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RESEARCH ARTICLE

Morphological characterization and variability of leaves, peduncles, inflorescences and fruits in Abaca (*Musa textilis* Née) cultivars from Aklan, Philippines

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Abstract

Morphological characterization of plants is fundamental for plant identification and breeding programs. Abaca (*Musa textilis* Née) is endemic to the Philippines and belongs to the *Musaceae* family. Five locally described cultivars-*Bisaya*, *Tabukanon*, *Agbayanon*, *Negro* and *Totoo*-are widely used by farmers in Aklan. Detailed morphological data on these cultivars are limited and lack extensive studies, necessitating further research for crop development. This study describes and compares the morphological characteristics of five Abaca cultivars' leaves, peduncles, inflorescences and fruits. A mixed research methodology and field survey were conducted to compare the morphological characteristics across the eight leading Abaca-producing municipalities in Aklan. A linear mixed-effects model (LMM) was employed to account for the variability of the data and handle an unbalanced design where some cultivars are not present in specific locations. The fixed effect of variety was tested using ANOVA derived from the LMM to assess significant differences, followed by Tukey's HSD method at a 5% level. Results showed that *Totoo* and *Agbayanon* had larger leaf morphology while all cultivars exceeded *Tabukanon,* which had the shortest leaf. Inflorescence morphology varied across abaca cultivars, indicating genetic diversity, which is useful for cultivar differentiation. In peduncle morphology, differences were very significant among all cultivars, *Agbayanon* shows a greater number of nodes with fruits, *Totoo* shows a greater number of fruits per node and *Negro* shows longer fruits, that could be cultivated for seed production. Such information provides relevant policies that could benefit breeders, researchers, farmers and other users to identify and maximize the crop's potential.

Keywords

Abaca; cultivar diversity; morphology; *Musa textilis* Née; natural fibre

Introduction

Abaca (*Musa textilis* Née) is a herbaceous, monocotyledonous and natural fiber-producing crop and is extensively grown in the Philippines. This crop is endemic to the country and resembles the banana plant, both belong to the family *Musaceae* (1). Unlike bananas, Abaca produces highly durable fibre but inedible fruits. Its fiber is deemed the strongest natural fiber, due to its high durability and tensile strength primarily used as ropes, cords, marine cordages and reinforcing materials. Abaca is now a preferred material in the production of pulp for specialty papers, currency notes and non-woven product applications making it the most valuable source of natural fiber due to its versatility. Due to its high export potential, driven by the increasing demand in the global market, the Philippines is known for being one of the largest exporters of Abaca. This top-dollar earner crop provides revenue for the country and significantly contributes to the gross domestic product (GDP) (2).

Among all agronomic crops produced in the country, Abaca is considered one of the major export commodities that significantly contribute to the growing demand for raw fibre, tea bags, pulp, paper, handicrafts and other related products (3). Although the Philippines is the world's largest producer of Abaca fibre, it falls behind in meeting the demands of the increasing consumer market for natural fibre. It faces several challenges, including pests and diseases, the absence of high-yielding varieties, limited information and extensive studies on cultivars, all of which result in decreased fibre productivity. This highlights the importance of urgent research on locally grown cultivars, particularly their morphological characterization, which is essential for varietal identification and breeding programs in enhancing fibre production in the country. Morphological characterizations are fundamental in the field of agriculture for varietal identification, crop improvement and breeding programs. Currently, there are three varieties registered under the National Seed Industry Council (NSIC): Abuab, Inosa and Tangongon (4) and these varieties are widely used for fibre production in the different parts of the country. Cultivars grown in the province of Aklan are not yet registered with NSIC and fully characterized. Moreover, detailed morphological data of these cultivars are limited and require further studies.

There are no more than 200 accessions documented in the Philippines, but not all species produce marketable fibres (5). Studies have shown that there are more than 700 accessions of Abaca maintained in field gene banks in the country, excluding those naturally occurring in the wild. They all exhibited different morphological characteristics and fibre yields (6-9). Describing the morphological characteristics of Abaca is essential for the identification, classification and documentation of the *Musaceae* family. It also provides valuable insights into how the Abaca plant interacts with its environment. This information aids in the identification and classification process by analyzing the external and internal structures of the plants. The morphological study of Abaca cultivars will offer crucial data on the physiological traits of Abaca in Aklan and help identify their unique characteristics. This knowledge can contribute to taxonomy and genetics which is highly significant for both farmers and researchers.

The Philippine Fiber Industry Development Authority (PhilFIDA) reported that Aklan secured the 5th position among the top 10 Abaca fibre-producing provinces in the year 2022, emerging as the primary contributor to Abaca production in the Western Visayas region. The Abaca yield in Aklan is predominantly attributed to five identified cultivars, namely *Bisaya*, *Tabukanon*, *Agbayanon*, *Totoo* and *Negro*. These cultivars are locally recognized and widely utilized by farmers throughout the province. However, despite their economic importance, these cultivars remain insufficiently studied and poorly understood in terms of their genetic, agronomic and morphological characteristics. The *Musa* group has a diversity of characters ranging from cluster structure, morphology and size of fruit/fingers and therefore has a multitude of cultivars (10). Somatic mutations are probably in charge of the remarkable morphological diversity obtained in *Musa* (11). Moreover, the breeders performed crossings between *Musa* varieties wild species and cultivars. This gives rise to hybrids with better disease resistance, adding to this group's genetic diversity (12). However, very little information is available on the morphological features of many varieties and cultivars due to the high heterogeneity of the Abaca and *Musa* families.

Characterization allows for simple and fast discernment between phenotypes and enables simple alignment of accessions, also serving to verify the trueness-to-type of homogenous samples, as it must be in the levels of the criteria used by breeders and other germplasm users (10). Moreover, there is still a lack of existing literature, technical guidance and phenological traits of Abaca cultivars in the province, necessitating further research for crop development and maximizing its potential. The study aims to describe and compare the morphological characteristics of the leaves, peduncles, inflorescence and fruit of five Abaca cultivars (*Tabukanon*, *Bisaya*, *Agbayanon*, *Negro* and *Totoo*) using Abaca qualitative and quantitative morphological descriptors from PhilFIDA for the identification of the variety or from other types. The information on the characterization of Abaca cultivars would help breeders, researchers, farmers and other users to identify and improve the crop. The data generated can also provide relevant information in crafting policies and enhancing programs and projects that could benefit the farmers, producers, stakeholders and government agencies in achieving the global demand for high-quality Abaca fibre.

Materials and Methods

Research design

This study employed a mixed research methodology that generated both qualitative and quantitative data. It is a systematic approach for gathering, evaluating and integrating both quantitative and qualitative research on the comprehensive morphological characterization of the Abaca across eight municipalities in the province of Aklan.

Study site

The field survey comparing the morphological characteristics of the five abaca cultivars was carried out across eight Abaca-producing municipalities in Aklan: Altavas, Balete, Banga, Ibajay, Libacao, Malinao, Makato and Madalag. According to PhilFIDA, these municipalities significantly contribute to the fibre production in the province. Fig. 1 illustrates the location of the study.

Sample collection

A minimum of 10 samples from each of the five Abaca cultivars, namely *Bisaya*, *Tabukanon*, *Agbayanon*, *Totoo* and *Negro* (Fig. 2a-6a, respectively), replicated three times within the municipality, were collected from the leading eight Abaca

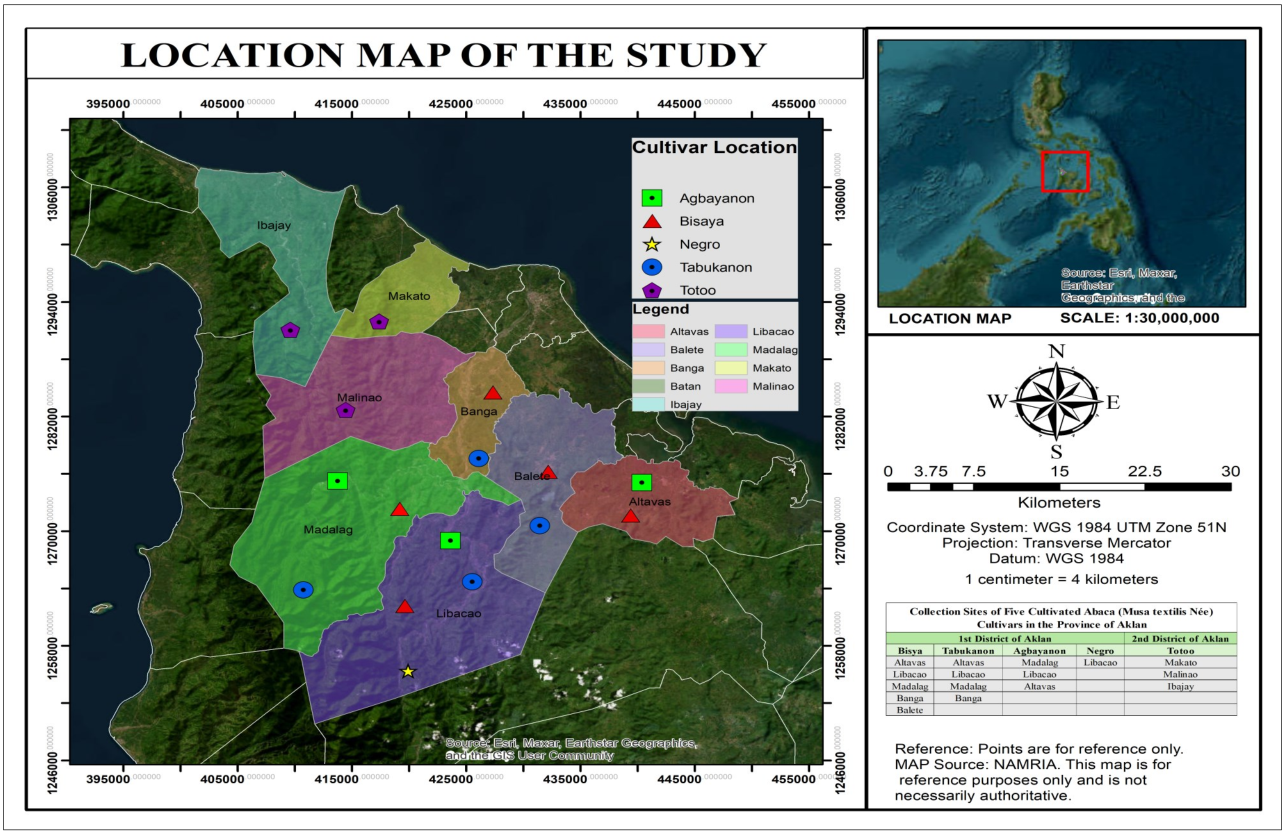

Fig. 1. Location map of the study.

municipalities in Aklan province. The flag leaves were subjected to obtain the morphological data of the Abaca cultivars to describe the characteristics according to its leaves, inflorescence and fruits.

Data gathered

Agroclimatic conditions: The agroclimatic conditions of the sites where the sample plants were collected, including rainfall, soil type, vegetation cover and elevation, were gathered. Rainfall data was sourced from the Global Historical Weather and Climate Data in the identified sites. This information provides the annual rainfall during the growing season of the Abaca cultivars in those locations. The soil type for the identified sites was determined using data from the Bureau of Soils and Water Management (BSWM). Elevation was measured and recorded using a geographical positioning system (GPS). Furthermore, vegetation cover information was obtained from the most recent data provided by the National Mapping and Resource Information Authority (NAMRIA).

Leaves: Morphological characteristics of leaves, peduncles, inflorescences and fruits of the Abaca cultivars were evaluated through validation and comparison of botanical descriptors of Abaca (12) as provided by PhilFIDA. Data on the different Abaca cultivars regarding its leaves, peduncle, inflorescences and fruits were collected on-site using the prescribed measurement procedures. A minimum of ten mature Abaca replicated three times within the selected municipality was analyzed. The selected sample plants of the five-cultivar exhibiting a flag leaf were subjected for analysis to obtain the data needed differentiate the growth performance and morphological characteristics of the different Abaca cultivars in the field, in terms of leaf and petiole habit, lamina tip shape (LTS), lamina-based handedness (LBH), lamina base equality (LBE), leaf length (cm), leaf width (cm) and petiole length (cm).

Peduncle: The peduncle serves as the primary stem that provides support to either a single flower or a cluster of flowers. Subsequently, it also bears the weight of the fruit. Originating from the main stem, this central stalk holds multiple pedicels. Bracts or modified leaves may be present at the nodes of the peduncle. Peduncle is the stalk that supports the flowers and fruits of the Abaca, the peduncle length, width, circumference and number of nodes with and without fruit were measured (13, 14).

Inflorescence: The height of the pseudostem increases progressively as leaves emerge sequentially, reaching its peak when the inflorescence appears at the plant's apex (15). The male and female flower of the Abaca was collected and observed from thirty sample plants per cultivar. Bud size length (cm), width (cm), shape, bract base shape and bract apex shape were recorded and measured.

Flowers of the Abaca plant: The plant undergoes the development of both male and female flowers, although they mature at distinct time intervals, ensuring that Abaca plants are naturally inclined towards cross-pollination (16). Hence, length of male and female flowers, compound tepal, free tepal, style, stigma and stamen were measured using a ruler in centimetres.

Fruit: The Abaca fruit, which emerges from the female flower, resembles its botanical relative, the banana, characterized by green skin and white pulp. However, unlike the banana, the Abaca fruit is unsuitable for consumption due to the substantial presence of large black seeds (17). Moreover, the number of hands, fruits or fingers, fruit length (cm) and fruit shape were recorded and measured.

Statistical tool analysis

The data were encoded/tabulated using Microsoft Excel 2020 and analysed using R statistical software (version 4.4.3, R Core

Team, 2023). A linear mixed-effects model (LMM) was employed to manage data variability and handle an unbalanced design, certain cultivars are not present in specific locations. In the model, locations were included as a random effect to handle the variability in sampling sites, while variety was considered as a fixed effect to evaluate the influence of different Abaca cultivars on morphological traits. The fixed effect of variety was tested using ANOVA derived from the LMM to assess significant differences in morphological characteristics among the Abaca cultivars. Significant results were further analysed using Tukey's HSD method at 5 % level to determine differences between cultivars.

