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Morphological Diversity and Production of Six Sago (*Metroxylon* spp.) Accessions from Tana Luwu, South Sulawesi, Indonesia

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ABSTRACT

Tana Luwu area owns a relatively high diversity and production potential of sago, but it has not yet been managed optimally. This study aims to identify and analyze the diversity of morphological characteristics and the production of various sago accessions in Tana Luwu. Based on morphological characteristics, the sago palm in Tana Luwu is divided into two groups by the presence of thorns on the rachis and petioles. The presence of thorns has the largest coordinate axis angles, representing a higher diversity distance than other morphological characteristics. Some accessions show very high production potential, with a total production of 476.66 kg per dry tree starch. The average sago production in the six accessions is 276.40 kg per dry tree starch. Accessions with a yield potential > 200 kg per dry starch are observed in Kapa, Uso, Kasimpo, and Sabbe. Therefore, sago in these accessions is potentially developed to obtain superior varieties. Two significant morphological characteristics that contribute to sago production are stem height (r = 0.73) and the number of leaves (r = 0.78).

INTRODUCTION

Sago is a carbohydrate-producing plant is potentially used as an alternative food since its productivity reaches 20-40 t/ha (Bintoro et al., 2018) and 800 kg/tree (Ehara et al., 2018). The quantity of sago production in Aceh, Meranti, Pontianak, Luwu, and Piru varies from 200-400 kg/trunk. On peatlands, sago production reaches 150-300 kg of dry starch/trunk (Konuma, 2018). Therefore, the production and diversity of sago in Indonesia are potentially becoming a future provider of world food resources (Donowati, 2018). On the other hand, the productivity of sago in Tana Luwu is still very low at 0.6 t/ha on average (DITJENBUN, 2017) compared to its production, which can reach 250 – 1000 kg/trunk (Kamma et al., 2021).

Generally, sago plants in Tana Luwu are naturally grown and semi-cultivated (Hidayat et al., 2018). The lack of optimal maintenance of sago palms possibly causes stunted growth with a longer harvest period (Ruli et al., 2017). Sustainable management of sago through the adoption of cultivation techniques (Trisia et al., 2016), the use of qualified seeds (Novarianto et al., 2020), and post-harvest management (Markus Rawung & Indrasti, 2021) are needed in North Luwu. Thinning of the tillers is needed on an ongoing basis because many young outgrowths are left, continue to grow, and can be harvested, several years later after the mother plant is harvested (Nabeya et al., 2015). This leads to competition among individual young plants in a clump and causes less optimal starch formation. *Metroxylon* sago palms only bear fruit once in their lifetime and then die, so they will be wasted if not harvested (Mcclatchey et al., 2006). Sago plants can be harvested after the trunk formation reaches 6.40 years for the thorny species and 9.75 years

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for the thornless species (Pasolon, 2015). A study in Fiji showed that the decline in sago populations is due to habitat loss and unsustainable harvest management (Watling, 2018).

Sago starch production is related to leaf area, trunk volume, and duration of growth (Yamamoto et al., 2014). Amyloplast, an organelle in which the starch granules are accumulated, has a very different size in each sago variety (Nitta, 2018). Sago leaf area is a key factor in determining starch yield, while variety is essential in determining leaf area (Yamamoto, 2018). Local farmers have classified the best local sago varieties based on the starch content and taste of the porridge (Pasolon, 2015). The community uses morphological markers, i.e., the presence of thorns, thorn pattern, stem shape, and height, to distinguish between accessions (Pratama et al., 2018). The presence of spines in the vegetative phase of sago is not related to the genetic variation (Kjær et al., 2004). Morphological characteristic variations observed in the five varieties of sago are the shape, size, and color of the stems, leaves, flowers, fruit, and seeds (Sahetapy & Karuwal, 2015). Three morphological characteristics of sago, including the number of leaves, rachis length, and tree height, significantly contribute to the formation of stem diameter (Sari et al., 2020). The highest diversity was found in stem height and rachis length (Mustamu et al., 2021).

Based on the original habitat and the presence of thorns, sago palms are divided into three main groups (Rahayu et al., 2013). The differences in leaf and trunk morphology represent high diversity in sago species (Riska, 2010). The diversity of an organism can be identified through the study of morphology, protein, and DNA (Abbas et al., 2010). Data on the high diversity of genotypes and phenotypes of sago accession in Indonesia are beneficial if they were determined based on conserved characteristics (Purwoko et al., 2019). Phylogenetic studies involving morphological and molecular data can be a reference for identifying the species-relatedness level of various types of sago accessions (Rahman et al., 2021). This study aims to identify and analyze the diversity of morphological characteristics and the production of various sago accessions in Tana Luwu.

MATERIALS AND METHODS

Time and Study Location

The study was carried out from May 2020 to June 2021 in North Luwu Regency, South Sulawesi. The distribution of the sample (Fig. 1) was divided into Pasamai Village, Belopa District (3°23'39" S, 120°20'58" E), East Bosso Village, North Walenrang District, Salujambu Village (2°45'51" S, 120°10'05" E), Lamasi District, Luwu Regency (2°47'41" S, 120°13'00" E), Tobulung Village, Bara District, Palopo City (2°56'36" S, 120°10'07" E), Lawawe Village, Baebunta District (2°47'09" S, 120°14'45" E), and Waelawi Village, West Malangke District (2°51'11" S, 120°19'40" E).

Observation Procedure of Morphological and Production Characteristics

Observations and sampling were executed by creating a 2500 m^2 (50 m x 50 m) plot in sago land at each sampling location. Morphological characteristics of sago palms were observed during the mature stage using the destructive sampling method by cutting down four sago trees in each accession. The observation of morphological characteristics was similarly conducted based on visual observation and information from key respondents. Sampling was done through direct observation of 16 morphological and production characteristics. The morphological characteristics observed were: number of leaflets on the left side, number of leaflets on the right side, leaf length, rachis length, petiole length, stem height and diameter, bark thickness, trunk girth, leaf and leaflet area, number of leaves, and the presence of thorns. As for the production characteristics, the observation included yield, moisture content, and sago production. Observations were carried out in six accessions with four repetitions, respectively, so the total sample was 24. The distance between observation plots was > 200 m.

