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Morpho-agronomic performance and phenotypic diversity of adlay (*Coix lacryma-jobi* L.) genotypes from Mindanao, Philippines

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Abstract

Adlay is an underutilised cereal crop with high nutritional value and potential for climate resilience; however, limited information on the variability of locally collected germplasm constrains its improvement and wider utilisation. This study evaluated the morpho-agronomic performance and phenotypic diversity of 15 adlay genotypes collected from Mindanao and grown under Musuan, Bukidnon conditions. Eighteen quantitative and one qualitative trait were assessed using a randomised complete block design with 3 replications. Analysis of variance revealed significant differences among genotypes for key traits, including germination percentage, days to emergence, plant height, number of nodes, leaf width, 100-seed weight and grain yield. Grain yield ranged from 2621 to 4676 kg ha^{-1}, with Tapol genotypes recording the highest values. Pearson correlation analysis showed that grain yield was strongly and positively associated with vegetative (r = 0.85) and productive tillers (r = 0.82), while negatively correlated with days to flowering (r = -0.70) and maturity (r = -0.73), indicating that earlier phenological development was associated with higher grain yield under the conditions of the study. The Standardised Shannon-Weaver Diversity Index (H′ = 0.75) indicated moderate diversity, particularly for yield-related and phenological traits. Principal component analysis revealed that vegetative traits and reproductive phenology were the major contributors to the observed multivariate variation. Overall, the evaluated genotypes exhibited substantial morpho-agronomic variation, with the Tapol genotypes showing promising grain yield in the present evaluation. Given the single-location, single-season design, however, these findings should be considered preliminary; multi-location and multi-season validation is needed to confirm genotype performance and trait associations.

Keywords: adlay; agronomic performance; phenology; phenotypic diversity; yield

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Introduction

Global food security is increasingly challenged by population growth, climate change, declining arable land and biotic stresses affecting crop productivity. Plant pests and diseases alone are estimated to reduce global crop production by approximately 10–40 %, posing a major threat to sustainable food systems (1). At the same time, the growing global population is expected to increase food demand substantially over the coming decades, intensifying pressure on agricultural production systems (2). These challenges highlight the need to diversify crop production and explore resilient alternative cereals capable of sustaining food security under changing environmental conditions.

Adlay or Job's tears (*Coix lacryma-jobi* L.; 2n = 2x = 20) is a promising alternative cereal crop valued for its high nutritional content, health benefits and its adaptability to diverse growing conditions. Several adlay genotypes have been documented, including Kiboa, Gulian, Ginampay, Pulot, Tapol and Dwarf types (3–8). These genotypes represent valuable genetic resources for crop improvement and varietal development programmes. Previous studies have demonstrated substantial genetic and phenotypic variation within *Coix lacryma-jobi* germplasm collections. In the Philippines, considerable diversity has been reported among adlay populations collected from different regions, highlighting the value of local germplasm for crop improvement and conservation (5, 7). Likewise, multivariate analyses of Job's-tears germplasm have identified plant architecture, flowering behaviour and yield-related traits as major contributors to phenotypic differentiation among accessions (9). Population genetic studies further suggest that environmental adaptation, natural outcrossing and farmer-mediated selection play important roles in shaping diversity within Coix populations (10). These findings underscore the importance of systematic germplasm characterisation as a prerequisite for effective breeding, conservation and varietal development programmes.

Despite these advances, comprehensive morpho-agronomic characterisation of adlay accessions collected

from Mindanao remains limited. Most previous studies have focused on varietal performance, propagation, agronomic management and diversity in selected adlay collections (3–8, 11, 12), while information on the phenotypic diversity and trait relationships of locally collected Mindanao accessions remains scarce. The present study addresses this gap by characterising 15 adlay genotypes collected from different areas of Mindanao using a broad set of morpho-agronomic traits and by examining their phenotypic diversity and trait associations under the environmental conditions of Musuan, Bukidnon. This provides baseline information on the performance and relationships among agronomic traits within this locally collected germplasm and supports the identification of promising genotypes and candidate traits for further evaluation in adlay improvement programmes. Therefore, this study aimed to evaluate the morpho-agronomic performance, phenotypic diversity and trait associations among 15 adlay genotypes collected from different areas of Mindanao and grown under Musuan conditions and to identify promising genotypes for further evaluation in adlay improvement and conservation programs.