Results and Discussion

Agroclimatic condition

According to global historical weather and climate data, Aklan typically receives about 82.24 millimetres (3.24 inches) of precipitation and has 162.27 rainy days (44.46 % of the time) annually (18). According to NAMRIA, as of 2020, 56 % of land cover in Aklan was natural forests and 15 % was non-natural tree cover, In Aklan, the top 4 regions represent 54 % of all tree cover. Madalag had the most tree cover at 24.4 kha compared to an average of 6.76 kha, followed by Malinao (24.4 k/ha), Libacao (12.2 k/ha), Ibajay (8.86 k/ha) and Balete (6.92 k/ha). Most of the plantation of Abaca where the study was conducted is fully shaded and under different vegetation. Most farmers practice intercropping the Abaca with other crops such as coconut, bamboo, cacao and other agronomic crops. In parts of hilly areas, most plantations are planted with leguminous trees (ie. rain trees and maganhop trees) as these trees help improve soil quality through their beneficial effects on biological, chemical and physical conditions (19). Additionally, all Abaca samples were collected in areas less than 500 elevation (masl) and a slope of <8 (gently sloping to undulating). According to the soil map from the BSWM, most of the soil in the identified municipalities where samples were collected, were classified as mountainous soil, alimodian clay loam, sigcay clay and umingan sandy loam.

Leaves

Table 1 shows the LMM ANOVA results for Abaca cultivars' leaf morphological characteristics. The results indicate that Abaca cultivars differ significantly in terms of leaf length, $F(4, 8.61) = 8.08$, $p = 0.005$; leaf width, $F(4, 8.35) = 4.71$, $p = 0.028$; and petiole length, $F(4, 9.22) = 9.95$, $p = 0.002$. Fig. 2b-e to 6b-e show leaf morphology of the cultivars. The results indicate that the five Abaca cultivars are morphologically different in terms of the leaves. Statistically, significant differences in terms of leaf length, width and petiole length were observed among the different Abaca cultivars gathered in the field. These may be attributed to different factors such as genetic diversity and environmental factors. According to the study which assessed the genetic diversity of Abaca (*Musa textilis* Née) germplasm in the Philippines using simple sequence repeat (SSR) markers, a high level of genetic variability was observed within the Philippine germplasm (20). Their findings indicated that genetic diversity was higher in the Visayas region compared to the Mindanao region. Hence, the present study was conducted in Western Visayas, which may explain the statistically significant morphological differences observed in the leaves of various abaca cultivars, likely attributable to their underlying genetic diversity. This highlights the importance of differentiating the morphology of the Abaca cultivars; likewise, morphological grouping of Abaca may provide a useful tool for the genetic improvement of this crop. Hence, further studies on the genomic profile are very important, which will help in breeding programs and improve genetic and phenotypic traits of the fibre of the Abaca.

The findings showed that environmental factors such as sunlight significantly affect the leaf morphology of the Abaca. Abaca are known to be shade-loving plants and are suited to grow best under shaded conditions. Abaca plants planted in the shaded condition showed a significant increase in leaf lengths up to 50 % and width compared to the plants grown in open areas exposed to the sunlight (0 % shade) (21). This response is attributed to the adaptive response avoidance of photoinhibition, photooxidation damage and midday depression that negatively affected the plants grown in full sunlight. In contrast, plants that are exposed to sunlight can cause stress and have adverse effects on the midday depression, thus negatively affecting the leaf morphology of the Abaca, particularly in seedling and early vegetative states (21).

Moreover, the petiole is a stalk that connects the blade with the leaf base. The blade is the major photosynthetic surface of the plant and appears green and flattened in a plane perpendicular to the stem. The petiole is a very important part of the Abaca plant as it holds the Abaca leaves connecting to the Abaca stalk, providing energy through photosynthetic activity. Variation of the petiole length is very important for leaf positioning and light acquisition. The leaf petiole of the Abaca directs the orientation of the leaves exposed to light and can significantly affect the

Table 1. ANOVA results for leaf morphological characteristics of abaca cultivars using linear mixed-effects model (LMM)

Fixed effects	Sum Square	Mean Square	NumDF	DenDF	F-value	p-value
Length of leaves						
Cultivars	7108.20	1777	4	8.61	8.08	0.005*
Width of leaves						
Cultivars	676.16	169.04	4	8.35	4.71	0.028 *
Petiole length						
Cultivars	1671.10	417.78	4	9.22	9.95	0.002 **

*Significant at 5 % level. **Significant at 1 % level. NumDf= Numerator Degrees of freedom; DenDf = Denominator Degrees of freedom. F-tests performed Satterthwaite's method to approximate Dendf.

photosynthetic activity of the plant due to exposure to light, hence impacting energy acquisition (22).

Hence, genetic and environmental factors could influence the leaf morphology of the Abaca cultivars in the province of Aklan resulting in different variations. Abaca plants are known to be location specific. Determining the leaf morphology of the plant can provide valuable insights for breeders and researchers to enhance the photosynthetic activity, stress tolerance of the Abaca and produce more fibre, which are instrumental to optimizing the productivity of the Abaca.

Leaf length

Table 2 shows EMMs for leaf morphological characteristics of Abaca cultivars, derived from the linear mixed-effects model (LMM) to account for random effects. For the cultivars, the shortest leaf length was produced by *Tabukanon* (M = 145 cm, 95 % CI [126, 164]), while the longest leaf length (M = 198 cm, 95 % CI [176, 219]) and leaf width (M = 58.8 cm, 95 % CI [50.5, 67.1]) were recorded with *Totoo.* Table 3 summarizes the Pairwise comparisons of leaf morphological characteristics among Abaca cultivars results showed longer leaf length of *Totoo* (MD = 52.64; SE = 13.0); *Bisaya* (MD = 50.87; SE = 10.3); and *Agbayanon* (MD = 47.58; SE = 12.9) compared with *Tabukanon.*

Registered varieties such as Inosa, Abuab and Tangongon range their leaf length from 171 to 220 cm. The finding shows that *Totoo* (198 cm) had longer leaves, followed by *Bisaya* (196 cm) and *Agbayanon* (192 cm) (13). However, results revealed that *Negro* (168 cm) and *Tabukanon* (145 cm) are below this range having the shortest leaf. The leaf is a key organ for plants' photosynthesis, respiration and transpiration. Its size and shape will affect photosynthetic efficiency and plant growth, which are closely related to plant growth potential, nutrient supply, yield, quality and resistance (23). Hence, a smaller leaf surface area can lead to less photosynthetic activity, thus less fibre yield will be extracted (24). Abaca's fibre is obtained from the leaves of the plant (1). Hence, larger leaves have a better chance of absorbing the available light due to the surface area and enhancing photosynthetic activity that could produce more fibre as it grows larger.

Leaf width

Statistics show that Abaca cultivars exhibited significant differences in leaf width, with cultivars *Agbayanon* and *Totoo* showing the widest leaf. EMMs revealed that *Totoo* showed the widest leaf (M = 58.8 cm, 95 % CI [50.5, 67.1]) and *Agbayanon* (M = 58.5 cm, 95 % [49.6, 67.4]) while *Tabukanon* shows the narrowest leaf width (M = 41.6 cm, 95 % CI [34.1, 49.0]) compared to other cultivars (Table 2). Additionally, Tukey's HSD pairwise comparisons further confirm that *Totoo* (MD = 17.24, SE = 5.04) had significantly wider leaves than *Tabukanon*.

Data indicates unique variation in terms of leaf width showing *Tabukanon* having the narrowest leaves (41.6 cm) compared to *Totoo* (58.8 cm) having the widest leaf followed *Agbayanon* (58.5 cm), *Negro* (54.9 cm) and *Bisaya* (49.0 cm). Compared to registered varieties, Inosa variety showed the narrowest leaf width (48 cm), while Tangongon and Abuab varieties have the widest leaves (70 cm) (14). Wider leaves are present in areas where water is available to enhance the transpiration rates and facilitate cooling. Abaca plant stems are made up of 93 % water and 1.3-5 % fibre (25). Large leaves have a better chance of absorbing the available light. The plant needs that light to create food through photosynthetic activity. Large, wide leaves are an adaptation to helping the plant make food while in a shady environment. The variation in leaves in terms of the width of the plant may be due to environmental stress such as water scarcity or hot temperatures (26).

Petiole length

EMMs showed that *Agbayanon* had the longest petiole length (M = 52.1 cm, 95 % CI [42.7, 61.6]) while *Tabukanon* produced the shortest petiole length (M = 26.4 cm, 95 % CI [18.6, 34.2]). The Tukey's HSD pairwise comparisons results (Table 3) further showed that *Bisaya* (MD = 23.54, SE = 4.50), *Totoo* (MD = 23.12, SE = 5.27) and *Agbayanon* (MD = 4.66, SE =

Table 2. Estimated Marginal Means (EMMs) for leaf morphological characteristics of Abaca cultivars

Characteristics	EMM	SE	95 % CI	
			Lower Bound	Upper Bound
Length of the leaves (cm)				
Agbayanon	192	10.28	170	215
Bisaya	196	7.53	179	212
Negro	168	18.43	127	210
Tabukanon	145	8.66	126	164
Totoo	198	9.72	176	219
Width of the leaves				
Agbayanon	58.5	4.04	49.6	67.4
Bisaya	49.0	2.90	42.6	55.4
Negro	54.9	7.53	38.1	71.7
Tabukanon	41.6	3.38	34.1	49.0
Totoo	58.8	3.75	50.5	67.1
Petiole length				
Agbayanon	52.1	4.28	42.7	61.6
Bisaya	50.0	3.02	43.3	56.6
Negro	47.5	8.27	29.2	65.8
Tabukanon	26.4	3.54	18.6	34.2
Totoo	49.5	3.90	41.0	58.1

SE= standard error; CI= confidence interval.

Table 3. Pairwise comparisons of leaf morphological characteristics of Abaca cultivars

Cultivars		Length of leaves		Width of leaves		Petiole length	
i	j.	Estimate (MD)	SE	Estimate (MD)	SE	Estimate (MD)	SE
Agbayanon	***Bisaya***	-3.29	11.7	9.544	4.72	2.17	5.09
	Negro	24.35	19.5	3.594	8.01	4.66 *	8.80
	Tabukanon	47.58 *	12.9	16.952	5.17	25.71	5.55
	Totoo	-5.06	14.1	-0.287	5.51	2.59	5.79
Bisaya	***Negro***	27.64	19.3	-5.951	7.92	2.49	8.72
	Tabukanon	50.87 *	10.3	7.407	4.16	23.54*	4.50
	Totoo	-1.78	12.3	-9.832	4.74	0.42	4.93
Negro	***Tabukanon***	23.23	19.4	13.358	7.95	21.05	8.73
	Totoo	-29.42	20.8	-3.881	8.41	-2.07	9.14
Tabukanon	***Totoo***	-52.64 *	13.0	-17.239 *	5.04	-23.12 **	5.27

Variety i and j denote the two Abaca cultivars being compared. MD=mean difference; SE=standard error. *****Significant at 5 % level. **Significant at 1 %. The Tukey's HSD method was used for post-hoc pairwise comparisons to control for family-wise error rates.

8.80) showed significantly longer petioles compared to *Tabukanon*.

The registered varieties range their leaf length from 48 cm (Inosa) up to 70 cm (Abuab and Tangongon) (14). Findings showed that T*abukanon* (26.4 cm) consistently shows the shorter leaf petiole among cultivars, which was lower than the registered variety range. In comparison, *Agbayanon* (52.1 cm) shows the longest followed by *Bisaya* (50 cm), *Totoo* (49.5 cm) and *Negro* (47.50 cm). The petiole is a stalk that connects the blade with the leaf base. The blade is the major photosynthetic surface of the plant and appears green and flattened in a plane perpendicular to the stem. The petiole is a very important part of the Abaca plant as it holds the Abaca leaves connecting to the Abaca stalk providing energy through photosynthetic activity, variation of the petiole length is very important for leaf positioning and light acquisition. Longer petioles have more advantages over other cultivars as they can position the surface of the leaves to capture lighter and optimize photosynthetic activity. It was found that some characteristics of Abaca fibre such as strength and physical properties depend on the position of its leaves (27).

Other leaf morphology

Other leaf morphology was also observed and described using descriptors from PhilFIDA (14) such as petiole margin corrugation (Fig. 2c-6c), petiole margin color (Fig. 2d-6d), lamina tip shape and lamina base (Fig. 2e-6e). Petiole margin corrugation was present in *Negro*, *Agbayanon* and *Totoo*, but absent in *Bisaya* and *Tabukanon*. In terms of lamina tip shape, no differences were observed between cultivars, which all had a blunt or rounded leaf apex. In addition, all Abaca cultivars exhibited right-handed lamina base, meaning that lamina base on the right side was larger than that on the left side. That said, base equality was rather variable as most cultivars displayed a markedly unequal base (>3 cm asymmetrically) when only Negro revealed as a (sub-equal) symmetric base, with <3 cm asymmetrical difference. The data show that leaf morphology varies a lot between leaves and between branches, indicating unique and distinct phenotypes. The differences in phenotypic traits observed can be attributed to genetic factors and environmental components and were discussed in several studies. This has vital implications for breeding programs to improve fibre quality and yield in Abaca cultivation. Knowledge of the morphological diversity might aid in choosing adequate cultivars for environmental conditions which would improve productivity.

Peduncle

Table 4 shows the results of the LMM ANOVA for peduncle morphological characteristics of Abaca cultivars. The results indicate that Abaca cultivars differ significantly in terms of peduncle length, $F(4, 9.66) = 8.52$, $p = 0.003$; width, $F(4, 7.82) = 13.55$, $p = 0.001$; circumference, $F(4, 11) = 131.96$, $p<0.001$; and number of notes with fruit, $F(4,11) = 12.00$, $p<0.001$. No significant effects were seen for empty node count ($p=0.512$) (Fig. 2f-6f).

