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Morphological characteristics and yields of several sweet potato (Ipomoea batatas L.) tubers

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Abstract. This study aims to evaluate certain tubers of new sweet potato clones for their morphological characters and yield under low input conditions in the middle highland. This study was conducted at Saree, Aceh Besar, the Province of Aceh (485 m ASL) from February to July 2015. The study used a Completely Randomized Block Design of non-factorial with 12 sweet potato clones consisting of nine clones passed by CIP-SEA Bogor, Indonesia (CIP-LSQ, CIP-1945, CIP-MAN, CIP-513, CIP-BDG, CIP-WHI-5, CIP-W86P, CIP-B9, and CIP-204), one national variety (Antin-1), and two local clones (Orange Saree and Purple Saree). The results showed that there were differences in the characters of 12 sweet potato clones in terms of their tuber shapes, skins and flesh colors. Sweet potato tuber shape being studied consisted of an oval, round and long. Tuber flesh color generally was white, cream, yellow, orange and purple. Meanwhile, CIP-1945, CIP-W86P, Local Orange Saree clones, and Antin-1 variety have orange tuber flesh. CIP-WHI5 clone has the highest number of tubers, while CIP-204 clone has the largest diameter and length of tubers, and the highest in tuber yield.

1. Introduction
Sweet potato (Ipomoea batatas L.) originated from Central America and is dispersed worldwide due to its high yield potential and wide adaptability [1]. This plant belongs to the family of Convolvulaceae and is an important food crop [2] which is widely grown in tropical, subtropical regions. Currently, there are over 6500 varieties of sweet potatoes worldwide [3] and they are basically distinguished by storage roots, skin color, flesh color, and some, by their origin.

Sweet potatoes are a good source of energy with an abundance of proteins, lipids, fiber, vitamins, and minerals as potassium [4]. They are rich in starch, which represents more than 50% of the carbohydrate components [5] which is high among other types of tubers. Sweet potato is one of the preferred crops producing the highest root dry matter content for human consumption, 70 percent of the dry weight of sweet potato is constituted by the starch content [6][7] and high dry matter content as a significant characteristic of a good sweet potato variety [8]. This plant plays a role in providing an important source of nutrition and is also used as a source of starch, alcohol and animal feed [6].

Sweet potato production in Indonesia in 2017 was 2,029 million tons with productivity of 18.36 t ha⁻¹, and a harvest area of 110.5 thousand ha, a decline in growth from the previous year [9]. The lower sweet potato production in Indonesia is caused by the reduced area of planting and the use of local varieties or clones which have low yields, have experienced a decline in quantity and quality so
that it affects the lower tuber yields. New clones that have good genetic traits should be introduced to provide higher production when compared with local clones. In addition, according to cultivars, local climatic conditions and cultural techniques also affect sweet potato production [10]. Sweet potato cultivars vary greatly in the potential yield of their tubers. An average fresh tuber yield of around 10-25 t ha<sup>-1</sup> in 16-20 weeks harvest has been obtained in many countries [11][12]. It is a plant that requires minimal cultivable supervision and can be grown all year round.

There is wide variability in tuber yields between sweet potato cultivars and between individual plants of the same cultivar, as influenced by cultivars itself, the origin of propagation material, environment, and soil factors [13]. Genetic and environmental factors influence leaf area, leaf production and abscess, leaf photosynthesis, tuber formation and development, total dry matter production, dry matter partitioning, and tuber yield [14]. In general, the formation tuber of sweet potatoes started at around 28 days after planting (DAP). At 49 DAP, 80% of the tubers can be identified. The shape of the tuber is usually round to oval with a flat to uneven surface. Sweet potato skins and tuber flesh color can be either white, cream, yellow, orange or purple [6][15] depends on the type. However, the most commonly sweet potato grown and taken for food is orange, white and cream tuber flash [16].

Sweet potatoes have different morphological characteristics such as leaves, stems, and tubers [17]. The productivity of each variety will be different even in the same environmental conditions. Therefore, the selection of suitable sweet potato varieties to be planted based on environmental conditions is very important. Sweet potato plant diversity can be studied through the identification of morphological characters and the purpose of the identification is to find out the important characteristics of plant species originating from various clones, so that it can be used as a source of genetic diversity in helping plant breeding activities. Generally, sweet potato yields in farmer's plots are low [18], due to the use of local genotypes but could be increased with the use of improving varieties [19], or new clones. The CIP-SEA clones need to be investigated further for their morphological characters and the level of their tuber yields with only organic material input in the medium highland. The aim of this study is to evaluate new sweet potato clones with morphological characters of its tubers and yield under low input conditions in the medium highland.