Materials and Methods

Experimental site

The experiment was conducted from January to July 2022 at the Agricultural Experiment Center of Central Mindanao University, Bukidnon, Philippines (7°51′34.27″ N, 125°03′03.51″ E; 312 msl). The site is classified under a type III climate, characterised by relatively weak seasonality, with a dry period from November to April and a wet period during the rest of the year (13), although some variability may occur due to the changing climate. During the experimental period, the area received a mean monthly rainfall of 193.6 mm, with rainfall increasing toward the later months of the study. The mean number of rainy days per month was 21. Average air temperature was relatively stable at 25.7 °C, while mean wind speed was low at 1.5 m sec^{-1} (14). Prior to planting, the experimental area was divided into 8 grids for soil sampling. Soil analysis showed variability across the sampling points, with pH ranging from 4.95–5.61, organic matter from 2.61–3.21 %, extractable P from 2.53–5.56 ppm and exchangeable K from 21–60 ppm.

Plant materials

Altogether 15 adlay genotypes were collected from different locations in Mindanao, including Cotabato, Bukidnon and Zamboanga (Fig. 1, Table 1). The genotypes were obtained from farmers, research institutions and government agencies. Although several accessions shared the same local names (e.g., Tapol, Gulian, Pulot, Kiboa and Dwarf), these were treated as distinct genotypes since they originated from different geographic locations.

Experimental design and treatments

The experiment was laid out in a randomised complete block design (RCBD) with 3 replications. An experimental area of 734.4 m² was divided into 3 blocks, with each block further subdivided into 15 plots corresponding to the 15 adlay genotypes. Each plot measured 3.0 × 3.6 m, with a planting distance of 100 × 60 cm, accommodating 28 plants per plot.

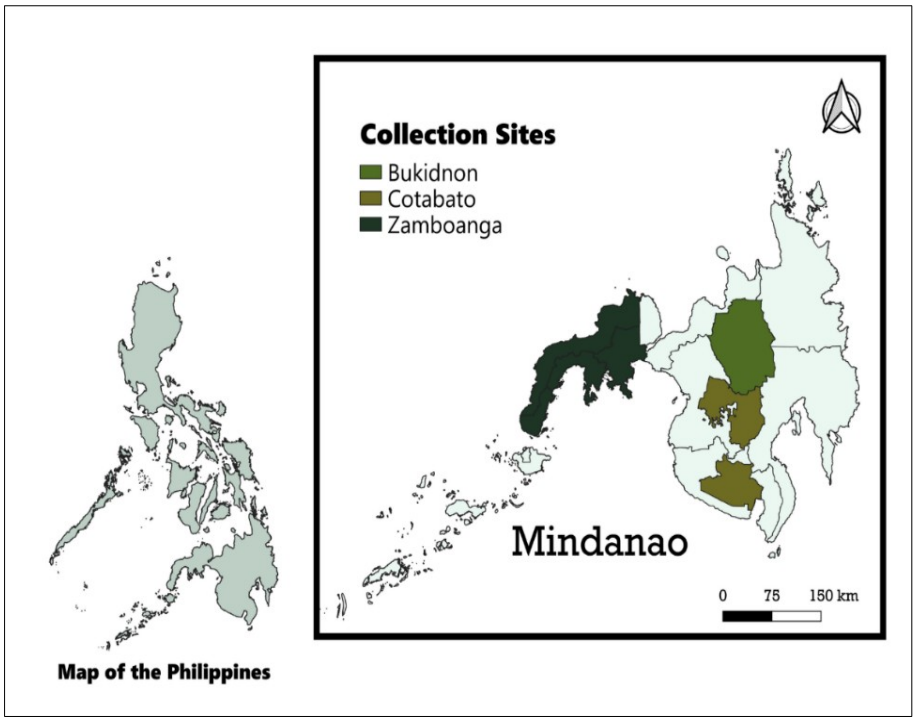


Fig. 1. Collection sites of adlay seeds in Mindanao.

Source: Quantum Geographic Information System (QGIS) ver. 3.4.3 (Madeira). The spatial data were obtained from PhilGIS.

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Table 1. List of adlay accessions collected from different geographic locations in Mindanao, Philippines

Genotype	Collection site	Local name	Source
Genotype 1	Cotabato	Pulot 1	Prof. Nympha Sapan
Genotype 2	Cotabato	Tapol 1	Prof. Nympha Sapan
Genotype 3	Cotabato	Gulian 1	Prof. Nympha Sapan
Genotype 4	Malaybalay City	Mataslay	DA-NMACLRC
Genotype 5	Malaybalay City	Kiboa 1	DA-NMACLRC
Genotype 6	Malaybalay City	Dwarf 1	Mr. Ortea
Genotype 7	Zamboanga	Tapol 2	DA-Region IX
Genotype 8	Zamboanga	Ginampay	DA-Region IX
Genotype 9	Zamboanga	Gulian 2	DA-Region XI
Genotype 10	Zamboanga	Pulot 2	DA-Region XI
Genotype 11	Valencia City	Dwarf 2	Mr. Joel Olino
Genotype 12	Valencia City	Tapol 3	Dr. Alejandro Panes
Genotype 13	Valencia City	Kiboa 2	Dr. Alejandro Panes
Genotype 14	Maramag	Gulian 3	CMU
Genotype 15	Maramag	Dwarf 3	CMU

Agronomic management practices

The experimental area was prepared by tractor harrowing to remove weeds and level the soil surface, followed by plowing and two harrowings to break soil clods and establish a favourable seedbed. Furrows were spaced 100 cm apart.