Data Processing and Analysis

Leaf area was calculated based on leaflet length and width of the intermediate leaf sheath of a mature-stage tree using the formula 1 (Fig. 2):

$S(e) = 0.785 \text{ Leaflet} \times W_{leaflet}$ ....1)

where S(e) is the leaf area, $L_{leaflet}$ is the length of the leaflets, and $W_{leaflet}$ is the width of the leaflets (Nakamura et al., 2004).

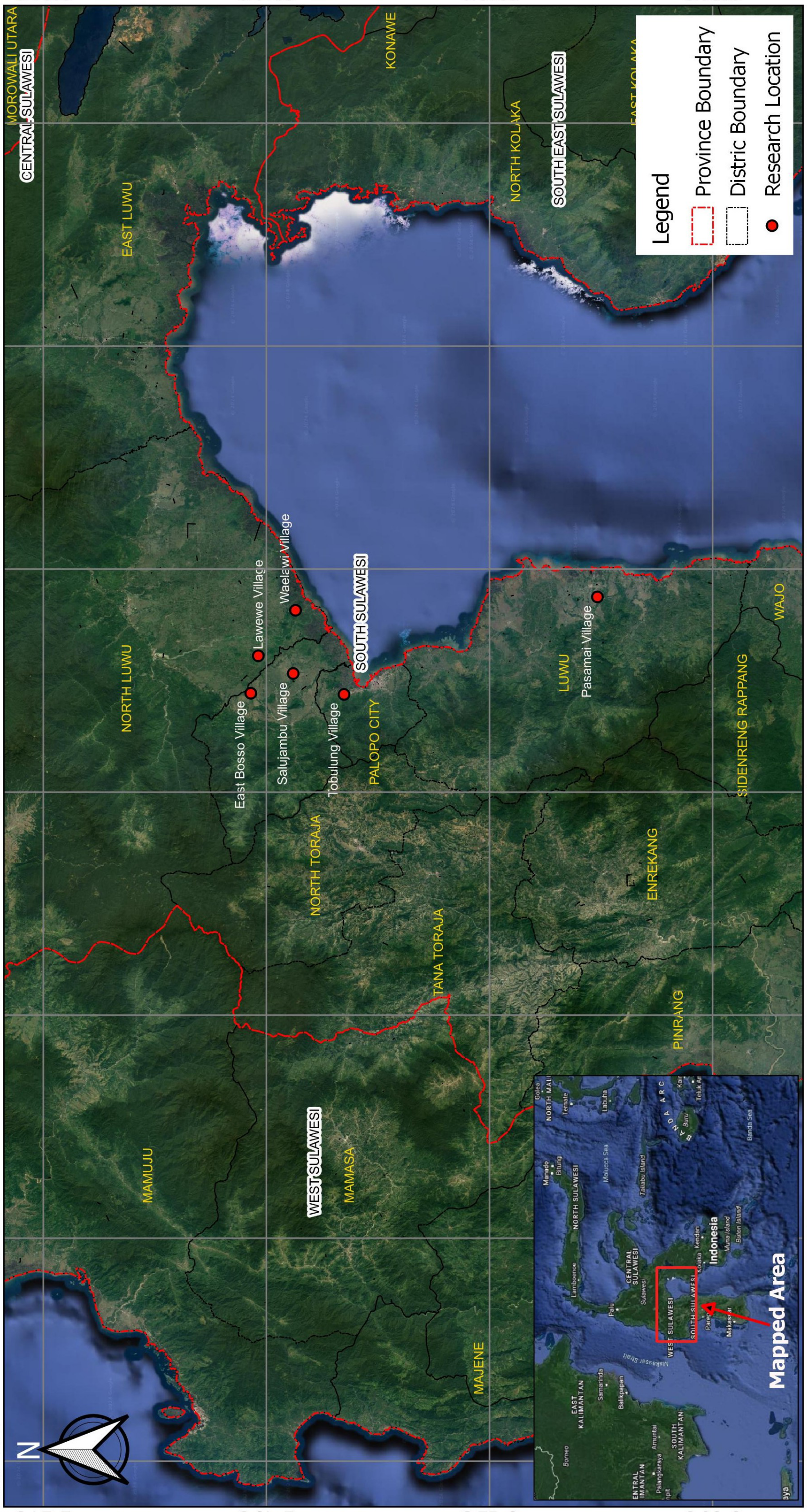

Fig. 1. Research Locations based on Google Earth Satellite Imagery 2022

The number of leaflets on the leaf sheath of a mature parent plant was quantified on both the right and left sides of the leaf blade (Fig. 3) (Nakamura et al., 2005). Leaf area was calculated using the formula 2:

S_{leaf}= ab π/8 + ac/2 ....2)

where S_{leaf} is the leaf area, a is the length of the rachis, b is the length of the leaflets on the left segment (LCL) + the right segment (LCR) in the middle of the rachis (a/2), and c is the length of the left leaflet (LBL)+ right (LBR) at from the base of the rachis (a/4) (Fig. 4) (Nakamura et al., 2009).

Starch production is directly proportional to stem weight (Ehara, 2009). Estimation of the potential for dry starch production per stem was based on the ratio of the volume of the pith samples taken from the bottom, middle, and top using a ring sample of defined volume. Starch production per tree was calculated by the formula 3:

Starch production per tree = [stem volume/sample volume] x dry starch sample weight x fk..............3)

Sago stem volume = π r^2 x height ....4)

where, π = 3.14 and r = sago stem radius, fk = correction factor (0.90) (Fathnoer et al., 2020).