2. Materials and Methods

2.1. Experimental Site

The study was conducted at the Research Farm of Agricultural Extention School, Districtof Saree, in the municipality of Aceh Besar, Aceh Province, Indonesia(at the middle highland with the altitude of 7485 m above sea level, the latitude of 5°26’27” N and longitude of 95°22’37”E), which took place in February-July 2015. The Soil was analyzed at the Soil Laboratory, Bogor Agricultural University. The type of soil in this study site was Andisol. The soil texture was Sandy Clay. The soil contains 21.30% sand, 43.95% silt, and 34.75% clay. The soil with pH of 4.51 is acidity, whereas the C, N, P, and K were 2.92%, 0.29%, 5.0 ppm and 0.73 me100g<sup>-1</sup> respectively.

2.2. Planting Materials

There were 12 types of sweet potato used in this study. The type of sweet potato consisted of nine clones as introduced by the International Potato Center-South East Asia (CIP-SEA) in Bogor (CIP-LSQ, CIP-1945, CIP-MAN, CIP-513, CIP-BDG, CIP-WHI5, CIP-W86P, CIP-B9, CIP-204), national variety of Antin I (from the Legume and Tuber Research Institute in Malang City, Central Java, Indonesia), and two local Aceh clones of Saree Orange, and Saree Purple (from farmers in Saree).

2.3. Field Culture, Planting and Harvesting

The land was plowed, harrowed and ridges. Plant beds were made each with a width of 100 cm, the height of 40 cm, and length of 225 cm. The cutting (stem and shoot cuttings) of sweet potato were planted on ridges at a distance of 50 cm between ridges and 25 cm within the ridge. Cuttings of 25 cm long were planted on the bed with one cutting per hole. Poultry manure was applied one week prior to
planting with a dosage of 20 t ha\(^{-1}\). Sufficient watering was done twice a day at 8.00 am in the morning and 5 pm in the afternoon, when it was not raining. Weeding was done manually when required. Replanting was carried out at 10 days after planting. Reversal of stem was done at two and three months after planting. Plants were harvested after four months. Five plants were harvested from each plot and each treatment.

2.4. Experimental Design, Data Collection and Analysis
This study apply12 treatments with non-factorial arranged in a Randomized Complete Block Design with three replications. Morphological characteristics of tubers (the shape, skin color and flesh color of tubers), diameter (cm), and length (cm) of tubers, and tuber yield in terms of the number of tubers, fresh tuber weight per plant (g), and production of tubers (t ha\(^{-1}\)) were evaluated. The data collected were analyzed using Analysis of variance (ANOVA), and the significance of treatment means was determined using Duncan’s Multiple Range Test (DMRT) at \(p = 0.05\) probability level [20]. Data were analyzed using SPSS version 22.0.

3. Results and Discussion
3.1. Morphological Characteristics of Sweet Potato Tubers
The results showed that the 12 types of sweet potatoes were varied in their morphological characteristics: the shape of tubers, tuber skin color, and tuber flesh color. The morphological characteristics of the tubers are shown in Table 1 and Figure 1. The tuber shape of CIP-LSQ, CIP-204, Local Orange Saree, and Local Purple Saree clones are oval, while the CIP-1945, CIP-MAN, CIP-BDG, CIP-W86P clones, and Antin-1 variety are long in their shape tubers. Meanwhile, CIP-513, CIP-WHI5, and CIP-B9 have round shapes. The variety of sweet potato tubers shape was analyzed in previous studies [21][22][5]. When tubers are sold for industrial processing, the selection of cultivars, the size, and the shape of the tubers play an important role [23]. Tubers shape is an important characteristic to influence peeling and trimming efficiency during processing [24].