Prior to planting, adlay seeds were soaked in water for 8 hr and incubated for 6 hr. Pre-germinated seeds were sown along the furrows at 60 cm hill spacing, with 5 seeds per hill. Thinning was performed before hilling-up, leaving two healthy seedlings per hill to maintain a uniform stand.

Prior to planting, vermicompost was applied at the rate of 1.5 t ha^{-1}. Inorganic fertilisers were applied in two split applications at 30 and 75 days after sowing based on the soil-test recommendation, targeting 80-60-60 kg $N\text{-}P_2O_5\text{-}K_2O$ ha^{-1}. The fertiliser sources and application rates were 18-46-0 at 3 bags ha^{-1}, 46-0-0 at 2.5 bags ha^{-1} and 0-0-60 at 2 bags ha^{-1}.

Hilling-up was conducted twice, at 4 weeks after planting and 2 weeks thereafter. Weeds were controlled through hand weeding. The trial was primarily rainfall-dependent, with supplemental irrigation provided when rainfall was insufficient. Insect pests were initially managed using fenobucarb and chlorpyrifos during the first week after planting, after which its application was discontinued to allow natural pest occurrence and assessment among the genotypes. Nets were installed to minimise bird and rat damage. Waterlogging occurred in portions of the third replication due to runoff from nearby irrigated lowland rice fields; canals were constructed and soil aeration was performed to alleviate the excess water.

Grains were harvested when approximately 80–90 % of the grains had turned brown or developed their characteristic mature colour. Panicles were manually cut, threshed and sun-dried in net bags until approximately 14 % moisture content. Clean seeds were then stored in labeled paper bags.

Data collection

A total of 15 adlay genotypes were characterised for 18 quantitative traits and one qualitative trait. Percent germination was recorded 7 days after sowing and calculated the percentage of germinated seeds. Days to emergence was recorded at 50 % emergence. Vegetative tillers were counted from 10 sample hills per plot at 75 days after planting. Days to flowering was recorded at 40–50 % pollen shedding, while flowering duration was recorded from flowering onset to 80–90 % cessation. The start of grain colour change was recorded at 40–50 % colour change and days to maturity at 80–90 % colour change. Plant height and number of nodes were measured from 10 sample plants per plot at maturity, while internode length was measured at the basal, middle and upper portions of the main stalk. Number of leaves was counted from the main stalk of 10 sample plants per plot at maturity. Leaf length was measured from the base to the tip of the middle leaf blade of 10 sample plants per plot at maturity, while leaf width was measured at the widest part of the same leaves. Productive tillers were counted from 10 sample hills per plot at maturity. Panicle length was measured from 10 sample panicles at maturity and grains per panicle were counted from the same panicles. The weight of 100 seeds was determined from three random samples of 100 seeds. Grain yield was determined by weighing the grain harvested from the 10 center plants, representing a net plot area of 2.4 m^2 and converting the yield to kg ha^{-1} based on the net plot area. Lodging score was evaluated as a qualitative trait at maturity. The main stem and tillers were evaluated using a 1–5 scale, where 1 = main stem erect, 2 = slightly lodging, 3 = main stem at a 45° angle, 4 = severe lodging and 5 = flat. These parameters were assessed as described in UPOV (15, 16).

Data analysis

Data were analysed using analysis of variance (ANOVA). Mean differences among genotypes were compared using Tukey's honestly significant difference (HSD) test at the 5 % level of significance. Phenotypic diversity was estimated using the standardised Shannon-Weaver diversity index (SSWDI), based on standard scale (17). For continuous quantitative traits, the observed range was divided into 10 phenotypic classes, with the class interval calculated as (highest value - lowest value)/10. Genotype values were assigned to the corresponding classes prior to diversity analysis. The diversity index was calculated as $H' = - \Sigma pi \log Pi$, where Pi is the proportion of genotypes in each phenotypic class. The resulting diversity

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indices were categorised as maximum diversity (H′ = 1.00), high diversity (H′ = 0.76–0.99), moderate diversity (H′ = 0.46–0.75), low or poor diversity (H′ = 0.10-0.45) and non-variable (H′ = 0.00). Pearson's product-moment correlation (PPMC) and principal component analysis (PCA) were performed using the mean values of the 15 genotypes (n = 15) to assess trait associations and patterns of phenotypic variation among the evaluated genotypes.