This study found highly significant differences in peduncle length among all Abaca cultivars. Width, circumference and fruiting nodes remained constant in terms of flowerless nodes. The peduncle is the stalk that supports the inflorescence, whose female flowers will develop into fruits. Hence, this plant part is crucial for the

Table 4. ANOVA results for peduncle morphological characteristics of Abaca cultivars using Linear Mixed-Effects Model (LMM)

Fixed effects	Sum Square	Mean Square	NumDF	DenDF	F-value	p-value
Peduncle length						
Cultivars	1010.40	252.610	4	9.66	8.52	0.003**
Peduncle width						
Cultivars	6.67	1.668	4	7.82	13.55	0.001**
Peduncle circumference						
Cultivars	271.23	67.804	4	11	131.96	p<0.001**
Number of empty nodes						
Cultivars	0.198	0.049	4	9.14	0.88	0.512
Number of nodes with fruit						
Cultivars	12.449	3.112	4	11	12.00	p<0.001**

*Significant at 5 % level. **Significant at 1 % level. NumDf= Numerator Degrees of freedom; DenDf = Denominator Degrees of freedom. F-tests performed Satterthwaite's method to approximate Dendf.

reproductive process which aids in assessing the overall crop productivity of the plants. The peduncle doesn't produce fibre; however, this plant part is an indicator of maturity and determines the proper time to harvest the fibre. This can also be an indicator of overall plant vigour, supplying nutrients to the flowers, fruits and seeds aiding vegetative reproduction. Classifying the variation of Abaca's peduncles can be used to identify unique markers from other cultivars. Moreover, Musa is prone to wind stress hence affecting the reproductive stage during natural calamities and stress, shorter or smaller peduncles are vulnerable to wind stress while thicker or longer peduncles have a chance to break easily due to wind stress and other environmental stress. By analysing variations in the peduncle of Abaca, it may be possible to identify unique markers distinguishing specific cultivars. Furthermore, since the *Musa* species are prone to wind stress, peduncle traits are critical under natural calamities and stress conditions.

Peduncle length

Data shows that Abaca cultivars show significant differences in terms of peduncle width, $F(4, 7.82) = 13.55$, $p = 0.001$). Among the varieties, Negro produced the longest peduncle length ($M = 59.8$ cm, 95% CI [44.2, 75.3]) as shown in Table 5. Hence, this is supported by the Tukey's HSD pairwise comparison results in Table 6, *Negro* produced the significantly longest peduncle width among the cultivars, with the mean differences in the following order: *Tabukanon* (MD = 2.84 cm, SE = 0.46), *Bisaya* (MD = 2.75 cm, SE = 0.46), *Totoo* (MD = 2.50 cm, SE = 0.49) and *Agbayanon* (MD = 2.08 cm, SE = 0.46).

It is a floral stem developed from the rhizome's meristem (growing point) that grows through the middle of the pseudostem and emerges at the top of the plant. Part of this stalk supports the banana bunch, hanging from the plant. Moreover, it is a crucial pathway for nutrient transportation, photosynthate and a water-conducting bridge between the developing bunch and the plant. Peduncle length has huge significance in mechanical stability, plant architecture and supporting the reproductive part of the Abaca. Moreover, *Negro* showed superior peduncle traits while *Tabukanon* showed the shortest length which could be helpful information for genetic selection for breeding programs. Peduncle also helps to provide a better position, extend the flowers for the pollinators, disperse seeds and enhance reproductive efficiency.

Peduncle width

Results showed that the *Negro* cultivars had the widest peduncle (EMM = 6.96 cm, 95 % CI [5.98, 7.94]), whereas *Tabukanon* has the narrowest (EMM = 4.12 cm, 95 % CI [3.67, 4.57]). Moreover, Tukey's HSD pairwise comparisons confirmed that *Negro* has a significantly wider peduncle than *Tabukanon* (MD = 2.84 cm, SE = 0.46), *Bisaya* (MD = 2.75 cm, SE = 0.46), *Totoo* (MD = 2.50 cm, SE = 0.49) and *Agbayanon* (MD = 2.08 cm, SE = 0.46).

A wider peduncle could be more advantageous to the plants as it provides nutrient and water transport aiding the development of reproductive parts of the plant

Table 5. Estimated Marginal Means (EMMs) for peduncle morphological characteristics of Abaca cultivars

Characteristics	EMM	SE	95 % CI	
			Lower Bound	Upper Bound
Peduncle length				
Agbayanon	51.0	3.55	43.2	58.8
Bisaya	39.1	2.49	33.6	44.5
Negro	59.8	7.03	44.2	75.3
Tabukanon	36.3	2.93	29.8	42.7
Totoo	53.9	3.21	46.8	61.0
Peduncle width				
Agbayanon	4.88	0.243	4.35	5.42
Bisaya	4.21	0.178	3.82	4.1
Negro	6.96	0.436	5.98	7.94
Tabukanon	4.12	0.205	3.67	4.57
Totoo	4.47	0.230	3.96	4.98
Peduncle circumference				
Agbayanon	16.62	0.460	15.60	17.63
Bisaya	6.31	0.321	5.61	7.02
Negro	16.35	0.940	14.28	18.42
Tabukanon	12.97	0.379	12.14	13.80
Totoo	14.77	0.414	13.86	15.68
Number of empty nodes				
Agbayanon	2.34	0.153	2.01	2.68
Bisaya	2.07	0.107	1.83	2.30
Negro	2.21	0.308	1.53	2.88
Tabukanon	2.04	0.126	1.76	2.31
Totoo	2.11	0.138	1.81	2.42
Number of nodes with fruit				
Agbayanon	7.75	0.327	7.03	8.47
Bisaya	6.31	0.228	5.81	6.81
Negro	7.15	0.668	5.68	8.62
Tabukanon	5.19	0.269	4.59	5.78
Totoo	6.82	0.294	6.18	7.47

SE= standard error; CI= confidence interval.

Table 6. Pairwise comparisons peduncle morphological characteristics of Abaca cultivars

Cultivars		Peduncle length		Peduncle width		Peduncle circumference		Number of nodes with fruit	
i	j.	Estimate (MD)	SE	Estimate (MD)	SE	Estimate (MD)	SE	Estimate (MD)	SE
Agbayanon	*Bisaya*	11.93	4.27	0.67	0.28	10.31 **	0.56	1.44 *	0.40
	Negro	-8.75	7.47	-2.08 *	0.46	0.27	1.00	0.60	0.71
	Tabukanon	14.71	4.64	0.76	0.31	3.65**	0.61	2.56**	0.43
	Totoo	-2.91	4.78	0.42	0.34	1.84	0.62	0.93	0.44
Bisaya	*Negro*	-20.68	7.42	-2.75 **	0.46	-10.04**	0.99	-0.84	0.71
	Tabukanon	2.78	3.78	0.09	0.24	-6.66**	0.50	1.13	0.35
	Totoo	-14.83 *	4.06	-0.26	0.29	-8.46**	0.52	-0.51	0.37
Negro	*Tabukanon*	23.46	7.42	2.84**	0.46	3.38*	0.99	1.96	0.70
	Totoo	5.85	7.73	2.50 **	0.49	1.77	1.03	0.33	0.73
Tabukanon	*Totoo*	-17.62 *	4.35	-0.35	0.31	-1.80	0.56	-1.64 **	0.40

*Significant at 5 % level. **Significant at 1 % level. NumDf= Numerator Degrees of freedom; DenDf = Denominator Degrees of freedom. F-tests performed Satterthwaite's method to approximate Dendf.

such as flowers, fruits and seeds. Moreover, a wider peduncle can reduce stress conditions such as strong wind and calamities as it provides good stability. Hence, morphological variation in terms of the peduncle is vital and could be further used in research, as an indicator for farmers and use as a phenotypic marker for breeding purposes. Moreover, cultivars with wider peduncles such as *Negro* and *Agbayanon* can be used in areas, provinces and regions that are prone to strong wind and typhoon calamities where they can withstand environmental stress. Meanwhile, *Tabukanon* with the narrowest peduncle, should be planted in more protective and covered vegetation or environment. A narrower peduncle could also limit the ability of the plant to cope with stress hence reducing the growth performance and fibre yield of the Abaca.

Peduncle circumference

Agbayanon cultivar shows the largest circumference, (M = 16.62 cm, 95 % CI [15.60, 17.63]), meanwhile *Bisaya* cultivar shows the smallest circumference, (M = 6.31 cm, 95 % CI [5.61, 7.02]), as shown in Table 5. Furthermore, pairwise comparison revealed (Table 6) that *Bisaya* had the smallest circumference among the cultivars, significantly differing from *Agbayanon* (MD = -10.31 cm, SE = 0.56), *Negro* (MD = -10.04 cm, SE = 0.99), *Totoo* (MD = -8.46 cm, SE = 0.52) and *Tabukanon* (MD = -6.66 cm, SE = 0.50).

The circumference of the peduncle is vital to the structural integrity of the reproductive organs of the Abaca as it carries the flowers and fruit of the Abaca. Hence, a larger circumference can provide more support for the fruit of the Abaca. Research studies revealed that there were morphological differences in *Musa* species particularly in the study of the *Musa* clones in Leyte where data revealed wide variation among clones for all traits evaluated (28). Results on the peduncle circumference were the same as other peduncle parameters. *Negro* shows good structural stability for the Abaca plants as it has a larger circumference which could be more advantageous and provide resilience against mechanical damages such as environmental stress, typhoon and strong winds. In contrast, *Bisaya* and *Tabukanon* with smaller circumferences are more vulnerable to breakage under stress environments.

Number of empty nodes

The number of empty nodes with no flowers and fruits remained constant and showed minimal variability across all cultivars. Results revealed that no significant effects were observed in terms of empty node count ($p=0.512$). Results suggest that cultivars don't allocate their resources in the first 2 nodes of the reproductive part of the Abaca (Fig. 2f-6f). However, it still provides valuable information on the overall growth pattern of the plant and genetic uniformity. Empty nodes can be advantageous in Abaca cultivars since it does not allocate nutrients and resources for reproductive development, thus focusing only on fibre yield. The study suggests that uniformity in empty nodes can be an indicator of the uniform potential of fibre yield production and genetically conserved traits as its resources are allocated for fibre production rather than reproductive growth.

Number of nodes with fruit

Agbayanon showed a significantly higher node count (M = 7.75, 95 % CI [7.03, 8.47]) with fruit compared to *Tabukanon* (M = 5.19, 95 % CI [4.59, 5.78]), as shown in the EMMs (Table 5). In support, HSD Tukey's pairwise comparison showed *Agbayanon* had a significantly higher node count with fruit compared to *Tabukanon* (MD = 2.56, SE = 0.43) and *Bisaya* (MD = 1.44, SE = 0.40) as shown in Table 6. Fig. 2g-6g shows the number of nodes with fruit of the five cultivars. Hence, the *Agbayanon* cultivar is significantly different from *Tabukanon* and *Bisaya*, which exhibit the highest number of nodes with fruits. A higher number of fruiting nodes correlates to the number of fruits and seeds produced, which can be advantageous in breeding programs to produce more sources of seedlings vegetatively. Nowadays, Abaca is the primarily produced through suckers and is not frequently produced sexually.

Understanding the number of nodes with fruit in an Abaca plant can provide valuable insights into the reproductive capacity in producing fruits, seeds and fibre yield performance. Although Abaca is used and primarily cultivated for its fibre, several nodes with fruit have a major role in growth performance and fibre yield. A higher number of nodes with fruits shows good performance in the reproductive activity of the plant, indicating the density of successfully pollinated flowers thus producing more fruits, which is also crucial for research and breeding programs.

However, the number of nodes with fruit could directly influence fibre yield as may it allocate its nutrients to the reproductive development in fruits which can impact the number of fibres produced and quality (tensile strength). Hence, a larger number of node fruits should be planted in environments with good and balanced conditions. Moreover, significant differences could also indicate genetic variability. Identifying the number of nodes of fruit helps in varietal identification, aids in breeding programs, agronomic production, cultural management and optimizing the fibre yield performance of Abaca.

Inflorescence

Abaca reaches maturity and begins to exhibit inflorescence or a flag leaf approximately 18 to 24 months after planting, though some cultivars mature in a shorter period depending on the variety. One of the key indicators of an Abaca plant's readiness for harvest is the presence of a flag leaf or inflorescence (flower clusters) emerging from the pseudostem. The *Musaceae* family is monoecious, meaning the Abaca inflorescence comprises both female (lower portion) and male flowers (upper portion) on the same plant, enclosed by bracts exhibiting dark reddish-brown mosaic patterns. The flowers are ebracteate, unisexual, zygomorphic and epigynous. *Musa* family, whether in wild species or cultivated, are notable for their striking inflorescences, which can be of a unique shape, large size and varied color (29). Abaca's inflorescence comprises a peduncle (flower stalk), an inflorescence axis (main flowering stalk), bracts, female flowers, male flowers and a terminal bud.

The inflorescence of *Musa* species develops from the base of the plant (terminal meristem) and emerges through the pseudostem, which is composed of overlapping leaf sheaths from which fibres are extracted. The flower bud can form and emerge at any time of the year (30). The Abaca inflorescence's development begins with female flower emergence from the flag leaf. The initial stage involves the formation of one to four large bracts, ranging from 12 to 20 cm in size, which enclose the developing female flowers that later develop into ovaries (fruit). Each nodal cluster contains 12 to 20 flowers arranged in two rows. A cluster's flowers typically function as either male or female, but some may also be hermaphroditic (both male and female) or neuter (neither male nor female) (31). Through every four clusters, the first three to nine clusters called hands, become female flowers and turn into edible fruits, called fingers. The next clusters, at a distance from the center, show male traits and have unfertilized fruits (32). This is called the male bud of the Abaca plant, which contains the male flowers.

Table 7 presents the result of LMM ANOVA for the inflorescence morphological characteristics of different Abaca cultivars This analysis demonstrates great variation in bud length, $F(4, 5.67) = 22.45$, $p = 0.001$; bud width, $F(4, 5.55) = 46.82$, $p < 0.001$; and circumference, $F(4, 11) = 14.93$, $p < 0.001$ between Abaca cultivars. Fig. 2f-6f shows the inflorescence of the five Abaca cultivars. It is also observable, based on studies, that Abaca cultivars are diverse with significant differences in inflorescence morphology, as observed in bud length, width and circumference. The results could be due to genetic diversity and environmental adaptability. On average, *Bisaya* appeared with significantly shorter buds in length, width and circumference than *Agbayanon* and *Negro*. These findings pointed out the genetic diversity of Abaca cultivars that is essential for genetic selection and breeding programs to gain the best traits and maximize the production of fibre yield to cater to the growing demand for Abaca fibre.

