support the findings and conclusions of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors would like to thank the Lembaga Pengelola Dana Pendidikan (LPDP), the Ministry of Finance, the Republic of Indonesia, for supporting the research by productive research (RISPRO) grant fiscal year 2021 (PRJ-31/LPDP/2021 on 29 January 2021).

References

[1] J. Dixon, "Production and consumption of cassava in Indonesia," *Bulletin of Indonesian Economic Studies*, vol. 15, no. 3, pp. 83–106, 1979.

[2] P. Van Der Eng, "Cassava in Indonesia: a historical re-appraisal of an enigmatic food crop," *South East Asian Studies*, vol. 36, no. 1, pp. 3–31, 1998.

[3] E. M. Salvador, V. Steenkamp, and C. M. E. McCrindle, "Production, consumption and nutritional value of cassava (Manihot esculenta, Crantz) in Mozambique: an overview," *Journal of Agricultural Biotechnology and Sustainable Development*, vol. 6, no. 3, pp. 29–38, 2014.

[4] J. A. Montagnac, C. R. Davis, and S. A. Tanumihardjo, "Processing techniques to reduce toxicity and antinutrients of Cassava for use as a staple food," *Comprehensive Reviews in Food Science and Food Safety*, vol. 8, no. 1, pp. 17–27, 2009.

[5] M. A. El-sharkawy, "Drought-tolerant cassava for Africa, Asia, and Latin America," *BioScience*, vol. 43, no. 7, pp. 441–451, 1993.

[6] P. A. Asare, I. K. A. Galyuon, J. K. Sarfo, and J. P. Tetteh, "Morphological and molecular based diversity studies of some cassava (Manihot esculenta crantz) germplasm in Ghana," *African Journal of Biotechnology*, vol. 10, no. 63, pp. 13900–13908, 2011.

[7] T. F. Mezette, C. G. Blumer, and E. A. Veasey, "Morphological and molecular diversity among cassava genotypes," *Pesquisa Agropecuária Brasileira*, vol. 48, no. 5, pp. 510–518, 2013.

[8] D. I. Roslim, N. Herman, M. Sofyanti, R. Chaniago, R. Restiani, and L. Novita, "Characteristics of 22 CASSAVA (Manihot esculenta crantz) genotypes from Riau Province, Indonesia," *SABRAO Journal of Breeding and Genetics*, vol. 48, no. 2, pp. 110–119, 2016.

[9] M. A. H. Mohamed, A. A. Alsadon, and M. S. Al Mohaidib, "Corn and potato starch as an agar alternative for Solanum tuberosum micropropagation," *African Journal of Biotechnology*, vol. 9, no. 1, pp. 12–16, 2010.

[10] W. M. G. Fukuda, C. L. Guevara, R. Kawuki, and M. E. Ferguson, *Selected Morphological and Agronomic Descriptors for the Characterization of Cassava*, International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, 1st edition, 2010.

[11] I. Raden, C. C. Nugroho, and S. Syahrani, "Identification and characterization of morphological diversity of Lemba (Curculigo latifolia) in East Kalimantan, Indonesia," *Biodiversitas*, vol. 18, no. 4, pp. 1367–1376, 2017.

[12] H. U. Jan, M. A. Rabbani, and Z. K. Shinwari, "Estimation of genetic variability in turmeric (Curcuma longa l.) germplasm using agro-morphological traits," *Pakistan Journal of Botany*, vol. 44, no. 1, 2012.

[13] A. Nduwumuremyi, R. Melis, P. Shanahan, and A. Theodore, "Interaction of genotype and environment effects on important traits of cassava (Manihot esculenta Crantz)," *The Crop Journal*, vol. 5, no. 5, pp. 373–386, 2017.

[14] S. Avivi, B. R. L. Sanjaya, S. Ogita, S. Hartatik, and S. Soeparjono, "Morphological, physiological and molecular responses of Indonesian cassava to drought stress," *Australian Journal of Crop Science*, vol. 14, no. 14, pp. 1723–1727, 2020.

[15] M. Garriga, J. B. Retamales, S. Romero-Bravo, P. D. S. Caligari, and G. A. Lobos, "Chlorophyll, anthocyanin, and gas exchange changes assessed by spectroradiometry in Fragaria chiloensis under salt stress," *Journal of Integrative Plant Biology*, vol. 56, no. 5, pp. 505–515, 2014.

[16] E. Kumagai, A. Araki, and F. Kubota, "Correlation of chlorophyll meter readings with gas exchange and chlorophyll fluorescence in flag leaves of rice (Oryza sativa L.) plants," *Plant Production Science*, vol. 12, no. 1, pp. 50–53, 2009.

[17] M. G. Cayon, M. A. El-sharkawy, and L. F. Cadavid, "Leaf gas exchange of cassava as affected by quality of planting material and water stress," *Photosynthetica*, vol. 34, no. 3, pp. 409–418, 1997.

[18] Y. Wang, "Comparison of morphological and physiological characteristics in two phenotypes of a rare and endangered plant," *Photosynthetica*, vol. 54, no. 3, 2016.

[19] R. I. Leon Pacheco, M. Pérez Macias, F. C. Fuenmayor Campos, A. J. Rodríguez Izquierdo, and G. A. Rodríguez Izquierdo, "Agronomic and physiological evaluation of eight cassava clones under water deficit conditions," *Revista Facultad Nacional de Agronomia Medellin*, vol. 73, no. 1, pp. 9109–9119, 2020.

[20] S. Mwamba, P. Kaluba, D. Moualeu-Ngangue et al., "Physiological and morphological responses of cassava genotypes to fertilization regimes in chromi-haplic acrisols soils," *Agronomy*, vol. 11, no. 9, p. 1757, 2021.

[21] R. P. Diniz and E. J. de Oliveira, "Genetic parameters, path analysis and indirect selection of agronomic traits of cassava germplasm," *Anais da Academia Brasileira de Ciencias*, vol. 91, no. 3, pp. 1–11, 2019.

[22] M. A. El-Sharkawy and J. H. Cock, "Photosynthesis of cassava (Manihot esculenta)," *Experimental Agriculture*, vol. 26, no. 3, pp. 325–340, 1990.

[23] J. Adjebeng-Danquah, V. E. Gracen, S. K. Offei, I. K. Asante, and J. Manu-Aduening, "Genetic variability in storage root bulking of cassava genotypes under irrigation and no irrigation," *Agriculture & Food Security*, vol. 5, no. 1, pp. 9–12, 2016.