Results and Discussion

Morpho-agronomic characterisation of adlay genotypes

The ANOVA revealed significant differences among the 15 adlay genotypes for several morpho-agronomic traits evaluated (Table 2). Highly significant variations ($p < 0.01$) were observed for percent germination, days to emergence, plant height, number of nodes, leaf width, weight of 100 seeds and grain yield. Meanwhile, days to flowering, number of leaves and length of internodes showed significant differences at $p < 0.05$, while the remaining traits showed non-significant variation.

Table 2. Summary of analysis of variance (ANOVA) for morpho-agronomic traits of adlay genotypes

Traits	Range of values	F-value	Pr > F	CV (%)
Percent germination	58–95 %	14.78**	0.0000	7.04
Days to emergence	4–7 DAS	20.07**	0.0000	6.26
Number of vegetative tillers	8–16 tillers	1.35ns	0.2436	27.09
Days to flower	94–108 DAS	2.37*	0.0250	4.58
Duration of flowering	25–35 DAF	1.17ns	0.3457	16.81
Start of grains to change colour	42–50 DAF	0.90ns	0.5722	3.44
Days to maturity	151–160 DAS	0.78ns	0.6821	3.75
Plant height	207–299 cm	3.44**	0.0026	7.44
Number of nodes	11–14 nodes	3.50**	0.0023	4.91
Length of internodes	16–21 cm	2.31*	0.0286	8.22
Number of leaves	9–11.33 leaves	2.15*	0.0415	6.86
Leaf length	61–71 cm	1.59ns	0.1423	5.43
Leaf width	4.4–5.6 cm	3.52**	0.0022	5.11
Number of productive tillers	8–16 tillers	1.32ns	0.2559	27.61
Panicle length	93–123 cm	2.04ns	0.0530	10.45
Number of grains/panicles	288–349 grains	0.52ns	0.9020	14.70
Weight of 100 seeds	7.67–12 g	5.72**	0.0000	8.16
Grain yield	2621–4676 kg	3.39**	0.0029	16.43

The mean performance of adlay genotypes for morpho-agronomic traits that showed significant variation (Table 3). The percentage of germination among the genotypes ranged from 58 to 95 %. Gulian 3 recorded the highest germination rate (95 %), which was statistically comparable with Gulian 1 (94 %), Pulot 2 (92 %) and Tapol 2 (90 %). In contrast, Mataslay exhibited the lowest germination percentage (58 %). Days to emergence varied significantly among genotypes, with Dwarf 2 emerging earliest at 4 days after sowing (DAS), whereas Pulot 1, Gulian 1, Mataslay, Kiboa 1 and Dwarf 1 were among the latest to emerge at 7 DAS.

Significant variation in plant height was observed, ranging from 207 to 299 cm. Kiboa 1 was the tallest genotype (299 cm), while Dwarf 3 was the shortest (207 cm). The number of leaves also differed significantly among genotypes, ranging from 11–14 leaves. Kiboa 1 recorded the highest number of leaves (14), followed by Gulian 3 with 13 leaves, while Tapol 1, Gulian 2 and Dwarf 3 had the lowest number of leaves at 11. Number of nodes also differed significantly, with Kiboa 1 recording the most nodes (14), whereas Tapol 1, Gulian 2 and Dwarf 3 had fewer nodes (11). Internode length ranged from 16–21 cm, with Tapol 1 and Gulian 1 exhibiting the longest internodes (21 cm) and Dwarf 3 the shortest (16 cm).

Leaf width showed significant variation among genotypes, ranging from 4.40 to 5.60 cm. Dwarf 2 had the widest leaves (5.60 cm), while Kiboa 1 had the narrowest (4.40 cm). For yield-related traits, the weight of 100 seeds varied significantly, with Dwarf 2 producing the heaviest seeds (12.00 g) and Tapol 2 recording the lightest (8.00 g).

Grain yield differed significantly among genotypes, ranging from 2621 to 4676 kg ha^{-1}. Tapol 1 produced the highest grain yield (4676 kg ha^{-1}), followed by Tapol 3 (4602 kg ha^{-1}) and Tapol 2 (4263 kg ha^{-1}), whereas Dwarf 1 recorded the lowest yield (2621 kg ha^{-1}). Grain yield had a coefficient of variation of 16.43 %, reflecting variability under the conditions of this study.

Correlation analysis of morpho-agronomic traits

The PPMC analysis revealed multiple highly significant relationships among the morpho-agronomic traits (Fig. 2). Number of vegetative tillers and the number of productive tillers showed the strongest correlation ($r = 0.96$, $p < 0.0001$), indicating a very strong positive association between the 2 traits.