Male bud

All morphological traits, including bud shape, bud size, bract color and behavior of the different cultivars in Aklan, specifically, *Bisaya*, *Tabukanon*, *Agbayanon, Totoo* and *Negro* were described using Abaca descriptors provided by PhilFIDA (14). These parameters are crucial factors in identifying and classifying cultivars in Aklan. Fig. 2l-6l shows the male buds of the five cultivars.

Male bud shape and size

All cultivars in Aklan exhibited a lanceolate bud shape, characterized as buds that are in spearhead, narrow, elongated and sharp point at the end (Fig. 2l-6l). As shown in the ANOVA table for male bud length, no significant differences were observed in terms of male bud size due to most cultivars, including *Bisaya*, *Tabukanon*, *Agbayanon* and *Totoo* range from 21-30 cm in length, except for *Negro* cultivar showing the longest male bud, exceeding 31 cm in length.

No variation was observed in terms of bract shape, as the table shows all the cultivars are categorized as intermediate, which means the shape exhibits balance shape, it is in between narrow or round shapes, or the buds are not perfectly rounded or pointed. The same

Table 7. ANOVA results for inflorescence morphological characteristics of Abaca cultivars using Linear Mixed-Effects Model (LMM)

Fixed effects	Sum Square	Mean Square	NumDF	DenDF	F-value	p-value
Length of bud						
Cultivars	129.54	32.385	4	5.67	22.45	0.001 **
Width of bud						
Cultivars	8.53	2.13	4	5.55	46.82	p<0.001 **
Circumference						
Cultivars	89.44	22.36	4	11	14.93	p<0.001 **

*Significant at 5 % level. **Significant at 1 % level. NumDf= Numerator Degrees of freedom; DenDf = Denominator Degrees of freedom. F-tests performed Satterthwaite's method to approximate Dendf.

observation was noted in bract apex shape, all cultivars were categorized as small shoulders, indicating All bracts are narrow or small shoulder, indicating a minimal widening (Fig. 2x-6x).

In terms of bract external face and coloration (Fig. 2x-6x), variations of colors and distinct markings were observed in some cultivars. Showing red-purple bract color were *Bisaya* and *Agbayanon* while *Tabukanon*, *Negro* and *Totoo* gave yellow-orange-red bracts. The most characteristic symptom for all cultivars was yellow discoloration at the apex of the bract. Also, two-thirds of all cultivars, including *Tabukanon*, *Agbayanon*, *Negro* and *Totoo*, did not present significant markings in the outer bract face; only *Bisaya* presented a discoloration in forms of stripes or lines (Fig. 2l & 2x).

Further variation was noted in bract base coloration. *Bisaya* and *Agbayanon* exhibited uniform pigmentation (color homogenous) extending to the base, whereas *Tabukanon*, *Negro* and *Totoo* displayed color discontinuation (loss of pigmentation) towards the base. Differences in bract-lifting behavior were also recorded; *Negro* and *Totoo* lifted only one bract at a time, while *Bisaya*, *Tabukanon* and *Agbayanon* lifted multiple bracts simultaneously. Despite these differences, all cultivars exhibited non-revolute bracts, meaning they lifted but did not roll or curl. Unlike banana species within the *Musa* genus, Abaca bracts do not develop a waxy layer on their surface (Fig. 2l-6l).

Male bud length

Table 8 shows the EMMs for inflorescence morphological characteristics of Abaca cultivars, derived from the linear mixed-effects model (LMM) to account for random effects. Among the cultivars, *Negro* produced the longest male bud (M = 33.7 cm, 95 % CI [24.2, 29.0]), while *Tabukanon* had the shortest (M = 21.4 cm, 95 % CI [19.1, 23.6]). A post-hoc Tukey's HSD test (Table 9) indicated that *Negro* exhibited significantly greater bud length compared to *Tabukanon* (MD = 12.37 cm, SE = 1.51), *Totoo* (MD = 11.65 cm, SE = 1.79), Bisaya (MD = 11.58 cm, SE = 1.48) and *Agbayanon* (MD = 7.14 cm, SE = 1.52). Additionally, *Agbayanon* demonstrated significantly longer bud length than *Tabukanon* (MD = 5.22 cm, SE = 1.04) and *Bisaya* (MD = 4.43 cm, SE = 0.94).

Male bud size of NSIC-registered varieties such as Inosa, Tangongon and Abuab ranges from 21 to 30 cm (14). In contrast, bud lengths for Abaca cultivars were found 21.4 cm to 33.7 cm with the *Negro* having the longest bud

Table 8. Estimated Marginal Means (EMMs) for inflorescence morphological characteristics of Abaca cultivars

Characteristics	EMM	SE	95% CI	
			Lower Bound	Upper Bound
Length of the bud				
Agbayanon	26.6	1.082	24.2	29.0
Bisaya	22.2	0.927	20.0	24.3
Negro	33.7	1.576	30.2	37.3
Tabukanon	21.4	0.988	19.1	23.6
Totoo	22.1	1.197	19.3	24.9
Width of the bud				
Agbayanon	8.89	0.182	8.58	9.38
Bisaya	7.10	0.152	6.75	7.45
Negro	8.99	0.274	8.37	9.61
Tabukanon	8.22	0.164	7.85	8.59
Totoo	9.19	0.197	8.74	9.65
Circumference				
Agbayanon	25.0	0.786	23.3	26.7
Bisaya	20.1	0.547	18.9	21.3
Negro	27.9	1.604	24.4	31.4
Tabukanon	22.2	0.647	20.7	23.6
Totoo	24.8	0.707	23.2	26.3

SE= standard error; CI= confidence interval.

Table 9. Pairwise comparisons of inflorescence morphological characteristics of Abaca cultivars

Cultivars		Length of the bud		Width of the bud		Circumference	
i	j.	Estimate (MD)	SE	Estimate (MD)	SE	Estimates (MD)	SE
Agbayanon	***Bisaya***	4.43 *	0.94	1.88 **	0.17	4.88 **	0.96
	Negro	-7.15 *	1.52	-0.01	0.27	-2.87	1.70
	Tabukanon	5.22 *	1.04	0.76 *	0.19	2.86	1.03
	Totoo	4.50	1.61	-0.22	0.27	0.23	1.06
Bisaya	***Negro***	-11.58 **	1.48	-1.89 **	0.27	-7.75 **	1.70
	Tabukanon	0.79	0.83	-1.11 **	0.15	-2.02	0.85
	Totoo	0.07	1.51	-2.09 **	0.25	-4.65 **	0.89
Negro	***Tabukanon***	12.37 **	1.51	0.78	0.27	5.74 *	1.69
	Totoo	11.65 **	1.79	-0.20	0.34	3.10	1.75
Tabukanon	***Totoo***	-0.72	1.55	-0.98 *	0.26	-2.63	0.96

Variety i and j denote the two Abaca cultivars being compared. MD=Mean difference; SE=standard error. *****Significant at 5% level. **Significant at 1%. The Tukey's HSD method was used for post-hoc pairwise comparisons to control for family-wise error rates.

compared to NSIC varieties, while the other (*Tabukanon, Agbayanon* and *Bisaya*) cultivars were still within the range of NSIC varieties.

Male bud width

Significant differences were observed in bud width among cultivars. *Bisaya* exhibited the smallest bud width (M = 7.10 cm, 95 % CI [6.75, 7.45]), while *Negro* consistently had the largest (M = 8.99 cm, 95 % CI [8.37, 9.61]) (Table 8). Tukey's HSD pairwise comparisons (Table 9) showed that *Bisaya* had significantly smaller bud width than *Totoo* (MD = -2.09 cm, SE = 0.25), *Negro* (MD = -1.89 cm, SE = 0.27), *Agbayanon* (MD = -1.88 cm, SE = 0.17) and *Tabukanon* (MD = -1.11 cm, SE = 0.15).

Male bud circumference

The widest bud circumference was observed in *Negro* (M = 27.9 cm, 95 % CI [24.4, 31.4]), whilst the narrowest was observed in *Bisaya* (M = 20.1 cm, 95 % CI [18.9, 21.3]). Pairwise comparison revealed that *Bisaya* has a significantly smaller circumference than *Negro* (MD = -7.75, SE = 1.70), *Agbayanon* (MD = -4.88, SE = 0.96) and *Totoo* (MD = -4.65, SE = 0.89) while *Negro* has a significantly larger circumference than *Tabukanon* (MD = 5.74, SE = 1.69).

Male flower

Table 10 shows the results of the LMM ANOVA for male flower morphological characteristics of Abaca cultivars. The results indicate that Abaca cultivars differ significantly in terms of stamen length, $F\ (4, 11) = 4.28$, $p = 0.025$; compound tepal, $F\ (4, 11) = 3.74$, $p = 0.037$ and stigma, $F\ (4,11) = 13.30$, $p<0.001$. No significant effects were observed for the length of the male flower ($p=0.726$), free tepal ($p=.0501$); style ($p=0.196$). Meanwhile, Table 11 shows the EMMs for male flower morphological characteristics of Abaca cultivars, derived from the linear mixed-effects model (LMM) to account for random effects. Further tests were conducted on parameters that have significant differences. Table 12 shows the results of pairwise comparisons of inflorescence morphological characteristics among Abaca cultivars. Although ANOVA indicated significant differences, no significant pairwise differences were found among cultivars for stamen and compound tepal lengths. Fig. 2s - x to 6s - x presents the male flower parts of the five Abaca cultivars.

The study indicates that male flower morphological traits vary across all cultivars such as length of stigma showed statistical differences which can provide valuable information in identifying the cultivars. However, results also indicated no significant differences in other traits such as male flower length, free tepal and style length, which can't be used to identify traits across all the cultivars for varietal identification. Notable morphological characteristics were observed in the *Agbayanon* cultivar, which exhibited the longest male flower length and compound tepal. Moreover, the *Bisaya* cultivar outperformed other cultivars in terms of stamen and stigma length. On the other hand, *Negro* and *Totoo* showed lower values in some morphological traits (e.g. stigma). Male flowers are short-lived and usually abscise, leaving a clean male peduncle where they occur. The inflorescence meristem at the apex of the peduncle terminates when it forms a final circinus, or flower, of neuter or male flowers (33-36).

Male flower length

Male flowers are found toward the distal end of the inflorescence (37). The study showed that no significant differences were observed among all cultivars in terms of male flower length. Among the cultivars, *Agbayanon*'s male flower produced the longest length (M = 5.37 cm, 95 % CI [4.61, 6.12]), although the differences were not statistically significant according to the ANOVA results (Table 10). Meanwhile, *Negro* exhibited the shortest male flower length (M = 4.82 cm, 95 % CI [3.27, 6.36]) as shown in Table 11. Other *Musa* species' male flowers have an average of 5 cm long (*Musa mannii*, *Musa nagalandiana*, *Musa ruiliensis*, *Musa argentii*) and all are in 2 rows, falling with bracts. Most of the Abaca cultivars observed have an average of 6 male flowers with 2 rows. Moreover, the male flower length of the Abaca cultivars ranges from 4.82 cm to 5.37 cm with *Negro* as the lowest and *Agbayanon* as the longest mean male length. Fig. 2s - t to 6s - t presents the cluster of male flowers and the entire male flower parts.

Male stamen

Data revealed that significant differences were observed in stamen among all cultivars. Moreover, *Bisaya* had the longest stamen (M = 3.97 cm, 95 % CI [3.46, 4.47]), Additionally, *Agbayanon* exhibited the shortest stamen

Table 10. ANOVA results for male flower morphological characteristics of Abaca cultivars using Linear Mixed-Effects Model (LMM)

Fixed effects	Sum Square	Mean Square	NumDF	DenDF	F-value	p-value
Male flower						
Cultivars	0.59	0.15	4	11	0.52	0.726
Stamen						
Cultivars	4.44	1.11	4	11	4.28	0.025 *
Compound tepal						
Cultivars	3.87	0.97	4	11	3.74	0.037 *
Free tepal						
Cultivars	0.97	0.24	4	11	0.89	0.501
Stigma						
Cultivars	0.18	0.04	4	11	13.30	p<0.001*
Style						
Cultivars	0.24	0.06	4	11	1.82	0.196

*Significant at 5% level. **Significant at 1% level. NumDf= Numerator Degrees of freedom; DenDf = Denominator Degrees of freedom. F-tests performed Satterthwaite's method to approximate Dendf.

Table 11. Estimated Marginal Means for male flower morphological characteristics of Abaca cultivars

Characteristics	EMM	SE	95 % CI	
			Lower Bound	Upper Bound
Male flower length				
Agbayanon	5.37	0.344	4.61	6.12
Bisaya	4.87	0.240	4.34	5.40
Negro	4.82	0.703	3.27	6.36
Tabukanon	5.03	0.284	4.41	5.66
Totoo	5.21	0.310	4.53	5.89
Stamen				
Agbayanon	2.72	0.327	2.00	3.44
Bisaya	3.97	0.228	3.46	4.47
Negro	3.01	0.668	1.54	4.48
Tabukanon	2.78	0.269	2.18	3.37
Totoo	3.06	0.294	2.41	3.71
Compound tepal				
Agbayanon	4.17	0.327	3.45	4.89
Bisaya	3.65	0.227	3.15	4.16
Negro	3.47	0.667	2.00	4.94
Tabukanon	4.69	0.269	4.10	5.28
Totoo	3.41	0.294	2.77	4.06
Free tepal				
Agbayanon	2.99	0.336	2.25	3.73
Bisaya	3.37	0.234	2.86	3.88
Negro	2.51	0.685	1.00	4.02
Tabukanon	3.16	0.276	2.55	3.76
Totoo	2.83	0.302	2.17	3.50
Stigma				
Agbayanon	0.50	0.037	0.42	0.58
Bisaya	0.76	0.026	0.70	0.82
Negro	0.43	0.075	0.26	0.60
Tabukanon	0.61	0.030	0.54	0.68
Totoo	0.65	0.033	0.57	0.72
Style				
Agbayanon	2.98	0.117	2.73	3.24
Bisaya	2.98	0.081	2.81	3.16
Negro	2.75	0.238	2.22	3.27
Tabukanon	2.78	0.096	2.57	2.99
Totoo	2.70	0.104	2.47	2.93

SE= standard error; CI= confidence interval.