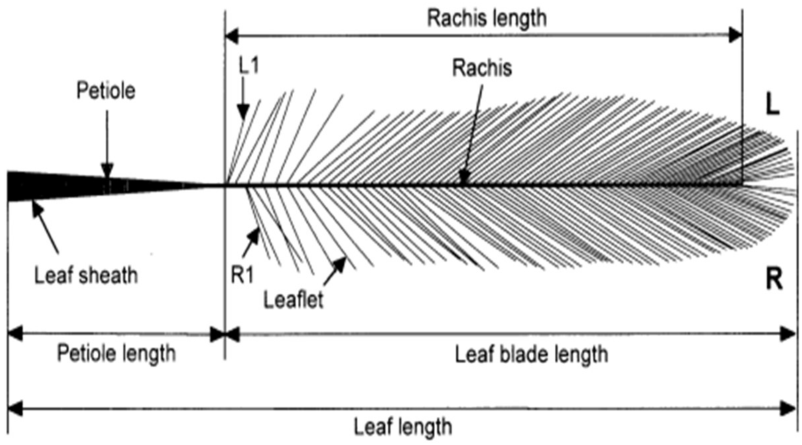

Fig. 2. Illustration of sago leaves (Nakamura et al., 2004)

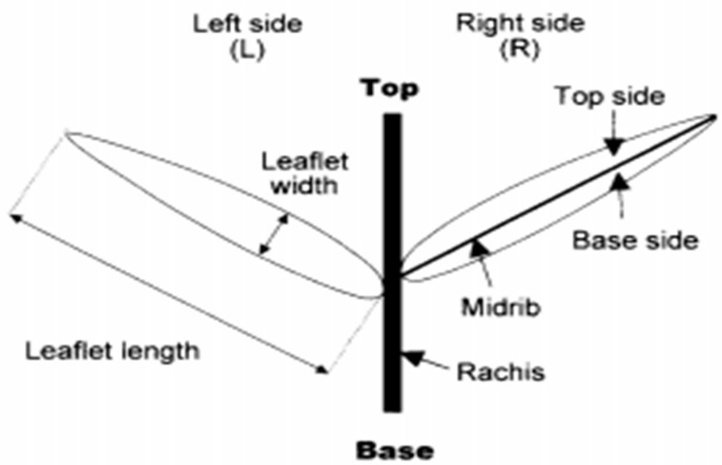

Fig. 3. Illustration of sago leaflets (Nakamura et al., 2005)

Moisture content was calculated using the formula 5:

Moisture content = [wet weight of starch/dry weight of starch x 100%] ....5)

The percentage of starch rendement was calculated using the formula 6:

The percentage of starch rendement = [weight of dry starch sample/weight of pith] x 100% ....6)

Production Potential = [Total production x number of mature trees cut x sago area] ....7)

The data collected were scored and analyzed to produce a dendrogram based on cophenetic distance (Sayekti et al., 2021) and Principal Coordinates Analysis (PCoA) using PBSTAT-EL 2.1 software (Sitaresmi et al., 2019). Principal component analysis (PCA) and correlation were performed using Minitab 6 Software (Gio & Rosmaini, 2016).

RESULTS AND DISCUSSION

Phenetic Relationships Based on Morphological Characteristics

Phenetic relationships of sago in North Luwu based on 16 morphological characteristics displayed various coefficients. The cophenetic distances of the six observed sago accessions were analyzed using cophenetic distance dendrogram (Fig. 5) and dissimilarity matrix (Table 1).

The analysis results showed that the dissimilarity coefficient ranged from 0.07 to 0.93. Sago accessions in North Luwu were divided into two main groups and each main group had two sub-groups. Group I, subgroup 1a, consisted of Kiduri1, Kiduri2, Kiduri3, and Kiduri4. While subgroup 1b is composed of Ute1, Ute2, Ute3, and Ute4. In group II, the subgroup 2a had Sabbe1, Sabbe2, Sabbe3, and Sabbe4 and Uso1, Uso2, Uso3, and Uso4, while group 2b consisted of Kasimpo1, Kasimpo2, Kasimpo3, and Kasimpo4 and Kapa1, Kapa2, Kapa3, and Kapa4. The lowest dissimilarity coefficient (Table 1) was observed in Ute1 and Ute4 (0.07), while the highest was found in Kiduri1 and Sabbe (0.93). In subgroup 1a, sago accessions had distinct characteristics, like the presence of thorns on the rachis and petioles, while sago in Ute accession in subgroup 1b was thornless. In group II, all accessions had no thorn on the rachis and petioles.

Morphological diversity was quantitatively classified based on the presence of thorns and the geographical distance between accessions (Kjær et al., 2004). The grown sago palms in eastern Indonesia were divided into two groups, the thorny species and the thornless one (Pasolon, 2015). There were 12 accessions of sago with different morphological characteristics (Dewi et al., 2016). Morphological characteristics, like the presence of thorns, leaf pattern, and leaf sheath length can be used as markers for each sago accession. Characteristic similarity can occur as a consequence of epigenetic events related to the distance from the growth location (Rahman et al., 2021).