Grain yield was most strongly associated with tiller production, showing highly significant positive correlations with the number of vegetative tillers ($r = 0.85$, $p < 0.0001$) and the number of productive tillers ($r = 0.82$, $p < 0.0001$). Leaf length also showed a strong positive correlation with grain yield ($r = 0.61$, $p < 0.0001$).

Phenological traits showed synchronised developmental progression, with days to flowering exhibiting strong positive correlations with days to maturity ($r = 0.81$, $p < 0.0001$) and start of grain to change colour ($r = 0.81$, $p < 0.0001$). In contrast, several phenological traits showed significant negative correlations with grain yield: days to flowering ($r = -0.70$, $p < 0.0001$), days to maturity ($r = -0.73$, $p < 0.0001$) and start of grain colour change ($r = -0.66$, $p < 0.0001$).

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Table 3. Mean performance of adlay genotypes for morpho-agronomic traits showing significant variation

Genotypes	PG	DE	DTF	PH	NN	LoI	NL	LW	W100S	GY
Pulot 1	63^{e}	7^{a}	105^{a}	259^{abc}	12^{ab}	20^{ab}	9.33^{b}	4.77^{b}	8.67^{b}	4334^{ab}
Tapol 1	70^{de}	6^{abc}	97^{a}	250^{abc}	11^{b}	21^{a}	9.33^{b}	4.90^{ab}	9.67^{b}	4676^{a}
Gulian 1	94^{a}	7^{abc}	105^{a}	267^{ab}	12^{ab}	21^{ab}	9.67^{ab}	4.97^{ab}	9.00^{b}	4170^{ab}
Mataslay	58^{e}	7^{ab}	100^{a}	249^{abc}	12^{ab}	19^{ab}	9.33^{b}	4.87^{ab}	9.00^{b}	3655^{ab}
Kiboa 1	69^{de}	7^{abc}	105^{a}	299^{a}	14^{a}	20^{ab}	11.33^{a}	4.40^{b}	9.67^{b}	3664^{ab}
Dwarf 1	69^{de}	7^{ab}	107^{a}	238^{bc}	12^{ab}	19^{ab}	9.67^{ab}	4.63^{b}	9.33^{b}	2621^{b}
Tapol 2	90^{ab}	5^{de}	100^{a}	244^{abc}	12^{ab}	18^{ab}	9.33^{b}	4.67^{b}	8.00^{b}	4263^{ab}
Ginampay	80^{abcd}	5^{de}	105^{a}	257^{abc}	12^{ab}	19^{ab}	9.67^{ab}	4.70^{b}	8.33^{b}	2893^{ab}
Gulian 2	73^{cde}	5^{de}	97^{a}	251^{abc}	11^{b}	19^{ab}	9.00^{b}	4.80^{b}	7.67^{b}	3983^{ab}
Pulot 2	92^{a}	5^{de}	106^{a}	243^{abc}	12^{b}	19^{ab}	9.33^{b}	4.67^{b}	8.33^{b}	3216^{ab}
Dwarf 2	65^{de}	4^{e}	94^{a}	226^{bc}	12^{b}	17^{ab}	9.67^{ab}	5.60^{a}	12.00^{a}	3025^{ab}
Tapol 3	74^{bcde}	6^{abc}	99^{a}	243^{abc}	12^{b}	19^{ab}	9.33^{b}	4.67^{b}	9.00^{b}	4602^{a}
Kiboa 2	86^{abc}	6^{cd}	103^{a}	254^{abc}	12^{ab}	18^{ab}	10.00^{ab}	4.67^{b}	9.00^{b}	3673^{ab}
Gulian 3	95^{a}	6^{bcd}	108^{a}	243^{abc}	13^{ab}	19^{ab}	9.67^{ab}	4.87^{ab}	8.33^{b}	3249^{ab}
Dwarf 3	73^{cde}	6^{bcd}	103^{a}	207^{c}	11^{b}	16^{b}	9.00^{b}	5.00^{ab}	8.67^{b}	3165^{ab}
F-Value	14.78^{**}	20.07^{**}	2.37^{*}	3.44^{**}	3.50^{**}	2.31^{*}	2.15^{*}	3.52^{**}	5.72^{**}	3.39^{**}
CV (%)	7.04	6.26	4.58	7.44	4.91	8.22	6.86	5.11	8.16	16.43

Means in the same column with at least one common letter are not significantly different from each other based on Tukey's HSD test at 0.05 probability.

PG: percent of germination; DE: days to emergence; DTF: days to flower; PH: plant height; NN: number of nodes; LoI: length of internodes; NL: number of leaves; LW: leaf width; W100SL: weight of 100 seeds; GY: grain yield.