Table 1. Morphological characteristics of tubers from 12 types of sweet potatoes

<table>
<thead>
<tr>
<th>Types</th>
<th>Shape</th>
<th>Skin Color</th>
<th>Flesh Color</th>
<th>Diameter (cm)</th>
<th>Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIP-LSQ</td>
<td>Oval</td>
<td>Yellow</td>
<td>White</td>
<td>4.06^1</td>
<td>12.17^d</td>
</tr>
<tr>
<td>CIP-1945</td>
<td>Length</td>
<td>Reddish-Purple</td>
<td>Orange</td>
<td>3.37^d</td>
<td>12.73^e</td>
</tr>
<tr>
<td>CIP-MAN</td>
<td>Length</td>
<td>Cream</td>
<td>Cream</td>
<td>4.48^g</td>
<td>11.68^c</td>
</tr>
<tr>
<td>CIP-513</td>
<td>Round</td>
<td>Reddish-Purple</td>
<td>Cream</td>
<td>5.51^h</td>
<td>11.92^cd</td>
</tr>
<tr>
<td>Antin-1</td>
<td>Length</td>
<td>Reddish-Purple</td>
<td>Dark-Orange</td>
<td>1.92^a</td>
<td>11.87^cd</td>
</tr>
<tr>
<td>CIP-BDG</td>
<td>Length</td>
<td>Dark-Purple</td>
<td>Dark-Purple</td>
<td>2.60^b</td>
<td>11.63^c</td>
</tr>
<tr>
<td>CIP-WHI5</td>
<td>Round</td>
<td>White</td>
<td>White</td>
<td>4.45^g</td>
<td>8.50^a</td>
</tr>
<tr>
<td>CIP-W86P</td>
<td>Length</td>
<td>Rose-colored</td>
<td>Orange</td>
<td>3.07^c</td>
<td>14.78^fg</td>
</tr>
<tr>
<td>CIP-B9</td>
<td>Round</td>
<td>Cream</td>
<td>Yellow</td>
<td>5.21^b</td>
<td>10.70^b</td>
</tr>
<tr>
<td>CIP-204</td>
<td>Oval</td>
<td>White</td>
<td>White</td>
<td>6.30^1</td>
<td>16.60^g</td>
</tr>
<tr>
<td>Local Orange Saree</td>
<td>Oval</td>
<td>Orange</td>
<td>Orange</td>
<td>3.13^c</td>
<td>12.12^d</td>
</tr>
<tr>
<td>Local Purple Saree</td>
<td>Oval</td>
<td>White</td>
<td>Purplish-White</td>
<td>3.84^e</td>
<td>14.65^f</td>
</tr>
</tbody>
</table>

Notes: Numbers followed by the same letter in the same column are not significantly different at the 0.05 DMRT test level.

In terms of tuber skin color, the 12 types of sweet potatoes showed the differences, where CIP-LSQ clone had yellow tuber skin color, CIP-1945, CIP-513 clones, and Antin-1 variety had a reddish-purple tuber skin color, CIP-MAN and CIP-B9 clones have creamy skin color, CIP-WHI5, CIP-204, and Local Purple Saree clones have a white tuber skin color, CIP-W86P clone has a rose-colored tuber skin color, Local Saree Orange clone has an orange tuber skin color, while CIP-BDG clone has a dark purple tuber skin (Table 1 and Figure 1). However, the color of the tuber skin does not determine the color of the tuber flesh, such as CIP-1945 and CIP-513 clones which has a reddish-purple tuber skin.
color, but the color of their tuber flesh is orange and cream respectively. Sweet potato tuber skin has a variety of colors: white, cream, yellow, pink, red, orange, and dark purple [5].

The difference in the color of the tuber skin illustrates the different types of pigments contained in sweet potatoes. In terms of tuber flesh, the 12 types of observed sweet potatoes showed the differences, where CIP-LSQ, CIP-WHI-5, and CIP-204 clones had white tuber flesh, CIP-1945, CIP-W86P, Local Orange Saree clones have orange tuber flesh, Antin-1 variety has a dark orange flesh color, CIP-MAN, and CIP-513 clones have creamy flesh, CIP-B9 clone has a yellow flesh color, CIP-BDG clone has a dark purple tuber color and the Local Purple Saree clone has a purplish-white tuber color, both types of clones have a pigmented color with anthocyanin (Table 1 and Figure 2). Sweet potato flesh is homogeneous and has secondary color diffusion, such as the color of the tuber skin. Sweet potato clones with orange and purple tuber flesh color have high beta carotene and anthocyanin content [25][22], compared to sweet potato clones which have yellow, white or cream tuber flesh. The color of the tuber flesh can also reflect the concentration of pigment contained. The more concentrated the color of tuber flesh the higher the beta carotene content [26]. Sweet potato varieties with white or pale-yellow flesh are less sweet and moist than those of red, pink or orange flesh [27].