Table 12. Pairwise comparisons of male flower morphological characteristics of Abaca cultivars

Cultivars		Stamen		Compound tepal		Pistiliode		Stigma	
i	j.	Estimate (MD)	SE	Estimate (MD)	SE	Estimate (MD)	SE	Estimate (MD)	SE
Agbayanon	***Bisaya***	-1.25	0.40	0.51	0.40	2.00 **	0.19	-0.26 **	0.05
	Negro	-0.30	0.71	0.70	0.71	1.29 *	0.35	0.07	0.08
	Tabukanon	-0.06	0.43	-0.52	0.43	0.78 *	0.21	-0.11	0.05
	Totoo	-0.34	0.44	0.76	0.44	1.01 **	0.21	-0.15	0.05
Bisaya	***Negro***	0.95	0.71	0.18	0.70	-0.71	0.34	0.33 *	0.08
	Tabukanon	1.19	0.35	-1.04	0.35	-1.22 **	0.17	0.15 *	0.04
	Totoo	0.91	0.37	0.24	0.37	-0.99 **	0.18	0.11	0.04
Negro	***Tabukanon***	0.24	0.70	-1.22	0.70	-0.51	0.34	-0.18	0.08
	Totoo	-0.05	0.73	0.06	0.73	-0.28	0.36	-0.22	0.08
Tabukanon	***Totoo***	-0.28	0.40	1.28	0.40	0.24	0.19	-0.04	0.05

Variety i and j denote the two Abaca cultivars being compared. MD=Mean difference; SE=standard error. *****Significant at 5 % level. **Significant at 1 %. The Tukey's HSD method was used for post-hoc pairwise comparisons to control for family-wise error rates.

among the cultivars (M = 2.72 cm, 95 % CI [2.00, 3.44]). However, further tests using pairwise comparison (Table 12) did not yield significant differences within the group, this indicates that the stamen length can be a potentially reliable trait for varietal identification, but further validation is needed. Most species of *Musa* have an average of 2.5 cm stamen length (*Musa nagalandiana*; *Musa mannii*; *Musa argentii*). Moreover, all Abaca cultivars collected have 5 stamens and are cream in color (Fig. 2u - 6u), with *Bisaya* (3.97 cm) the longest followed by *Totoo* (3.06 cm), *Negro* (3.01 cm), *Tabukanon* 2.78 cm and *Agbayanon* with the shortest length of stamen.

Compound and free tepal

Study shows significant differences were detected across all the Abaca cultivars (F (4, 11) = 3.74, p = 0.037). EMMs shown in Table 10, show that among cultivars, *Agbayanon* was observed to have the longest compound tepal (M = 4.17 cm, 95 % CI [3.45, 4.89]), *Totoo* had the shortest compound tepal (M = 3.41 cm, 95 % CI [2.77, 4.06]). Despite the linear mixed-effects model (LMM) ANOVA showing significant variability, the pairwise comparison showed no significant differences within the specific cultivar, indicating no pronounced traits were observed. However, the compound tepal of Abaca cultivars ranges from 2.41 cm - 4.17 cm in length.

In terms of free tepal, *Bisaya* had the longest free tepal (M = 3.37 cm, 95 % CI [2.86, 3.88]) while *Negro* had the shortest free tepal M = 2.51 cm, 95 % CI [1.00, 4.02]). However, no significant differences were observed among all cultivars (p = 0.501). Data indicates no morphological variation in terms of length of free tepal was observed among all cultivars and does not influence the differentiation of morphological attributes of cultivars as shown in Table 12. Fig. 2w - 6w shows the free tepal of the five Abaca cultivars.

Compound tepal's basic color without considering lobe color is cream, with very few or no visible signs of pigmentation and the yellow lobe color of compound tepal was observed in all cultivars (Fig. 2w - 6w). Moreover, the longest compound tepal was observed in *Tabukanon* (4.69 cm), followed by *Agbayanon* (4.17 cm), *Bisaya (*4.17 cm), *Negro* (3.47 cm) and *Totoo* with the shortest compound tepal. Depending on the species and cultivars, some species also have at least 2.5 cm up to 5.5 cm compound tepal (*Musa argentii, Musa nagalandiana* and *Musa mannii*).

In terms of free tepal, translucent white free tepal color, oval free tepal shape and smooth free tepal appearance were observed among all cultivars. Little or no visible development was observed in the *Bisaya* (Fig. 2v) and *Tabukanon* (Fig. 3v), developed in *Agbayanon* (Fig. 4v) and very developed in *Totoo* (Fig. 5v) and *Negro* (Fig. 6v) cultivars in free tepal apex development. Male free tepal of Abaca cultivars show no significant differences; free tepal of Abaca cultivars in Aklan ranges from 2.51 to 3.16 cm in length.

Stigma and style

LMM ANOVA for stigma length exhibited highly significant differences in all cultivars (Table 10). *Bisaya* had the longest stigma recorded (M = 0.76 cm, 95 % CI [0.70, 0.82]), while *Negro* recorded the shortest stigma length (M = 0.43 cm, 95 % CI [0.26, 0.60]) as shown in EMMs (Table 11). *Bisaya* had longer stigma than *Agbayanon*, *Tabukanon* and *Negro*.

In terms of style, statistics showed no significant differences in all cultivars as shown in LMM ANOVA (Table 10). Results showed the length of the style range from 2.70 cm to 2.98 cm. This morphological trait is not a distinguishing factor in classifying the Abaca cultivars. Other characteristics of style and stigma were the same, such as style basic color (cream), shape (straight) and all were without pigmentation across all cultivars. Likewise, stigma has the same cream color. In comparison, other *Musa* species' length of stigma and style ranges from 2.2–2.4 cm long (*Musa mannii*), while other species have longer such as *Musa argentii* with 4.7 cm long,

Trait variation among Abaca cultivars suggests genetic diversity of floral morphology that warrants thorough study. Comparing the others about flower length and stigma on study was that *Negro* had the number length most. *Agbayanon* had longer stamen, free tepal, ovary and style than other cultivars. While *Bisaya* shows shorter stamen length and compound tepal, *Totoo* showed longest compound tepal and the shortest in free tepal. *Tabukanon* showed the shortest length of flowers, ovaries, stigma and style of female flowers. Flowers morphological differences of Abaca was different from each other. Female flowers are a very important reproductive trait of Abaca, as they provide fruits and seeds for genetic dispersal. Hence, the study shows variation in genetic diversity across cultivars. Fig. 2m - r to 6m - r presents the female flower parts of the five Abaca cultivars.

Table 13 shows the results of the LMM ANOVA for male flower morphological characteristics of Abaca cultivars. The results indicate that Abaca cultivars differ significantly in terms of length of female flower $F(4, 5.40) = 39.30$, $p < 0.001$, stamen length, $F(4, 11) = 7.75$, $p = 0.003$; compound tepal, $F(4, 11) = 20.14$, $p<0.001$; ovary, $F(4, 5.99) = 32.22$, $p<0.001$; stigma, $F(4,7.75)=5.33$, $p<0.023$; and style $F(4, 11) = 21.05$, $p<0.001$. EMM based on a linear mixed-effects model (LMM) used to account for random effects for morphological characteristics of female flowers of Abaca cultivars is presented in Table 14. Table 15 shows the pairwise comparisons results of female morphological traits among the Abaca cultivars. In addition, the study also emphasizes:

Female flower

Table 13. Results for male flower morphological characteristics of Abaca cultivars using Linear Mixed-Effects Model (LMM)

Fixed effects	Sum Square	Mean Square	NumDF	DenDF	F-value	p-value
Female flower						
Cultivars	13.14	3.28	4	5.40	39.30	p<0.001 **
Stamen						
Cultivars	2.47	0.62	4	11	7.75	0.003 **
Compound tepal						
Cultivars	6.52	1.63	4	11	20.14	p<0.001 **
Free tepal						
Cultivars	1.50	0.38	4	8.95	5.56	0.016 *
Ovary						
Cultivars	7.81	1.95	4	5.99	32.22	p<0.001 **
Stigma						
Cultivars	0.15	0.04	4	7.75	5.33	0.023 *
Style						
Cultivars	1.09	0.27	4	11	21.05	p<0.001 **

*Significant at 5% level. **Significant at 1% level. NumDf= Numerator Degrees of freedom; DenDf = Denominator Degrees of freedom. F-tests performed Satterthwaite's method to approximate Dendf.

Table 14. Estimated Marginal Means (EMMs) for female flower morphological characteristics of Abaca cultivars

Characteristics	EMM	SE	95 % CI	
			Lower Bound	Upper Bound
Female flower length				
Agbayanon	9.40	0.331	8.65	10.15
Bisaya	8.41	0.303	7.69	9.13
Negro	10.56	0.429	9.61	11.50
Tabukanon	6.96	0.314	6.23	7.68
Totoo	9.08	0.391	8.16	10.01
Stamen length				
Agbayanon	2.79	0.181	2.39	3.19
Bisaya	1.69	0.126	1.41	1.97
Negro	2.49	0.370	1.68	3.31
Tabukanon	2.02	0.149	1.69	2.35
Totoo	2.10	0.163	1.74	2.46
Compound tepal				
Agbayanon	4.18	0.183	3.78	4.58
Bisaya	2.99	0.127	2.71	3.27
Negro	4.30	0.373	3.48	5.13
Tabukanon	3.18	0.150	2.85	3.51
Totoo	4.50	0.164	4.14	4.87
Free tepal				
Agbayanon	3.95	0.185	3.54	4.36
Bisaya	3.20	0.139	2.90	3.51
Negro	3.46	0.321	2.73	4.18
Tabukanon	3.17	0.158	2.82	3.52
Totoo	2.93	0.179	2.53	3.33
Ovary				
Agbayanon	5.80	0.23	5.28	6.32
Bisaya	4.14	0.20	3.66	4.61
Negro	5.78	0.33	5.05	6.52
Tabukanon	3.80	0.22	3.30	4.29
Totoo	5.20	0.26	4.59	5.81
Stigma				
Agbayanon	0.759	0.058	0.632	0.885
Bisaya	0.732	0.042	0.638	0.825
Negro	0.882	0.103	0.651	1.113
Tabukanon	0.555	0.049	0.44	0.662
Totoo	0.807	0.055	0.686	0.928
Style				
Agbayanon	3.38	0.073	3.22	3.54
Bisaya	2.78	0.051	2.67	2.89
Negro	2.71	0.149	2.38	3.04
Tabukanon	2.63	0.060	2.49	2.76
Totoo	2.94	0.066	2.80	3.09

SE= standard error; CI= confidence interval.

All cultivars exhibited highly significant results for female flower length ($p < 0.001$). *Negro* produced the longest female flower of the cultivars (M = 10.56 cm, 95 % CI [9.61, 11.50]) In contrast, *Tabukanon* had the least female flower (M = 6.96 cm, 95 % CI [6.23, 7.68]), ovary (M = 3.80 cm, 95 % CI [3.30, 4.29]) as shown in Table 14. Further tests using pairwise comparison reveals that *Tabukanon* exhibited a significantly shorter female flower compared to *Agbayanon* (MD = -2.00 cm, SE = 0.21), *Negro* (MD = -1.99 cm, SE = 0.31) and *Totoo* (MD = -1.40 cm, SE = 0.34). *Bisaya* also had a significantly shorter female flower than *Agbayanon* (MD = -1.66 cm, SE = 0.19) and *Negro* (MD = - 1.65 cm, SE = 0.30).

Female flowers appear lower in the inflorescence and turn into fruits. Other *Musa* species such as *Musa argentina* have flower sizes 8.5-9.0 cm long (38), *Musa paradisiaca,* 5.2-6.2 cm in length (37) and *Musa manii* have 6.7-7 cm long (39). In comparison, *Negro* outperformed all the cultivars and was quite longer than other *Musa* species mentioned having the longest flower (10.54 cm), followed by *Agbayanon* (9.40 cm), *Totoo* (9.08 cm), *Bisaya* (8.41 cm) and *Tabukanon* (6.96 cm) as the shortest. Fig. 2m - n to 6m - n presents the cluster of ovaries and entire female flower, respectively.