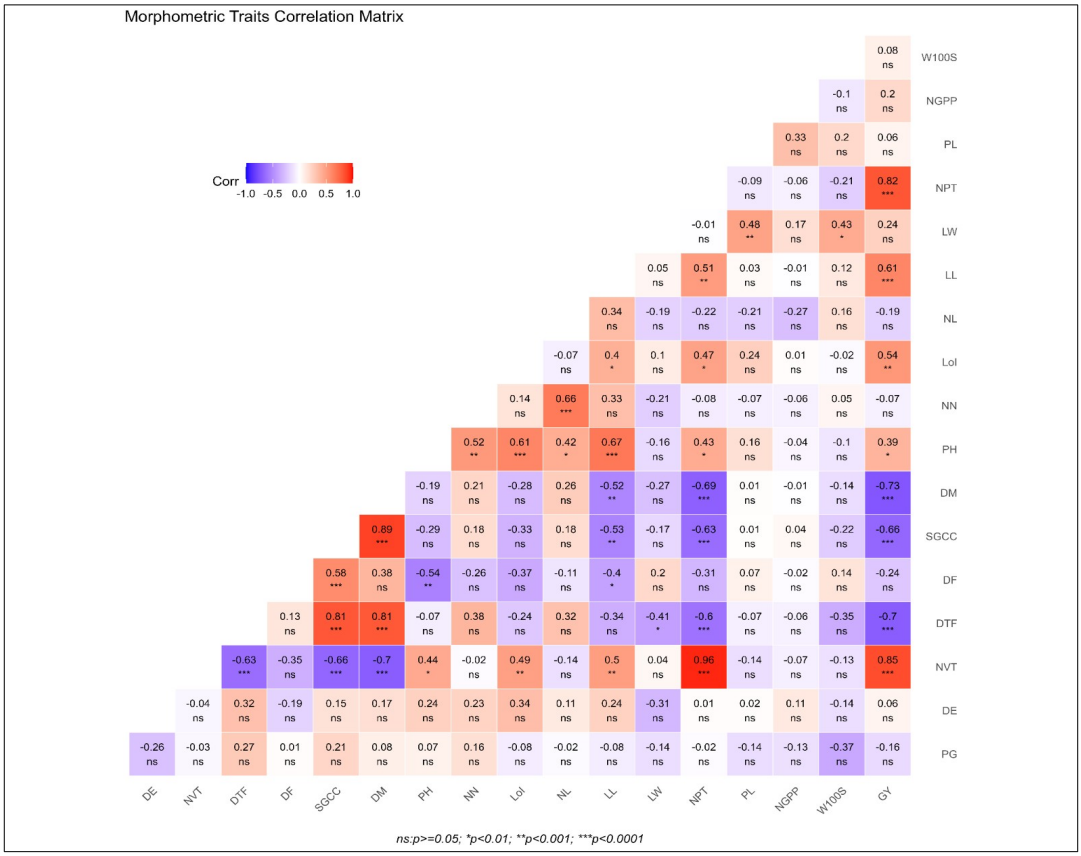


Fig. 2. Pearson's correlation coefficients among morpho-agronomic traits of adlay genotypes.

PG: percent germination; DE: days to emergence; NVT: number of vegetative tillers; DTF: days to flower; DF: duration of flowering; SGCC: start of grains to change colour; DM: days to maturity; PH: plant height; NN: number of nodes; LoI: length of internodes; NL: number of leaves; LL: leaf length; LW: leaf width; NPT: number of productive tillers; PL: panicle length; NGPP: number of grains per panicle; W100S: weight of 100 seeds; GY: grain yield.

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Plant architecture traits showed coordinated development, with plant height positively correlated with the number of nodes (r = 0.52, p < 0.001), length of internodes (r = 0.61, p < 0.0001), number of leaves (r = 0.42, p < 0.01), leaf length (r = 0.67, p < 0.0001), number of vegetative tillers (r = 0.39, p < 0.01) and number of productive tillers (r = 0.43, p < 0.01).

Phenotypic diversity of adlay genotypes

The SSWDI (H′) computations revealed substantial phenotypic diversity among the evaluated adlay genotypes, with an overall mean H′ value of 0.75, indicating moderate diversity across morpho-agronomic traits (Table 4).

Traits exhibiting high diversity (H′ = 0.76–0.99) included % germination (H′ = 0.92), number of vegetative tillers (H′ = 0.91), number of productive tillers (H′ = 0.90), panicle length (H′ = 0.90), days to maturity (H′ = 0.88), days to flowering (H′ = 0.87), leaf length (H′ = 0.85), grain yield (H′ = 0.85), duration of flowering (H′ = 0.84) and start of grain colour change (H′ = 0.80).