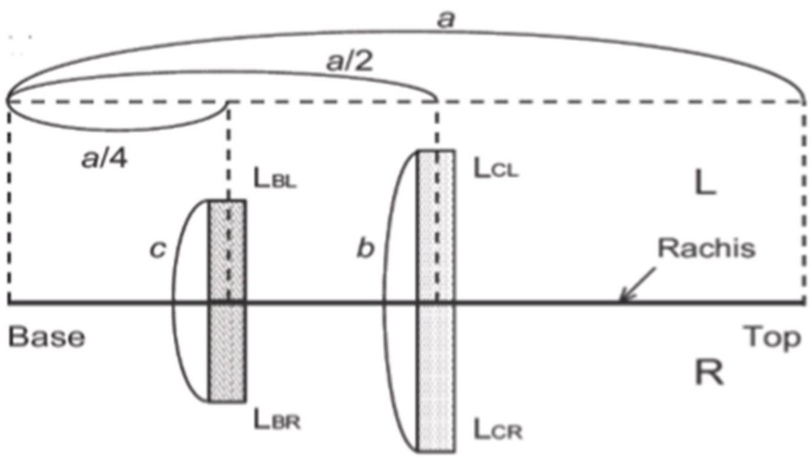

Fig. 4. Mechanism of measuring sago leaves (Nakamura et al., 2009)

Table 1. Dissimilarity coefficient matrix based on morphological characters

Accessions	KP1	KP2	KP3	KP4	KS1	KS2	KS3	KS4	UT1	UT2	UT3	UT4	US1	US2	US3	US4	SB1	SB2	SB3	SB4	KD1	KD2	KD3
KP2	0.13																						
KP3	0.15	0.18																					
KP4	0.15	0.15	0.23																				
KS1	0.45	0.40	0.45	0.38																			
KS2	0.43	0.45	0.38	0.40	0.20																		
KS3	0.45	0.45	0.45	0.45	0.10	0.20																	
KS4	0.38	0.43	0.50	0.40	0.18	0.23	0.23																
UT1	0.60	0.65	0.58	0.58	0.73	0.60	0.73	0.70															
UT2	0.63	0.68	0.63	0.65	0.65	0.63	0.63	0.63	0.20														
UT3	0.58	0.68	0.60	0.65	0.70	0.60	0.68	0.58	0.18	0.13													
UT4	0.63	0.65	0.55	0.63	0.68	0.58	0.65	0.68	**0.07**	0.18	0.15												
US1	0.58	0.55	0.55	0.50	0.38	0.33	0.38	0.48	0.50	0.55	0.60	0.48											
US2	0.55	0.58	0.53	0.53	0.38	0.38	0.35	0.53	0.55	0.63	0.60	0.55	0.13										
US3	0.50	0.58	0.58	0.60	0.43	0.40	0.38	0.38	0.58	0.53	0.50	0.53	0.20	0.18									
US4	0.58	0.60	0.53	0.55	0.45	0.35	0.48	0.45	0.55	0.60	0.53	0.55	0.23	0.13	0.18								
SB1	0.68	0.65	0.63	0.73	0.55	0.50	0.48	0.53	0.73	0.68	0.68	0.70	0.58	0.55	0.50	0.53							
SB2	0.58	0.55	0.68	0.60	0.48	0.45	0.48	0.43	0.65	0.68	0.68	0.65	0.45	0.55	0.53	0.60	0.28						
SB3	0.60	0.65	0.60	0.63	0.50	0.43	0.40	0.48	0.68	0.63	0.63	0.65	0.53	0.48	0.53	0.53	0.23	0.28					
SB4	0.65	0.65	0.65	0.70	0.58	0.50	0.55	0.50	0.58	0.63	0.60	0.65	0.60	0.60	0.55	0.55	0.18	0.30	0.20				
KD1	0.73	0.75	0.83	0.75	0.80	0.75	0.80	0.73	0.63	0.63	0.65	0.70	0.65	0.68	0.65	0.68	**0.93**	0.75	0.80	0.78			
KD2	0.75	0.73	0.78	0.80	0.83	0.83	0.78	0.80	0.65	0.63	0.70	0.73	0.70	0.75	0.68	0.78	0.83	0.83	0.85	0.73	0.13		
KD3	0.80	0.83	0.85	0.80	0.80	0.78	0.78	0.75	0.73	0.60	0.70	0.70	0.68	0.73	0.65	0.70	0.80	0.85	0.78	0.83	0.18	0.20	
KD4	0.78	0.80	0.83	0.83	0.75	0.80	0.75	0.75	0.70	0.58	0.68	0.70	0.68	0.70	0.63	0.73	0.83	0.80	0.83	0.80	0.13	0.15	0.15