![Figure 1](image1.png)

**Figure 1.** The shape and color of the tuber skin of 12 types of sweet potatoes

![Figure 2](image2.png)

**Figure 2.** The color of the tuber flesh of 12 types of sweet potatoes (a) oranges, (b) cream, (c) white and (d) purplish-white and dark purple

The morphological character of a plant is determined by the influence of environmental conditions and genetic factors (variety). The two factors will interact during the plant's life cycle so that the shape (tubers) appear that are similar to each other, or completely different. If the influence of the environment is dominant rather than genetic, then there may be morphological variations of one species that live in several populations [28]. These environmental conditions can be in the form of soil conditions, climate, or even availability of water [29]. Morphological characters that are stable and are not influenced by environmental factors may include leaf shape, leaf color, petiole, leaf bone and stem, sweet potato skin color and sweet potato flesh. While morphological characters that are easily changed as influenced by the environment may include tendrils length, leaf stalk length, leaf size, and tubers yield [30].

Table 1 shows that tuber diameter varies from 1.92 to 6.30 cm whereas the largest tuber diameter was found in CIP-204 clones that were significantly different from other clones and varieties, while
the lowest average tuber diameter was found in the Antin-1 variety. Tuber length varies from 8.5-16.60 cm whereas the longest tuber was found in the CIP-204 clone which was not significantly different from the CIP-W86P clone, but significantly different from the other clones and other varieties. The shortest tuber in CIP-WHI5 clone and significantly different from clones and other varieties. This result is lower than the results of [31] using 11 cultivars in Nigeria obtained a tuber diameter ranging from 0.8 - 8.23 cm and a tuber length between 5.83-21.67 cm, in a research using NPK fertilizer (15:15:15) with a dose of 300 kg ha\(^{-1}\) in soil at a pH of 6.75. Research by [32] using 15 cultivars obtained tuber diameters ranging from 3.01-8.5 cm and tuber length 16.0-24.5 cm, in research using manure 25 tons ha\(^{-1}\) and using NPK fertilizer according to recommendations to pH of 6.8. The width, length, and thickness are the most important parameter in the design of grading, handling, processing and packaging systems [33]. Knowledge of length, width, volume, surface area and center location of mass may be applied in the designing of sorting machinery, in predicting surface needed when applying chemicals, shape factor (sphericity), and yield in the peeling operation (surface area) [34]. When tubers are marketed for industrial processing, the portions of certain size-grades and the tuber shape play an important role [23].

3.2. Effect of Sweet Potato Types on Tuber Yield

The results of the analysis of variance showed that the types of sweet potato had a very significant effect on the number of tubers per plant, tuber fresh weight, and tuber yield. Table 2 shows that the highest number of crop tubers found in CIP-WHI5 treatment which was significantly different from the other clones. The lowest number of tubers per crop was found in CIP-MAN clone, and not significantly different from CIP-1945, Antin-1, CIP-B9, and Local Purple Saree. The higher tuber fresh weights and the higher tuber yield were found in CIP-LSQ and CIP-204 clones which were significantly different from the other clones. The lowest fresh tuber weights and yield were found in CIP-MAN (7.95 t ha\(^{-1}\)) clone which was not significantly different from CIP-1945, CIP-513, Local Orange Saree, and Local Purple Saree clones. CIP-204 clone with the largest tuber diameter (6.3 cm) and tuber length (16.6 cm).

Table 2. Average number of tubers, fresh tuber weight, and tuber production due to the treatment of sweet potato types

<table>
<thead>
<tr>
<th>Types of Clones</th>
<th>Number of Tuber</th>
<th>Tuber Fresh Weight (g)</th>
<th>Yield (t ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIP-LSQ</td>
<td>3.80 (2.06) d</td>
<td>336.67 (18.27) e</td>
<td>26.93 (5.21) e</td>
</tr>
<tr>
<td>CIP-1945</td>
<td>1.87 (1.54) ab</td>
<td>123.78 (11.10) ab</td>
<td>9.90 (3.21) ab</td>
</tr>
<tr>
<td>CIP-MAN</td>
<td>1.73 (1.49) a</td>
<td>99.33 (9.96) a</td>
<td>7.95 (2.90) a</td>
</tr>
<tr>
<td>CIP-513</td>
<td>3.40 (1.97) d</td>
<td>161.67 (12.73) abcd</td>
<td>12.93 (3.66) abcd</td>
</tr>
<tr>
<td>Antin-1</td>
<td>2.80 (1.81) bcd</td>
<td>216.00 (14.68) cd</td>
<td>17.28 (4.21) cd</td>
</tr>
<tr>
<td>CIP-BDG</td>
<td>3.33 (1.96) d</td>
<td>209.33 (14.13) bcd</td>
<td>16.75 (4.06) bcd</td>
</tr>
<tr>
<td>CIP-WHI5</td>
<td>5.60 (2.47) e</td>
<td>229.50 (15.10) d</td>
<td>18.36 (4.32) d</td>
</tr>
<tr>
<td>CIP-W86P</td>
<td>3.27 (1.94) d</td>
<td>193.67 (13.91) bcd</td>
<td>15.49 (3.99) bcd</td>
</tr>
<tr>
<td>CIP-B9</td>
<td>2.13 (1.62) abc</td>
<td>233.67 (15.30) abc</td>
<td>18.69 (4.38) d</td>
</tr>
<tr>
<td>CIP-204</td>
<td>3.53 (2.01) d</td>
<td>443.00 (21.05) e</td>
<td>35.44 (5.99) e</td>
</tr>
<tr>
<td>Local Orange Saree</td>
<td>3.00 (1.85) cd</td>
<td>135.33 (11.55) abc</td>
<td>10.83 (3.34) abc</td>
</tr>
<tr>
<td>Local Purple Saree</td>
<td>1.80 (1.51) ab</td>
<td>122.33 (11.05) ab</td>
<td>9.79 (3.20) ab</td>
</tr>
</tbody>
</table>