Traits showing moderate diversity (H′ = 0.46–0.75) included leaf width (H′ = 0.74), number of grains per panicle (H′ = 0.74), 100-seed weight (H′ = 0.73), length of internodes (H′ = 0.66) and days to emergence (H′ = 0.55).

In contrast, low diversity (H′ = 0.10–0.45) was observed for the number of nodes (H′ = 0.41) and lodging score (H′ = 0.11), indicating limited variability among the evaluated genotypes for these traits.

Table 4. Phenotypic diversity of adlay genotypes based on the Standardised Shannon-Weaver diversity index (H′)

Traits	H' value	Remarks
Percent germination	0.92	Highly diverse
Number of vegetative tillers	0.91	Highly diverse
Number of productive tillers	0.90	Highly diverse
Panicle length	0.90	Highly diverse
Days to maturity	0.88	Highly diverse
Days to flowering	0.87	Highly diverse
Leaf length	0.85	Highly diverse
Grain yield	0.85	Highly diverse
Duration of flowering	0.84	Highly diverse
Start of grains to change colour	0.80	Highly diverse
Plant height	0.76	Highly diverse
Leaf width	0.74	Moderately diverse
Number of grains/panicles	0.74	Moderately diverse
Weight of 100 seeds	0.73	Moderately diverse
Length of internodes	0.66	Moderately diverse
Number of leaves	0.51	Moderately diverse
Days to emergence	0.55	Moderately diverse
Number of nodes	0.41	Poorly diverse
Lodging score	0.11	Poorly diverse
Mean	0.75	Moderately diverse

Principal component analysis of morpho-agronomic traits

Principal component analysis (PCA) revealed variation among the 15 adlay genotypes based on their morpho-agronomic traits. The first principal component (PC1) accounted for 30.1 % of the total variance, while the second principal component (PC2) accounted for 24.8 %, giving a cumulative variance of 54.9 % for the first two components (Table 5). The PCA biplot showed that the genotypes were distributed across the four quadrants of the PC1-PC2 coordinate system (Fig. 3).

Table 5. Eigenvalues and percentage of variance explained by the principal components based on morpho-agronomic traits of 15 adlay genotypes

Component	Eigen value	Variance (%)	Cumulative Variance (%)
PC1	5.42	30.10	30.10
PC2	4.47	24.82	54.92
PC3	2.80	15.57	70.49
PC4	1.81	10.05	80.55
PC5	1.30	7.21	87.75

Principal components with eigenvalues > 1 were retained based on the Kaiser criterion.

The contribution of variables to PC1 showed that plant height (PH) had the highest contribution (14.7 %), followed by leaf length (LL, 13.2 %), duration of flowering (DF, 11.4 %), leaf width (LW, 9.7 %), number of nodes (NN, 7.7 %), length of internodes (LoI, 7.6 %), number of vegetative tillers (NVT, 7.1 %), grain yield (GY, 6.7 %), number of productive tillers (NPT, 6.5 %) and number of leaves (NL, 5.8 %) (Table 6).

Table 6. Contribution (%) of morpho-agronomic traits to the first two principal components (PC1 and PC2)

Traits	PC1 (%)	PC2 (%)
Plant height	14.7	0.8
Leaf length	13.2	0.0
Duration of flowering	11.4	0.7
Leaf width	9.7	2.7
Number of nodes	7.7	6.4
Length of internodes	7.6	0.0
Number of vegetative tillers	7.1	6.5
Grain yield	6.7	11.4
Number of productive tillers	6.5	5.4
Number of leaves	5.8	4.2
Days to emergence	4.4	1.1
Weight of 100 seeds	1.5	0.4
Start of grain colour change	1.2	15.5
Panicle length	1.0	0.8
Number of grains per panicle	0.8	6.1
Days to flowering (DTF)	0.4	19.1
Days to maturity (DM)	0.1	14.9
Percent germination (PG)	0.1	3.7