Remarks: KP=Kapa, KS = Kasimpo, UT = Ute, US = Uso, SB = Sabbe dan KD = Kiduri

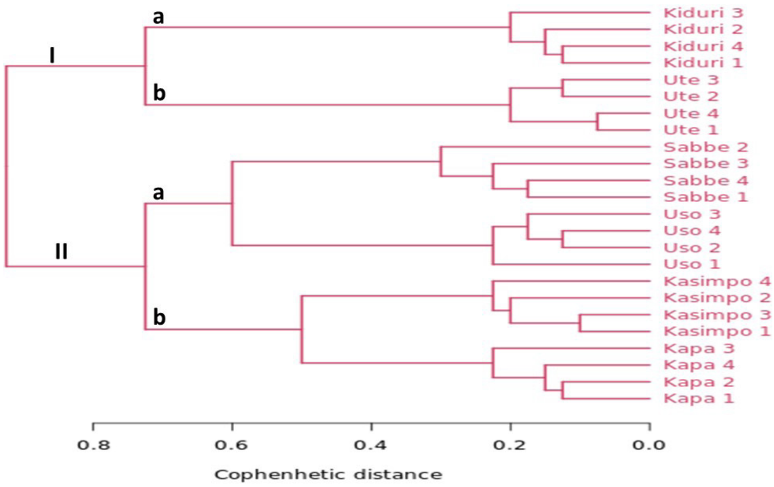

Fig. 5. Dendrogram of the cophenetic distance

Fig. 6. Plot Score based on PCoA

According to the analysis of the accessions grouping based on coordinates 1 and 2. Sago accessions were divided into four quadrants (Fig. 6). Accessions, namely Sabbe1, Sabbe2, Sabbe3, and Sabbe4 were in quadrant I, and the coordinates were closest to the X-axis. Also, in quadrant I accessions Uso1, Uso2, Uso3, and Uso4 were close to the Y and X-axis, while Kasimpo3 was very close only to the Y-axis. Quadrant II consisted of Kiduri2, Kiduri3, and Kiduri4 and their coordinates were very close to the Y-axis line. Two different accessions were observed in quadrant III; Kiduri1 was closer to the Y-axis, while Ute1, Ute2, Ute3, and Ute4 were closer to the Y and X-axis. Quadrant IV also consisted of two accessions; Kasimpo1, Kasimpo2, and Kasimpo4 were located adjacent to the Y-axis, and accessions Kapa1, Kapa2, Kapa3, and Kapa4 were closer to the X-axis. The level of relationship between accessions and individuals was depicted in each coordinate. The closer the axis and coordinates of each accession and individuals in each quadrant represent a closer relationship. Principal coordinate analysis (PCoA) results showed that coordinate points of Kiduri2, Kiduri3, and Kiduri4 accessions were close to each other in the same quadrants. In contrast, the coordinate of other accessions was distributed over three quadrants. Sago palms from various regions in Indonesia were divided into three groups based on the PCoA analysis (Purwoko et al., 2019).

Morphological Diversity Based on Principal Component Analysis (PCA)

Observations of 16 morphological characteristics of sago from 6 accessions in Tana Luwu showed diversity in the leaves, stems, thorns, and starch. The contribution of the principal component analysis showed the highest level of diversity in each PC (Principal Component) group (Table 2). In PC16, leaf length (LL) possessed the highest variability value (71%). Meanwhile, leaf length (LL) and rachis length (RL) had the lowest contribution (27%) in PC11. Other components with high contribution values were PC3 and PC5, namely leaf area (LA) of 66% and 64%. In PC6, skin thickness (TBT) was 60%, and leaf area (LA) was 65% on PC7, while the number of leaves (NL) on PC13 was 67%. The morphological diversity of the 16 morphological characteristics had high variability data values, both positive and negative.

Principal component analysis (PCA) is a statistical tool to simplify complex data and comprehend the main factors that determine the relationship between components in a system (Vidal et al., 2020). The present study demonstrated leaf length factor contributed the highest characteristic value component. Characteristic strength that contributes to diversity can be analyzed with principal component analysis to identify characters that define a variety (Afuape et al., 2011). Accession of sago in natural populations demonstrated three main components (Pratama et al., 2018). Analysis of the main components of the morphological characteristics of sago was divided into two groups (Rahman et al., 2021). Five varieties of sago on Saparua Island show morphological variations in shape, size, and color on stems, leaves, flowers, fruit, and seeds (Sahetapy & Karuwal, 2015).

The presence of thorns (PT) on the Biplot diagram exhibited the largest axis angle, thus revealing a higher diversity distance than other morphological characteristics (Fig. 7). The number of leaflets on the right side (NLR), rendements (R), and leaf area (LA) showed the closest angle distance with no angle observed on the axis line, which represented very close features between each characteristic. Likewise, rachis length (RL) and the number of leaves (NL) were on the same axis line, indicating a very strong correlation. Sago palms were grouped into three main groups based on the habitat origin and the presence of thorns using cluster analysis (Rahayu et al., 2013).

The highest variable vector length was observed in the presence of thorns, while the lowest was in the petiole length. These data showed high diversity in the presence of thorns, while the diversity of petiole length was low. Despite being located in the same area, the observed sago accessions exhibited distinct morphological characteristics, possibly due to their genetic differences since morphological characteristics were influenced by the environment (Botanri et al., 2011). The presence of thorns on sago palms is an epigenetic event and is influenced by the environment (Novero et al., 2012). If an increase in variable values displays a positive correlation, the value of the variable pair will also increase. Meanwhile, a negative correlation occurs when an additional variable causes a decrease in another variable (Marzuki et al., 2008).

Table 2. Morphological Diversity Matrix Based on Principal Component Analysis (PCA)

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14	PC15	PC16
NL	0.32	-0.16	0.66	0.14	-0.32	-0.04	0.13	0.19	0.04	0.31	-0.27	-0.02	0.67	0.25	-0.08	0.00
NLL	0.25	0.01	-0.45	0.10	0.22	-0.16	0.16	-0.02	0.39	0.32	-0.27	-0.44	-0.30	-0.07	-0.11	0.00
NLR	0.19	0.23	-0.41	0.41	0.17	-0.23	-0.04	-0.24	-0.01	-0.04	0.25	0.39	0.32	-0.31	0.16	-0.00
LL	0.33	-0.27	0.02	-0.08	-0.14	-0.07	0.06	0.06	-0.05	-0.03	**0.27**	0.11	-0.15	-0.19	-0.36	**0.71**
RL	0.33	-0.27	0.02	-0.08	-0.14	-0.07	0.06	0.06	-0.05	-0.03	0.27	0.11	-0.15	-0.19	-0.36	-0.71
PL	0.05	-0.46	-0.07	-0.04	0.64	0.19	-0.10	-0.04	-0.24	0.04	-0.38	0.33	0.04	0.07	-0.11	0.00
TH	0.27	0.24	0.03	-0.23	0.15	-0.27	-0.51	0.23	-0.03	-0.47	-0.22	-0.25	0.21	-0.09	-0.18	0.00
TD	0.28	0.22	0.08	-0.10	0.06	-0.02	0.23	-0.70	-0.21	-0.16	0.02	-0.13	0.01	0.44	-0.19	0.00
TBT	0.16	-0.09	-0.38	0.35	-0.24	0.60	-0.01	0.11	-0.22	-0.40	-0.06	-0.21	-0.08	0.03	0.08	0.00
TC	0.31	0.10	0.15	-0.31	0.01	0.25	-0.04	-0.15	-0.35	0.36	-0.04	-0.23	0.06	-0.50	0.37	0.00
LLA	0.18	0.20	0.38	0.18	0.28	-0.01	0.65	0.31	0.03	-0.31	-0.13	0.03	-0.02	-0.18	0.08	0.00
LFA	0.19	-0.11	0.44	0.28	-0.11	0.21	-0.31	-0.36	0.55	-0.09	-0.21	0.12	-0.10	-0.19	0.04	0.00
PT	-0.28	0.37	-0.05	0.06	-0.22	0.11	0.07	-0.09	-0.19	0.12	-0.43	0.18	-0.03	-0.33	-0.56	0.00
R	0.16	0.19	-0.30	-0.59	-0.09	0.31	0.16	0.05	0.41	-0.11	-0.07	0.41	0.05	0.07	0.10	0.00
MC	-0.17	-0.43	-0.15	-0.17	-0.31	-0.39	0.24	-0.27	-0.05	-0.34	-0.34	-0.04	0.04	-0.25	0.25	-0.00
SP	0.32	0.17	0.03	0.11	-0.24	-0.28	-0.15	0.16	-0.26	0.12	-0.29	0.36	-0.49	0.25	0.28	-0.00
Eigen Value	7.07	2.24	1.83	1.10	1.00	0.78	0.58	0.50	0.41	0.15	0.13	0.11	0.07	0.02	0.01	0.00
Proportion	0.44	0.14	0.11	0.07	0.06	0.05	0.04	0.03	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Cumulative	0.44	0.58	0.70	0.77	0.83	0.88	0.91	0.94	0.97	0.98	0.99	0.99	1.00	1.00	1.00	1.00
Standard deviation	0.18	0.26	0.31	0.26	0.26	0.26	0.26	0.25	0.26	0.25	0.23	0.25	0.26	0.25	0.26	0.26