Stamen

EMMs for female stamen length (Table 14) showed *Agbayanon* exhibited the longest stamen (M = 2.79 cm, 95 % CI [2.39, 3.19]), while *Bisaya* produced the shortest stamen length (M = 1.69 cm, 95 had stamen lengths much shorter than *Agbayanon* (MD = -1.11 cm, SE = 0.22) details, which can be seen in Table 16. Interestingly stamen length of the Abaca cultivars in Aklan are shorter than other *Musa* species (*Musa argentii* - 2.5-3.2 cm; *Musa ruiliensis* 5-4.5 cm; *Musa mannii* 2.6-3.2 cm). *Bisaya* showed the shortest stamen length (1.69 cm), followed by *Tabukanon* (2.02 cm), *Totoo* (2.10 cm) and *Negro* (2.49 cm) as the longest

Table 15. Pairwise comparisons female flower morphological characteristics of Abaca cultivars

Cultivars		Female flower		Stamen		Compound tepal		Free tepal	
i	j.	Estimate (MD)	SE	Estimate (MD)	SE	Estimate (MD)	SE	Estimate (MD)	SE
Agbayanon	*Bisaya*	0.99 *	0.23	1.11 **	0.22	1.19 **	0.223	0.745	0.205
	Negro	-1.16	0.37	0.300	0.393	-0.122	0.396	0.492	0.339
	Tabukanon	2.44 **	0.25	0.771	0.239	1.00 **	0.24	0.780	0.226
	Totoo	0.32	0.51	0.694	0.244	-0.323	0.246	1.022 *	0.258
Bisaya	*Negro*	-2.146 **	0.36	-0.806	0.391	-1.313 *	0.394	-0.254	0.333
	Tabukanon	1.454 **	0.20	-0.335	0.196	-0.189	0.197	0.035	0.181
	Totoo	-0.675	0.49	0.412	0.206	-1.514 **	0.208	0.276	0.226
Negro	*Tabukanon*	3.600 **	0.36	0.471	0.390	1.124	0.393	0.288	0.336
	Totoo	1.472	0.58	0.394	0.404	-0.201	0.408	0.530	0.368
Tabukanon	*Totoo*	-2.128 *	0.50	-0.078	0.221	-1.33 **	0.22	0.241	0.239

Cultivars		Ovary		Stigma		Style	
i	j.	Estimate (MD)	SE	Estimate (MD)	SE	Estimate (MD)	SE
Agbayanon	*Bisaya*	1.662 **	0.193	0.027	0.065	0.599 **	0.09
	Negro	0.013	0.312	-0.124	0.109	0.666 *	0.16
	Tabukanon	2.00 **	0.21	0.204	0.072	0.750 **	0.10
	Totoo	0.598	0.352	-0.049	0.079	0.433 **	0.10
Bisaya	*Negro*	-1.65 *	0.30	-0.151	0.108	0.067	0.16
	Tabukanon	0.340	0.171	0.177	0.058	0.152	0.08
	Totoo	-1.064	0.333	-0.076	0.069	-0.166	0.08
Negro	*Tabukanon*	1.99 **	0.31	0.327	0.108	0.084	0.16
	Totoo	0.585	0.423	0.075	0.117	-0.233	0.16
Tabukanon	*Totoo*	-1.40 *	0.34	-0.252 *	0.073	-0.317 *	0.09

Variety i and j denote the two Abaca cultivars being compared. MD= Mean difference; SE=standard error. *****Significant at 5% level. **Significant at 1%. The Tukey's HSD method was used for post-hoc pairwise comparisons to control for family-wise error rates.

stamen length (2.79 cm). Fig. 2o - 6o presents the stamen of the five Abaca cultivars.

Compound and free tepal

Significant differences were observed in compound and free tepal among all Abaca cultivars. EMMs revealed that *Totoo* yielded the longest compound tepal (M = 4.50 cm, 95 % CI [4.14, 4.87]). *Bisaya* produced the shortest compound tepal (M = 2.99 cm, 95 % CI [2.71, 3.27]) (Table 5). Further tests using Tukeys HSD pairwise comparison revealed, *Bisaya* was significantly shorter compared to *Totoo* (MD = -1.51 cm, SE = 0.20), *Negro* (MD = -1.31 cm, SE = 0.39) and *Agbayanon* (MD = -1.19 cm, SE = 0.22). Similarly, *Tabukanon* exhibited shorter compound tepal than *Totoo* (MD = -1.33 cm, SE = 0.22) and *Agbayanon* (MD = -1.00 cm, SE = 0.24). On the other hand, *Totoo* displayed the shortest free tepal (M = 3.95 cm, 95 % CI [3.54, 4.36]) and *Agbayanon* exhibited the longest free tepal (M = 3.95 cm, 95 % CI [3.54, 4.36]). In terms of free tepal, only *Agbayanon* showed significantly longer lengths compared to *Totoo* (MD = 0.22 cm, SE = 0.22) in Table 16.

Other compound tepals in *Musa species* are less than 4 cm long such as *Musa acuminata (*3.2-3.3cm), *Musa loklok* from Bario, Borneo deep green, have 5 cm while 4 cm compound tepal, *Musa nagalandiana* (2.5 cm) and free tepal (1 cm) from Nagaland, northeast India, *Musa mannii* compound tepal (3.8-4 cm) and free tepal (3.2-3.5 cm); *Musa argentii* compound tepal (4.5 cm) and free tepal (3.5 cm). In comparison, some Abaca cultivars in Aklan have longer compound tepals such as *Totoo* (4.50 cm), *Negro* (4.30 cm) and *Agbayanon* (4.18 cm), while there are some cultivars that are shorter such as *Tabukanon* (3.18 cm) and *Bisaya* (2.99 cm). Whereas the free tepal of all cultivars is very long with *Agbayanon* (3.95 cm) as the highest followed by *Negro* (2.46 cm), *Bisaya* (3.20 cm), *Tabukanon* (3.17 cm) and *Totoo* (2.93 cm) recording the shortest free tepal length. The compound's basic color is cream, with very few or no visible signs of pigmentation and the yellow lobe color of compound tepal was observed in all cultivars (Fig. 2q-6q).

Table 16. ANOVA results for leaf morphological characteristics of Abaca cultivars using Linear Mixed-Effects Model (LMM)

Fixed effects	Sum Square	Mean Square	NumDF	DenDF	F-value	p-value
Number of hands						
Cultivars	13.28	3.32	4	11	15.83	p<0.001
Number of fruits or finger						
Cultivars	40.46	10.12	4	11	32.80	p<0.001
Fruit length						
Cultivars	9.58	2.40	4	11	14.87	p<0.001

*Significant at 5 % level. **Significant at 1 % level. NumDf= Numerator Degrees of freedom; DenDf = Denominator Degrees of freedom. F-tests performed Satterthwaite's method to approximate Dendf.

For free tepals, all cultivars were observed to have translucent white free tepal color, oval free tepal shape and several folding under apex (corrugated) (Fig. 2p-6p). Meanwhile, variation in terms of free tepal apex development was observed. Little or no visible development was observed across all cultivars.

Stigma and style

The EMMs in Table 14, reflects *Negro* produced the longest stigma (M = 0.88 cm, 95 % CI [0.65, 1.11]), while *Agbayanon* exhibited the longest style (M = 3.38 cm, 95 % CI [3.22, 3.54]). On the other hand, *Tabukanon* had the shortest female flower stigma (M = 0.56 cm, 95 % CI [0.44, 0.66]) and style (M = 2.63 cm, 95 % CI [2.49, 2.76]). The pairwise comparison revealed that *Tabukanon* had a significantly shorter stigma (MD = -0.25 cm, SE = 0.07) and style (MD = -0.32 cm, SE = 0.09). In contrast, *Agbayanon* exhibited a significantly longer style compared to other cultivars, with the following mean differences: *Tabukanon* (MD = 0.75 cm, SE = 0.10), *Negro* (MD = 0.66 cm, SE = 0.16), *Bisaya* (MD = 0.60 cm, SE = 0.09) and *Totoo* (MD = 0.43 cm, SE = 0.10).

Musa loklok style and stigma length are around 4 cm long (40), while *Musa manii* style and stigma range from 3.1-3.2 cm long (39) and *Musa Argentii* style cream, 2.8-3 cm long, stigma cream, 5 mm diameter (38). In comparison, *Negro* (0.882 cm) has a longer stigma, followed by *Totoo* (0.807 cm), *Agabayanon* (0.759 cm) and *Bisaya* (0.732 cm), while *Tabukanon* garnered the shortest stigma (0.55 cm). In terms of style length, *Agbayanon* has a longer style compared to others, followed by *Totoo* (2.94 cm), *Bisaya* (2.78 cm), *Negro* (2.71 cm) and *Tabukanon* (2.63 cm) exhibiting a shorter style. The same observation across cultivars was observed in style basic color (cream), shape (straight) and all are without pigmentation. Likewise, stigma has the same cream color as shown in Fig. 2o-6o.

Ovary

Among cultivars, *Agbayanon* exhibited the longest ovary (M = 5.80 cm, 95 % CI [5.28, 6.32]), *Tabukanon* had the shortest ovary (M = 5.80 cm, 95 % CI [5.28, 6.32]). Further tests show that *Bisaya* exhibited significantly shorter lengths compared to *Agbayanon* (MD = -1.66 cm, SE = 0.19) and *Negro* (MD = -1.65 cm, SE = 0.30). *Tabukanon* displayed shorter ovary lengths compared to *Agbayanon* (MD = -2.00 cm, SE = 0.21), *Negro* (MD = -1.99 cm, SE = 0.31) and *Totoo* (MD = -1.40 cm, SE = 0.34) as showed in Table 15.

According to the general morphology of the *Musa* (41), the ovary of female flowers constitutes two-thirds of the length of the whole flower. *Musa* species have no greater than 5 cm long in ovary (*Musa manii*- 2.9-3.5 cm long; *Musa ruiliensis* - 5 cm long; *Musa argentii* - 4.5-5 cm long; *Musa nagalandiana* - 1.5 cm long). Moreover, some Abaca cultivars in Aklan are greater than 5 cm long (*Agbayanon* - 5.80 cm; *Negro* - 5.78 cm; *Totoo* - 5.20 cm) while *Bisaya* (4.14 cm) and *Tabukanon* (3.80 cm) are shorter or less the 5 cm long. Moreover, all ovaries across cultivars are arched. However, there are some variations in terms of ovary basic color, green color for *Totoo*, *Negro*, *Bisaya* and *Tabukanon* while cream color in *Agbayanon* but eventually going green when exposed (Fig. 2r - 6r).

Fruit

The study highlighted morphological differences in terms of fruit across all cultivars. Data shows that *Agbayanon* and *Totoo* cultivars recorded more fruits than other cultivars. However, *Negro* shows longer fruits as compared to others. The data directly contribute to the reproductive activity and information from breeding programs and reproduction of Abaca cultivars for research and optimizing the yield performance in meeting the demand. Table 16 shows the LMM ANOVA results for Abaca cultivars' fruit morphological characteristics. The results indicate significant difference among the Abaca cultivars in terms of number of hands, $F(4, 11) = 15.83$, $p < 0.001$; number of fruits or finger, $F(4, 11) = 32.80$, $p < 0.001$; and fruit length, $F(4, 11) = 14.87$, $p < 0.001$. Table 17 shows the EMMs for fruit morphological characteristics of Abaca cultivars, derived from the linear mixed-effects model (LMM) to account for random effects. Fig. 2g-k to 6g-k presents the fruit morphology of the five Abaca cultivars in Aklan.

Number of hands

Table 17. Estimated Marginal Means (EMMs) for fruit morphological characteristics of Abaca cultivars

Characteristics	EMM	SE	95 % CI	
			Lower Bound	Upper Bound
Number of hands				
Agbayanon	7.75	0.294	7.10	8.40
Bisaya	6.31	0.205	5.86	6.76
Negro	7.15	0.601	5.83	8.47
Tabukanon	5.27	0.242	4.85	5.80
Totoo	7.32	0.264	6.74	7.90
Number of fruits or finger				
Agbayanon	11.27	0.357	10.48	12.05
Bisaya	9.46	0.248	8.91	10.01
Negro	11.40	0.728	9.80	13.00
Tabukanon	8.76	0.294	8.11	9.41
Totoo	13.11	0.321	12.40	13.82
Fruit length				
Agbayanon	7.56	0.258	6.99	8.13
Bisaya	6.89	0.180	6.47	7.26
Negro	9.96	0.526	8.80	11.12
Tabukanon	6.70	0.212	6.24	7.17
Totoo	7.32	0.232	6.81	7.83

SE= standard error; CI= confidence interval.

Table 18. Pairwise comparisons of fruit morphological characteristics of Abaca varieties

Varieties		Number of Hands		Number of Fruits or Finger		Fruit length	
i	**j.**	**Estimate (MD)**	**SE**	**Estimate (MD)**	**SE**	**Estimate (MD)**	**SE**
Agbayanon	**Bisaya**	1.44 *	0.36	1.81 *	0.44	0.698	0.31
	Negro	0.600	0.64	-0.13	0.77	-2.401 *	0.56
	Tabukanon	2.48 **	0.39	2.51 **	0.47	0.854	0.34
	Totoo	0.429	0.40	-1.84 *	0.48	0.239	0.35
Bisaya	**Negro**	-0.838	0.63	-1.94	0.77	-3.10 **	0.56
	Tabukanon	1.041	0.32	0.70	0.39	0.157	0.28
	Totoo	-1.009	0.33	-3.65 **	0.41	-0.458	0.29
Negro	**Tabukanon**	1.879	0.63	2.64 *	0.77	3.26 **	0.56
	Totoo	-.171	0.66	-1.71	0.80	2.64 **	0.58
Tabukanon	**Totoo**	-2.05 **	0.40	-4.35 **	0.44	-0.615	0.31

Variety i and j denote the two abaca varieties being compared.MD=Mean difference; SE=standard error. *****Significant at 5% level. **Significant at 1%. The Tukey's HSD method was used for post-hoc pairwise comparisons to control for family-wise error rates. A

The results showed a highly significant difference ($p < 0.001$) in the number of hands among all cultivars. According to the EMMs (Table 17), *Tabukanon* had the fewest number of hands (M = 5.27, 95 % CI [4.85, 5.80]), while *Agbayanon* exhibited the highest number (M = 7.75, 95 % CI [7.10, 8.40]). Pairwise comparisons (Table 18) indicated that *Agbayanon* had significantly more hands than *Tabukanon* (MD = 2.48 cm, SE = 0.39) and *Bisaya* (MD = 1.44 cm, SE = 0.36). Meanwhile, *Tabukanon* had significantly fewer hands than *Totoo* (MD = -2.05 cm, SE = 0.40).

The number of hands in a bunch is influenced by the number of female clusters in the inflorescence and varies depending on the genotype and environmental factors. Each "hand" consists of multiple "fingers," meaning a higher number of hands corresponds to a greater number of fruits and seeds, making it a crucial trait for genetic breeding and reproduction. Among the cultivars, *Agbayanon* (7.75), *Totoo* (7.32) and *Negro* (7.15) displayed similar numbers of hands per bunch, whereas *Bisaya* (6.31) and *Tabukanon* (5.27) had fewer as shown in Fig. 2g-6g. Unlike other members of the *Musa* family, such as banana, which are cultivated primarily for their fruit, Abaca typically has fewer hands. Additionally, a greater number of hands may indicate a more robust plant with higher biomass. Farmers can optimize hand production in plantation management and commercial fibre production.