Notes: Numbers followed by the same letter in the same column are not significantly different at the 0.05 DMRT test level.
Numbers in parentheses are the result of transformation \((x + 0.5)^{1/2}\).

Produced the highest tuber weights and yield (35.44 t ha\(^{-1}\)), even though the number of tubers was low (3.53), and not significantly different from CIP-LSQ clone (26.93 t ha\(^{-1}\)). This showed that CIP-204 clone had the largest tuber(s) so that it produced high yield, although the number of tubers was
lower, consistent with [32]. It is estimated phenotypic and genotypic levels of thirty genotypes for different characters [35].

At phenotypic levels, tuber per plant followed by length of tuber and girth of tuber exerted high positive direct effect on tuber yield per plant which indicates that these are the main contributors to the tuber yield. These characters can be considered for the selection of high yielding genotypes on the basis of their phenotypic data. It is recommended that the high yielding cultivars can be predicted by their on-field morphological characters [32]. There is no hold on the tuber’s skin and flesh color and the yield per plant. High yielding cultivars generally have tubers of white or light skin color with white, creamy or light-colored flesh, while low yielding ones generally have light purple, orange or purple colored skin or flesh. Therefore, color tubers of low yielding cultivars can be crossed with high yielding ones to incorporate the flavonoids to the light-colored high yielding cultivars for better commercialization.

Identification based on morphological character evaluation was carried out to determine the diversity of varieties [36]. The evaluation of the characteristic of sweet potato morphology in an ecogeographic region is useful for increasing efficiency and direct use as well as an effort to collect and conserve its genetic makeup [37]. When the identification of varieties based on the evaluation of morphological characters succeed in determining different types, the production and management of sweet potato germplasm become more effective and efficient. However, the existing identification is still very minimal so that it is one of the causes of low sweet potato production at this time.

4. Conclusion
Based on the morphological characteristics, the differences between the 12 types of sweet potatoes were observed and identified in terms of their shape of the tubers, skin color and color of the tuber flesh. CIP-LSQ, CIP-204, Local Orange Saree, and Local Purple Saree clones were characterized by oval tuber shapes, CIP-1945, CIP-MAN, CIP-BDG, CIP-W86P clones, and Antin-1 varieties were long, and CIP-513, CIP-WHI-5, and CIP B9 were round. Skin colors differed where CIP-WHI5, CIP-204, and Local Purple Saree clones were white, CIP-MAN and CIP-B9 clones were cream, CIP-LSQ clone was yellow, Local Saree Orange clone was orange, CIP-W86P clone was rose, CIP-1945, CIP-513 clones, and the Antin-1 variety were reddish-purple, and CIP-BDG clone was purple. Tuber flesh color differed where CIP-1945, CIP-W86P, Local Orange Saree clones were white (25%), CIP-MAN, and CIP-513 clones were cream, CIP-B9 clone was yellow, CIP-1945, CIP-W86P, and Local Orange Saree clones were orange, Antin-1 variety was dark orange, and CIP-BDG clone was dark purple. CIP-WHI5 clone produced the highest number of tubers and the CIP-204 clone produced the largest diameter and length of tuber and the highest tuber yield, and not significantly different from CIP-LSQ clone. Extensive genetic variability was found in number of tubers and fresh tuber weight.

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