Remarks: NL= Number of Leaves; NLL= Number of Leaflets on the left side, NLR= Number of Leaflets on the right side, LL= Leaf Length, RL= Rachis Length, PL= Petiole Length, TH= Trunk Height, TD= Trunk Diameter, TBT= Trunk Bark Thickness, TC= Trunk Circumference, LLA= Leaflet area, LFA= leaf area, PT= Presence of Thorns, R= Rendement, MC= Moisture Content, SP= Sago Production

Diversity of Production Characteristics

Sago accessions in the Tana Luwu area mainly demonstrated a high production value with an average of 276.66 kg/trunk (Table 3). The Kapa accession had the highest production with 476.66 kg dry starch/trunk on average. Meanwhile, the lowest production was found in Ute accession with an average value of 140.35 kg/trunk. In sago palm, the unused assimilated photosynthates are stored in the trunk as starch. Some products are used for the formation, development, and maintenance of the organs and structures needed to transport water molecules, and others are used in the respiration process (Bintoro et al., 2018). Almost 40-50% of the total starch accumulates in the intercellular spaces in the sago trunk tissue. Trunk volume is crucial in production as it stores starch (sink) when nutrients, water, and sunlight are optimally available and are not affected by environmental stress (Nitta, 2018). Photosynthetic activity is lower at air temperatures ranging from 25-29°C compared to 29-33°C (Azhar et al., 2018). North Luwu's climate includes a tropical climate, with a minimum air temperature of 21.20^{0}C and a maximum temperature of 33.8^{0}C with an average air humidity of 83% (BPS, 2017). Sago habitat characteristics are related to microclimate conditions with a temperature range of 28.7-29.5°C (Karim, 2021). Thorny sago minimizes the impact of stress by regulating turgidity in leaves due to its lower stomata opening than in thornless sago (A'fifah et al., 2019). The high rate of photosynthesis compared to the rate of transpiration in spiny sago makes it more efficient in water use and higher dry matter production.

Based on the morphological characteristics (Fig. 8), there were two groups of sago palms; thornless sago (ABDEF) and thorny sago (C). A trace of fallen thorns after the sheath is entirely open was observed in the thorny sago. The crown shape between sago accessions was generally V-shaped (ABCEF), while Ute accessions (D) had an irregular crown shape. The crown shape affects photosynthesis results because the leaflets will receive more optimal sunlight when it is more upright. Plant photosynthesis efficiency significantly depends on the sunlight intensity (Yustiningsih, 2019). Plant density significantly affects the pattern of sunlight interception (Ariyanto et a*l*., 2015). Sago plants require optimal sunlight ranging from 900 J/cm^2/day to form starch in the trunk. In shaded conditions, growth will slow down, the trunk diameter will be smaller, and the starch content will be lower even though there are no considerable differences in the trunk height (Bintoro et al., 2018).