Number of fingers (Fruits)

Significant differences ($p < 0.001$) were also observed in the number of fingers (fruits) across all cultivars. The EMMs (Table 17) showed that *Tabukanon* had the lowest fruit count (M = 8.76, 95 % CI [8.11, 9.41]), while *Totoo* produced the highest (M = 13.11, 95 % CI [12.40, 13.82]). Pairwise comparisons revealed that Agbayanon had significantly more fruits than *Bisaya* (MD = 1.81 cm, SE = 0.44) and Tabukanon (MD = 2.51 cm, SE = 0.47) but significantly fewer than *Totoo* (MD = -1.84 cm, SE = 0.48). Meanwhile, Tabukanon had significantly fewer fruits than *Totoo* (MD = -4.35 cm, SE = 0.44) and *Negro* (MD = -1.94 cm, SE = 0.77).

According to Galvez et al. (2018), the fruits of Abuab, Inosa and Tangongon cultivars generally do not exceed 12 per hand (14). The present study found that the mean number of fruits in *Negro* (11.40), *Agbayanon* (11.27), *Bisaya* (9.46) and *Tabukanon* (8.76) fell within this range, except for *Totoo* (13.11), which exceeded 12. The number of fruits per hand in *Totoo* ranged from 10 to 14, making it a preferred cultivar for the Philippine Fiber Industry Development Authority (PhilFIDA) in Aklan. PhilFIDA frequently selects *Totoo* seeds for plantation projects due to its higher fruit and seed production, which supports plantation establishment. Fig. 2h-6h presents the fruits per hand of the different Abaca cultivars.

Although Abaca fruits are not cultivated for consumption, they contain 50 to 350 seeds per finger, depending on the variety. Some farmers have attempted to eat Abaca fruits and describe them as edible but unpalatable. Wild animals such as monkeys, fruit bats and birds consume these fruits and help disperse the seeds naturally while feeding or through their faeces. Despite Abaca being primarily cultivated for its fibre rather than its fruit, fruit production remains an important trait for breeding programs focused on varietal selection and increasing plantlet production through sexual propagation.

Fruit length

The EMMs for fruit length (Table 17) indicated that *Tabukanon* had the shortest fruits (M = 6.70 cm, 95 % CI [6.24, 7.17]), while *Negro* had the longest (M = 9.96 cm, 95 % CI [8.80, 11.12]). Pairwise comparisons (Table 18) confirmed that *Negro* had significantly longer fruits compared to all other cultivars, with the following mean differences: *Tabukanon* (MD = 3.26 cm, SE = 0.56), *Bisaya* (MD = 3.10 cm, SE = 0.56), *Totoo* (MD = 2.64 cm, SE = 0.58) and *Agbayanon* (MD = 2.40 cm, SE = 0.56).

Previous studies have reported that Abaca fruits typically measure around 8 cm in length and 2.5 cm in diameter. Abaca fruits are inedible, featuring a green outer skin and a white pulp containing large black seeds (17). Interestingly, the present study found significant differences in fruit length among Abaca cultivars in Aklan, with *Negro* producing significantly longer fruits than the other cultivars. The fruit lengths recorded for *Agbayanon* (7.56 cm), *Totoo* (7.32 cm), *Bisaya* (6.80 cm) and *Tabukanon* (6.70 cm) were among the shortest, aligning with the findings of Bailey (1947), who reported that Abaca fruits generally grow to about 5.1-7.6 cm in length and 2.5 cm in diameter. The seeds are black and turbinate, measuring approximately 0.42 cm in diameter (42). Fig. 2i-j to 6i–j presents the length of the fruit and longitudinal section of fruit.

Fruit shape

All cultivars were observed to have straight (or slightly curved) fruit-shaped (longitudinal curve), bottle-necked apex, without any floral relicts (observed at the distal part

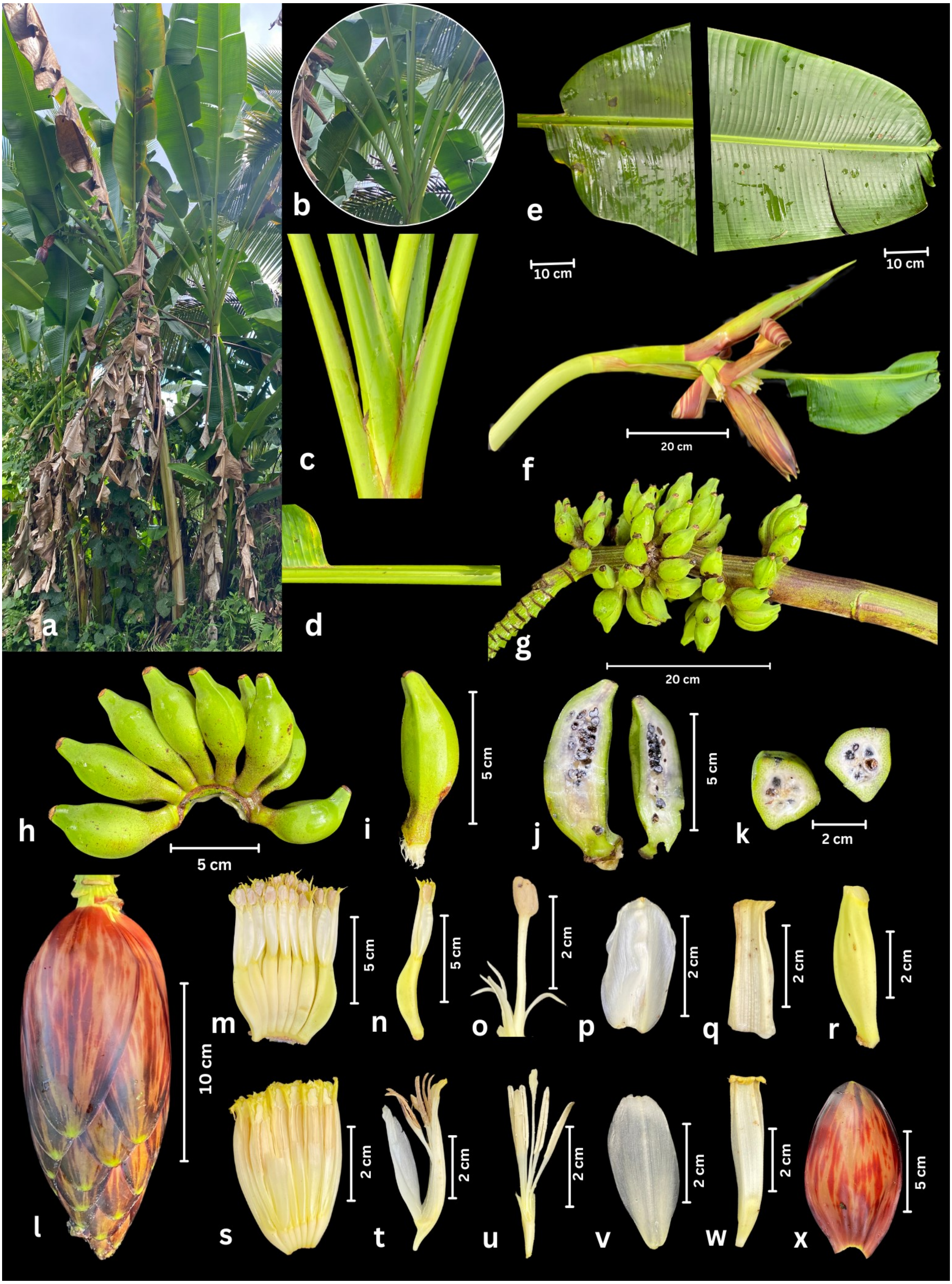

Fig. 2. Morphological characteristics of *Bisaya* cultivar: (**a**) matured *Bisaya* cultivar, (**b**) petiole habit, (**c**) petiole margin color and corrugation, (**d**) petiole margin, (**e**) leaf apex and leaf base, (**f**) inflorescence, (**g**) peduncle and fruit bunch, (**h**) hand, (**i**) finger, (**j**) longitudinal section of fruit, (**k**) cross-sectional of fruit, (**l**) male bud, (**m-r**) female flower parts: (**m**) cluster of ovaries, (**n**) entire female flower, (**o**) style, stigma and stamen, (**p**) free tepal, (**q**) compound tepal, (**r**) ovary, (**s-x**) male flower parts: (**s**) cluster of male flowers, (**t**) entire male flower, (**u**) flower without tepals, (**v**) free tepal, (**w**) compound tepal, (**x**) bract.

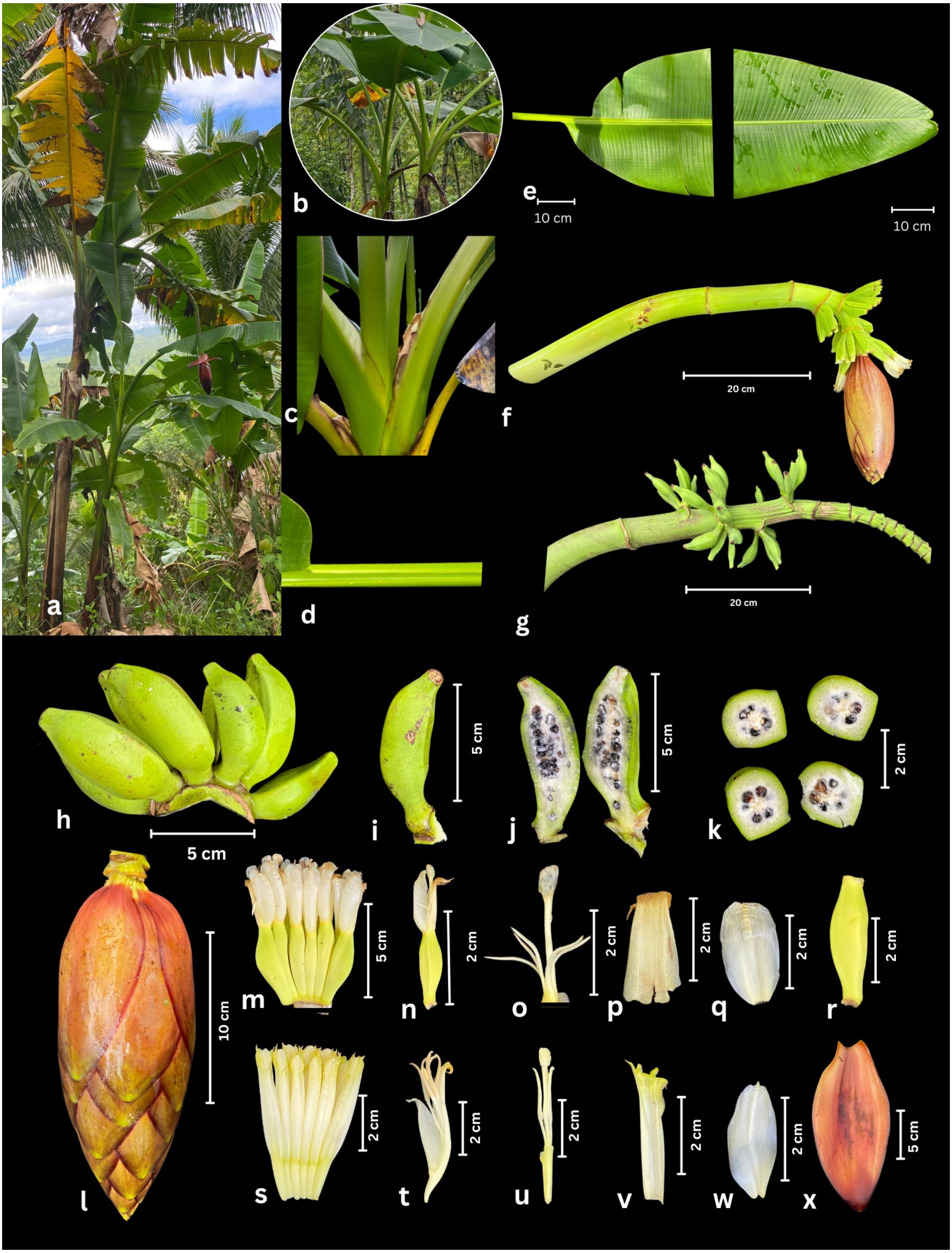

Fig. 3. Morphological characteristics of *Tabukanon* cultivar: (**a**) matured *Tabukanon* cultivar, (**b**) petiole habit, (**c**) petiole margin color and corrugation, (**d**) petiole margin, (**e**) leaf apex and leaf base, (**f**) inflorescence, (**g**) peduncle and fruit bunch, (**h**) hand, (**i**) finger, (**j**) longitudinal section of fruit, (**k**) cross-sectional of fruit, (**l**) male bud, (**m-r**) female flower parts: (**m**) cluster of ovaries, (**n**) entire female flower, (**o**) style, stigma and stamen, (**p**) free tepal, (**q**) compound tepal, (**r**) ovary, (**s-x**) male flower parts: (**s**) cluster of male flowers, (**t**) entire male flower, (**u**) flower without tepals, (**v**) free tepal, (**w**) compound tepal, (**x**) bract.