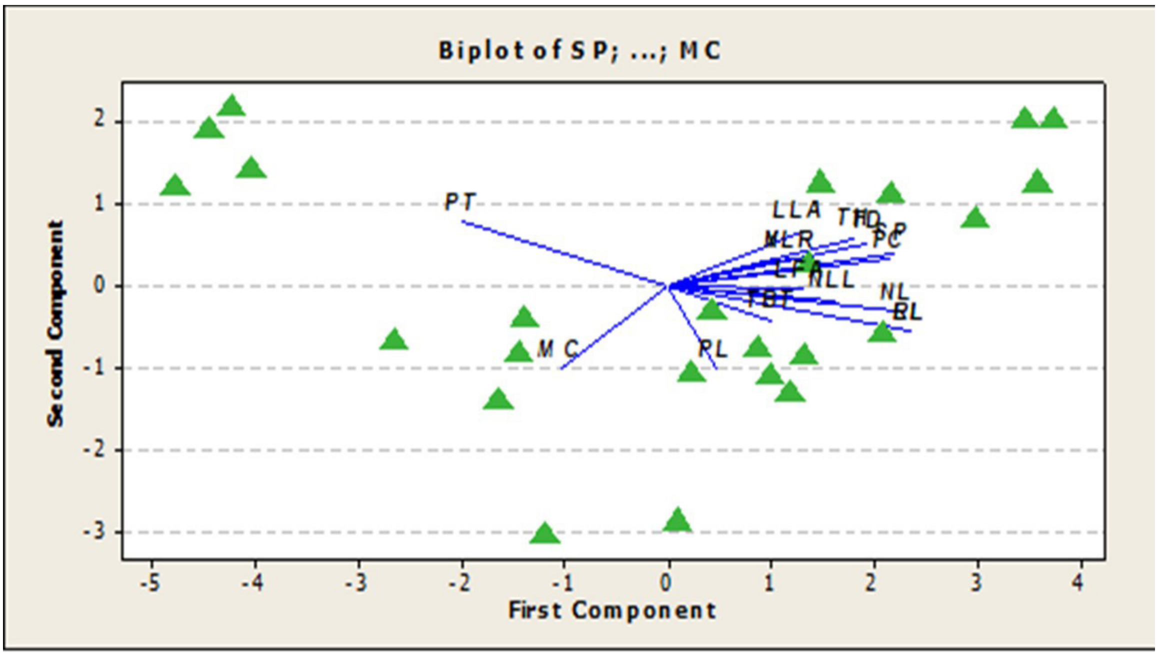

Fig. 7. Biplot diagram

The highest trunk height (14.47 m) and stem diameter (52.25 cm) were observed in Kapa accessions, resulting in 476.66 kg dry starch/trunk production. Meanwhile, the lowest production was found in the Ute accession, with 140.35 dry starch/trunk, trunk height at 8.75 m, and trunk diameter at 40.23 cm. Since the production average was above > 200 kg dry starch/trunk, sago production in the six accessions was categorized as high with an average of 276.40 kg dry starch/trunk. Starch production was positively correlated with trunk weight (Ehara, 2009). Starch accumulation begins at the base, reaches a maximum in the middle to two-thirds of the sheath-free trunk, and then sharply decreases at the top (Schuiling, 2009).

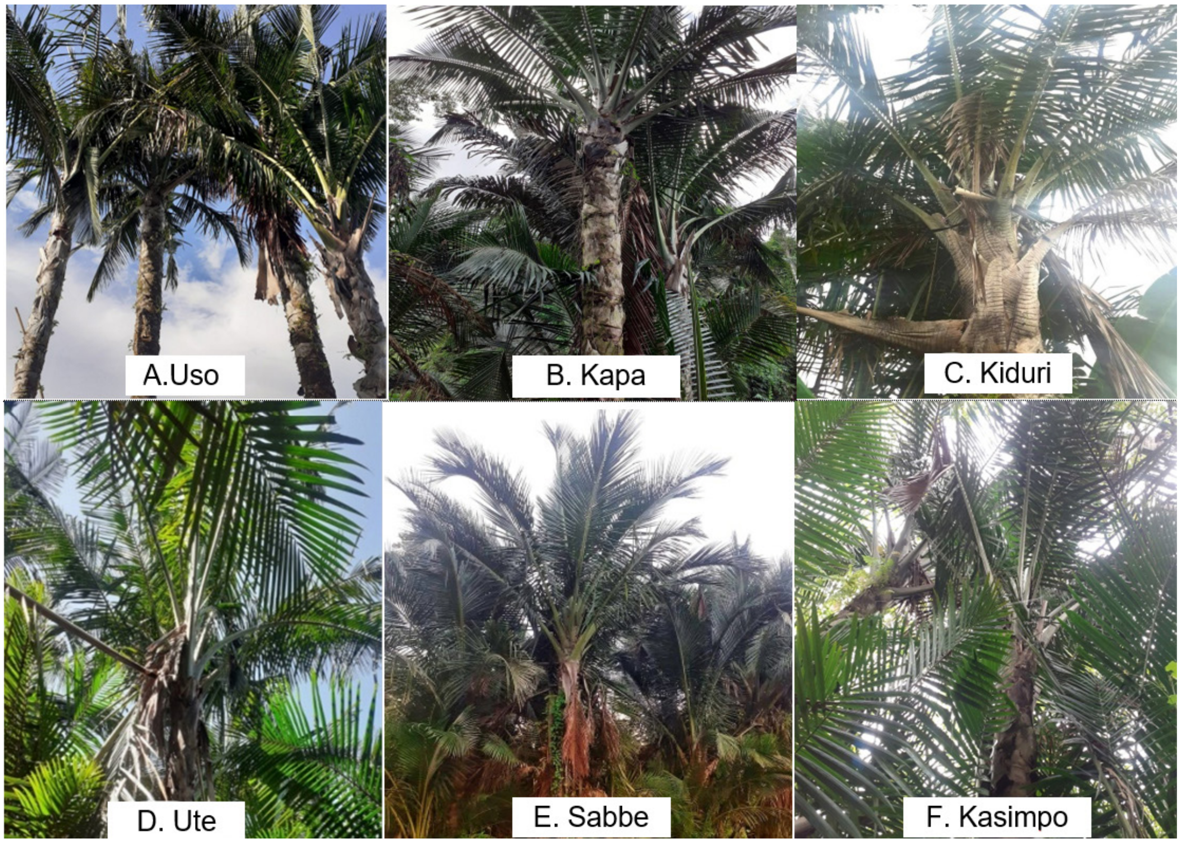

Fig. 8. Crown shape on the six sago accessions

Table 3. Production potential of six accessions of sago

Accessions	Rendement (%)	Trunk height (m)	Trunk diameter (cm)	Starch production (kg/tree)	Amount of ripe cutting (tree/ha)	Production potential (t/ha/year)
Kapa	24.22	14.47	52.25	**476.66**	70.00	33.24
Kasimpo	18.45	12.56	51.00	359.61	49.00	16.94
Ute	17.46	8.75	40.23	**140.35**	46.00	6.30
Uso	16.30	9.72	50.55	280.38	71.00	20.46
Sabbe	21.02	9.61	46.85	221.78	73.25	15.90
Kiduri	18.40	8.20	46.83	179.66	46.00	8.45
Average	19.31	10.55	47.95	276.40	59.21	16.88
Standard deviation	2.87	2.44	4.40	124.82	13.46	9.64
Coefisien of variation (%)	14.85	23.11	9.17	45.16	22.73	57.08

Table 4. Correlation matrix of morphological characteristics with production

Characters	SP	NLL	NLR	LL	RL	PL	TH	TD	TBT	TC	LLA	LFA	PT	R	MC	NL
SP	-															
NLL	0.48	-														
NLR	0.53	0.75**	-													
LL	0.69	0.51	0.26	-												
RL	0.69	0.51	0.26	1.00**	-											
PL	-0.20	0.19	-0.05	0.30	0.30	-										
TH	**0.73****	0.44	0.43	0.80	0.48	-0.07	-									
TD	0.64	0.43	0.48	0.53	0.53	-0.07	0.56	-								
TBT	0.31	0.46	0.44	0.40	0.40	0.13	0.06	0.17	-							
TC	0.67	0.32	0.19	0.69	0.69	0.08	0.66	0.79**	0.24	-						
LLA	0.41	0.13	0.13	0.28	0.28	-0.07	0.31	0.48	-0.08	0.42	-					
LFA	0.37	0.00	-0.02	0.46	0.46	0.06	0.22	0.38	0.11	0.40	0.35	-				
PT	-0.43	-0.50	-0.18	-0.9	-0.88	-0.57	-0.43	-0.4	-0.23	-0.51	-0.26	-0.47	-			
R	0.26	0.46	0.21	0.30	0.30	-0.13	0.43	0.39	0.25	0.50	0.02	-0.13	-0.15	-		
MC	-0.44	-0.20	-0.38	-0.10	-0.08	0.17	-0.54	-0.4	-0.17	-0.53	-0.55	-0.31	0.06	-0.24	-	
NL	**0.78****	0.48	0.20	0.88**	0.88**	0.06	0.42	0.48	0.46	0.62	0.37	0.54	-0.69	0.21	-0.2	-

Remarks: NLL= Number of Leaflets on the left side, NLR= Number of Leaflets on the right side, LL= Leaf Length, RL= Rachis Length, PL= Petiole Length, TH= Trunk Height, TD= Trunk Diameter, TBT= Trunk Bark Thickness , TC= Trunk Circumference, LLA= Leaflet area, LFA= leaf area, PT= Presence of Thorns, R= Rendement, MC= Moisture Content, NL= Number of Leaves, SP= Sago Production, * and **= significant at $P<0.05$ and $P<0.01$

Sago starch production varies widely in various regions. in South Sorong starch production can reach > 200 kg of dry starch/stem (Nurulhaq et al., 2022). Meanwhile, in Aimas District, Sorong Regency, dry starch production is relatively high with > 200 kg/tree (Ahmad et al., 2017). Superior sago accession contains > 200 kg/trunk starch content, therefore the listed accession is potentially developed (Dewi et al., 2016). Potential production of sago starch *M. rumphii* Mart. reaches 566.04 kg/ trunk and *M. Sylvestre* Mart. with 560.68 kg/trunk (Botanri et al., 2011). Types of sago Tuni and Molat are potentially developed since they have a high starch content (Al Qodri & Wawan, 2015).

Based on the correlation coefficient matrix of morphological characteristics and production (Table 4), two characteristics that significantly affect production were trunk height with r = 0.73 and the number of leaves with r = 0.78. Trunk height strongly influenced production, as in Kapa accession, which had the highest trunk height (14.47 m) with an average production of 476.66 kg dry starch/tree. Morphological and production of the thorny sago palm were in a low category (179.66 dry starch/ trunk) due to its low height and trunk diameter, which were 8.20 m and 46.83 cm, respectively.

The morphological characteristics of trunk height and number of leaves played an essential role in optimizing photosynthesis results since the trunk is a storage place for photosynthetic assimilation results (sink) while the leaves are an indispensable part of sunlight energy absorption through the photosynthesis process (source). Morphological characteristics, especially trunk height, diameter, and bark thickness affect production potential because starch is stored in the pith (Fathnoer et al., 2020). The photosynthetic assimilation rate is higher in plants with larger leaf areas and sink capacity, larger stem volumes, and longer harvesting ages (Yamamoto, 2018). The age of sago palms at the harvest stage after trunk formation is 6.4 years in the thorny species and 9.75 years in the thornless species (Rembon et al., 2014).

CONCLUSION

The morphological and production diversity of sago palm in six accessions is divided into two main groups. Group 1a consists of Kiduri accessions characterized by thorns on the rachis and petioles, while group 1b consists of Ute accessions characterized by the absence of thorns. Analysis of cophenetic distance based on the dissimilarity matrix showed the lowest dissimilarity coefficient is on Ute1 and Ute4 accession at 0.07. Meanwhile, the highest dissimilarity coefficient is observed in Kiduri1 and Sabbe at 0.93. These data provide information about the high diversity of sago plants in Tana Luwu based on their morphological characteristics. The highest value of variability based on Principal Component Analysis is on PC16, which is the leaf length (71%). While on PC11, the contribution of the main component of leaf length is the lowest at 27%. The presence of thorns has the largest coordinate axis angles, representing a higher diversity distance than other morphological characteristics. Generally, sago accessions in the Tana Luwu area possess high production potential with an average value of 276.66 kg/trunk. Accessions with yield potential > 200 kg/trunk dry starch are observed in Kapa, Uso, Kasimpo, and Sabbe, so sago in these accessions are potentially developed to become superior varieties. Two morphological characteristics that significantly contribute to sago production are stem height (r = 0.73) and the number of leaves (r = 0.78). Molecular analysis is needed to identify a more stable relationship. The superior traits of each accession can be used as a source of genetic information for the assembly of superior sago varieties through plant breeding.

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