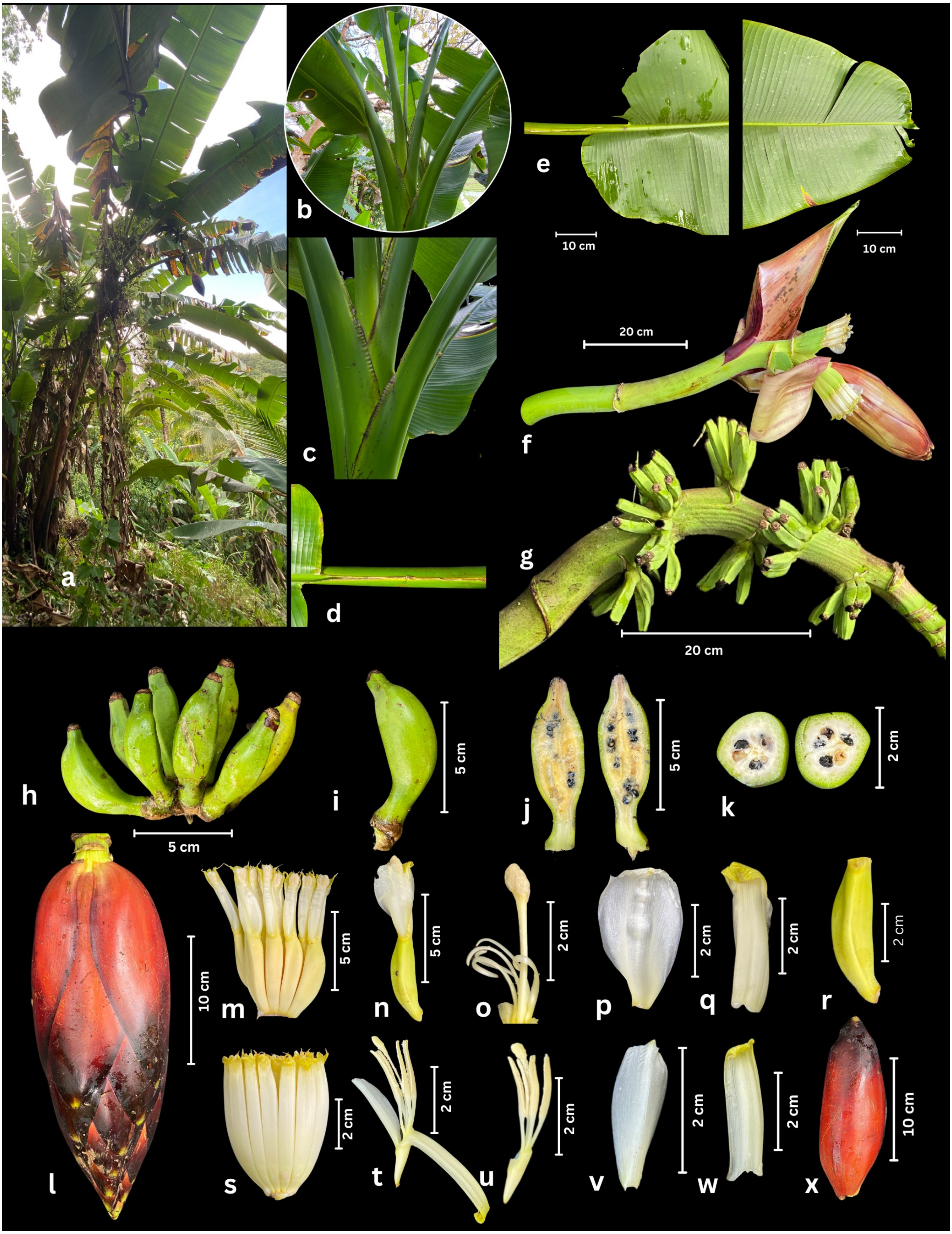

Fig. 4. Morphological characteristics of *Agbayanon* cultivar: (**a**) matured *Agbayanon* cultivar, (**b**) petiole habit, (**c**) petiole margin color and corrugation, (**d**) petiole margin, (**e**) leaf apex and leaf base, (**f**) inflorescence, (**g**) peduncle and fruit bunch, (**h**) hand, (**i**) finger, (**j**) longitudinal section of fruit, (**k**) cross-sectional of fruit, (**l**) male bud, (**m-r**) female flower parts: (**m**) cluster of ovaries, (**n**) entire female flower, (**o**) style, stigma and stamen, (**p**) free tepal, (**q**) compound tepal, (**r**) ovary, (**s-x**) male flower parts: (**s**) cluster of male flowers, (**t**) entire male flower, (**u**) flower without tepals, (**v**) free tepal, (**w**) compound tepal, (**x**) bract.

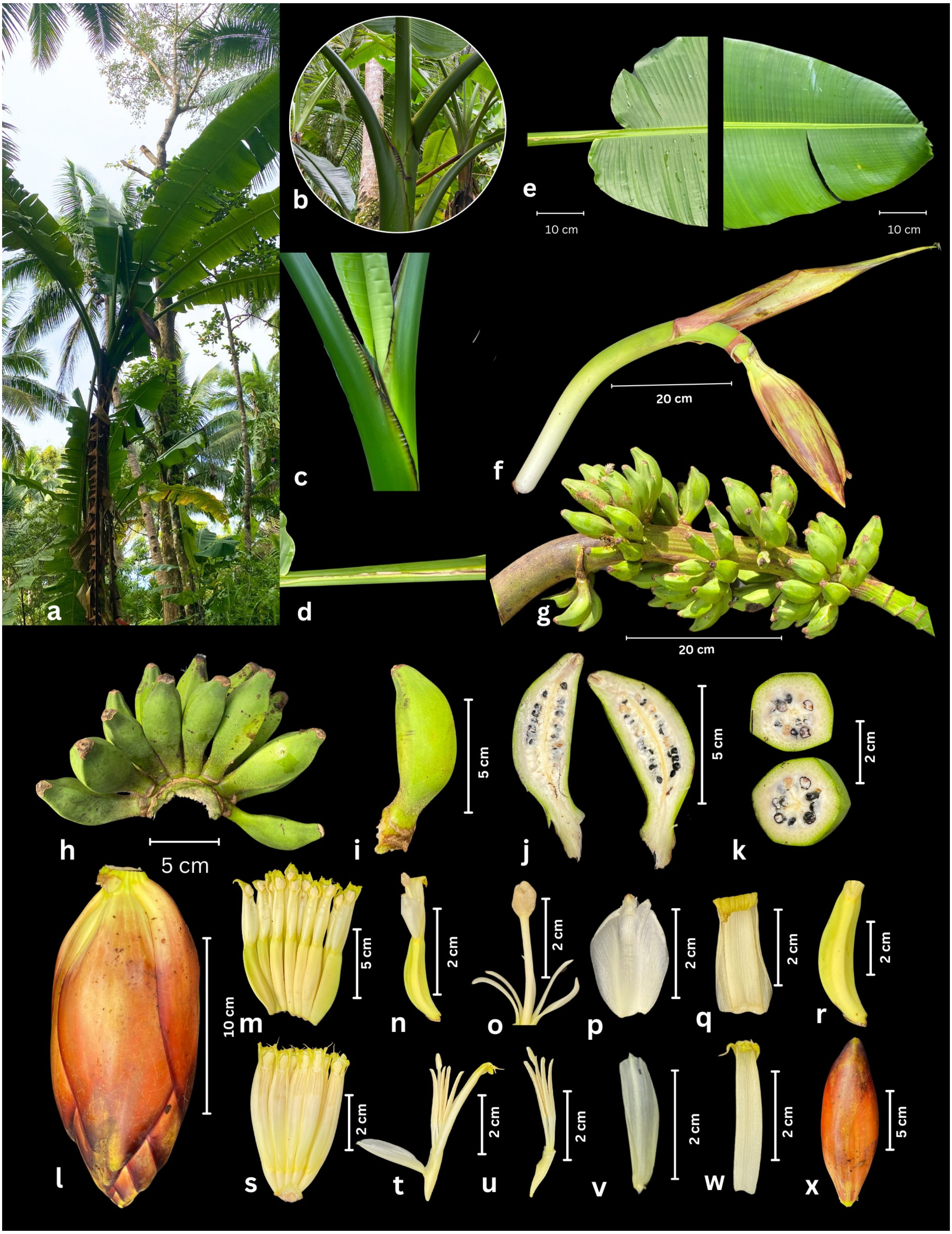

Fig. 5. Morphological characteristics of *Totoo* cultivar: (**a**) matured *Totoo* cultivar, (**b**) petiole habit, (**c**) petiole margin color and corrugation, (**d**) petiole margin, (**e**) leaf apex and leaf base, (**f**) inflorescence, (**g**) peduncle and fruit bunch, (**h**) hand, (**i**) finger, (**j**) longitudinal section of fruit, (**k**) cross-sectional of fruit, (**l**) male bud, (**m-r**) female flower parts: (**m**) cluster of ovaries, (**n**) entire female flower, (**o**) style, stigma and stamen, (**p**) free tepal, (**q**) compound tepal, (**r**) ovary, (**s-x**) male flower parts: (**s**) cluster of male flowers, (**t**) entire male flower, (**u**) flower without tepals, (**v**) free tepal, (**w**) compound tepal, (**x**) bract.

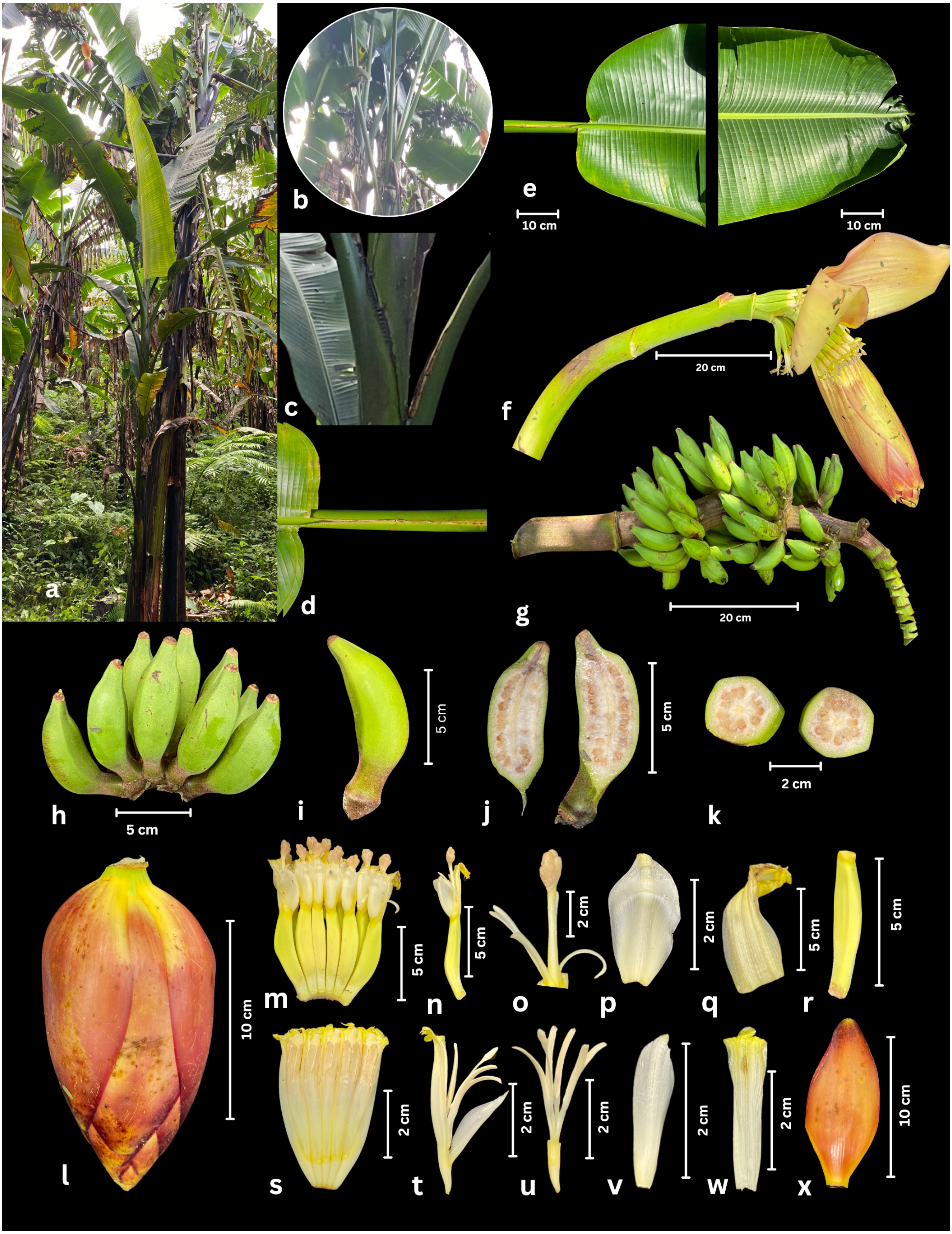

Fig. 6. Morphological characteristics of *Negro* cultivar: (**a**) matured *Negro* cultivar, (**b**) petiole habit, (**c**) petiole margin color and corrugation, (**d**) petiole margin, (**e**) leaf apex and leaf base, (**f**) inflorescence, (**g**) peduncle and fruit bunch, (**h**) hand, (**i**) finger, (**j**) longitudinal section of fruit, (**k**) cross-sectional of fruit, (**l**) male bud, (**m-r**) female flower parts: (**m**) cluster of ovaries, (**n**) entire female flower, (**o**) style, stigma and stamen, (**p**) free tepal, (**q**) compound tepal, (**r**) ovary, (**s-x**) male flower parts: (**s**) cluster of male flowers, (**t**) entire male flower, (**u**) flower without tepals, (**v**) free tepal, (**w**) compound tepal, (**x**) bract.

of the fruit or fruit apex), pedicel surface of the fruit is hairless, immature fruit is green and mature fruit are green -yellow green (Fig. 2i–6i). Results showed that all Abaca cultivars showed consistent morphological traits on some aspects of the fruits. Additionally, using the cross-section of the Abaca fruit (Fig. 2k-6k), the study provided visual observation of the arrangement of ovules, noting that *Bisaya*, *Tabukanon* and *Agbayanon* exhibit 2 rowed arrangements of ovules, whereas *Negro* and *Totoo* exhibit 4 rowed (more or less) arrangement of ovules.

Conclusion

The study noted considerable morphological variation among the Abaca cultivars, indicating their genetic diversity and potential adaptability. The results show that there was a high degree of variation among cultivars for leaf, peduncle, inflorescence and fruits. *Totoo* and *Agbayanon* showing larger leaf parameters, whereas *Tabukanon* showed smaller morphological parameters consistently. In peduncle morphology differences were very significant among all cultivars, *Agbayanon* shows a greater number of nodes with fruits, *Totoo* shows a greater number of fruits per node and *Negro* shows longer fruits that could be cultivated for seed production. Variations in flower morphology were observed among all the Abaca cultivars indicating the genetic diversity, which can be utilized to differentiate the cultivars and be useful in Abaca breeding programs to enhance the fibre yield. Such knowledge will provide useful insights for selecting potential cultivars for fibre and/or seed production, likewise, could benefit breeders, researchers, farmers and other users to identify and maximizing the potential of the crop.

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Authors' contributions

GTS crafted the proposals and conducted data gathering. FMNG monitored and critiqued the article. RTT, AGM and FTF participated in the study's design and critically reviewed the manuscript. AMLSL reviewed the statistical analysis. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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