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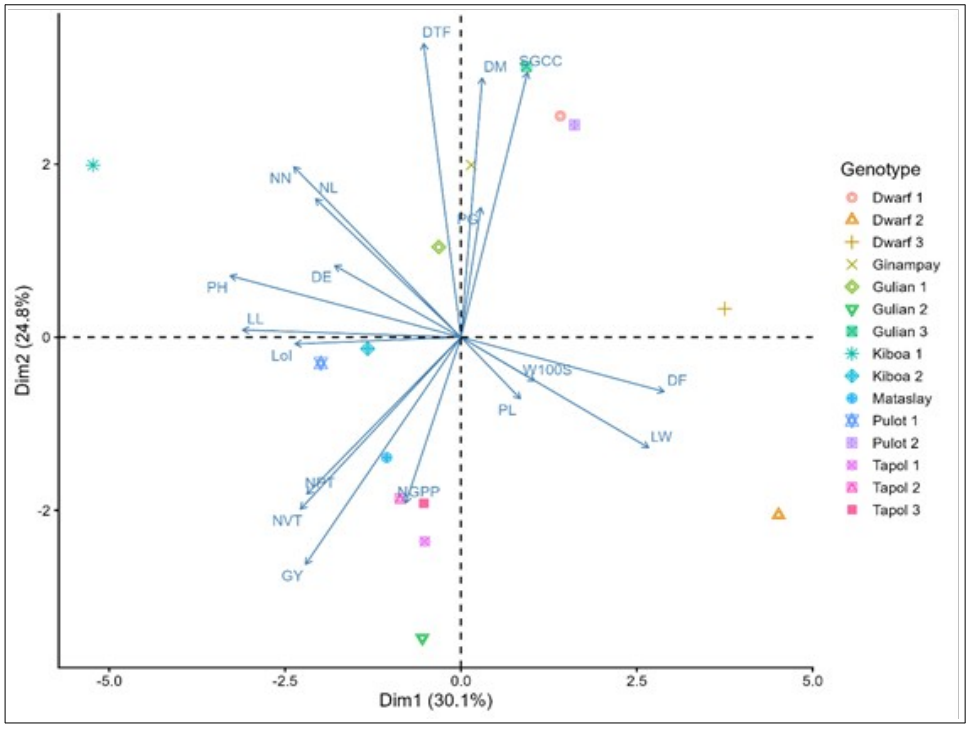


Fig. 3. PCA biplot showing the relationships among morpho-agronomic traits and adlay genotypes.

PG: percent germination; DE: days to emergence; NVT: number of vegetative tillers; DTF: days to flower; DF: duration of flowering; SGCC: start of grains to change colour; DM: days to maturity; PH: plant height; NN: number of nodes; LoI: length of internodes; NL: number of leaves; LL: leaf length; LW: leaf width; NPT: number of productive tillers; PL: panicle length; NGPP: number of grains per panicle; W100S: weight of 100 seeds; GY: grain yield.

For PC2, days to flowering (DTF) showed the highest contribution (19.1 %), followed by the start of grains to change colour (SGCC, 15.5 %) and days to maturity (DM, 11.4 %). Other variables contributing above the average contribution threshold were the number of vegetative tillers (NVT, 6.5 %), number of nodes (NN, 6.4 %) and number of grains per panicle (NGPP, 6.1 %). The remaining traits had lower contributions to PC2 (Table 6).

Morpho-agronomic performance of adlay genotypes

Under musuan conditions, the 15 adlay genotypes exhibited significant differences in several morpho-agronomic traits, reflecting variation in growth, development and yield-related characteristics. Consistent with earlier reports, adlay confirmed its status as a long-duration cereal, with maturity ranging from 151–160 DAS (~5–6 months), aligning with previous findings (18, 19). However, under suboptimal or off-season conditions, maturity can extend to 7–8 months (6, 20). Moreover, days to emergence (4–7 DAS) and days to flowering (94–108 DAS) varied significantly among genotypes, underscoring differences in phenological development within the evaluated germplasm. Earlier flowering and shorter vegetative periods may be advantageous under environments where late-season stresses affect reproductive development, as reported in wheat under terminal drought (21). Earlier emergence has likewise been associated with differences in plant fitness (22). In the present study, grain yield was negatively correlated with days to flowering and maturity, indicating that genotypes with earlier phenological development tended to produce higher yields under Musuan conditions. This association provides a basis for further evaluation of phenological traits in adlay, although their consistency as selection criteria requires validation across environments.

The genotypes differed in plant architecture, with Kiboa 1 exhibiting a notably tall stature, consistent with previous reports (18, 19). The components of height also varied, with internode length ranging from 16 cm (Dwarf 3) to 21 cm (Tapol 1 and Gulian 1), while node number ranged from 11 to 14. The significant variation in number of leaves, which ranged from 11 to 14, further indicates differences in vegetative growth and canopy development among genotypes. Kiboa 1, which produced the greatest number of leaves, also exhibited the greatest plant height and number of nodes, indicating greater vegetative growth than the other genotypes. In contrast, Dwarf 3, which had fewer leaves, fewer nodes and shorter stature, displayed a more compact plant architecture. Leaf width also differed significantly among genotypes, further contributing to the observed variation in plant morphology.

Analysis of yield component traits revealed significant phenotypic variation among the genotypes evaluated. Although the number of vegetative and productive tillers did not differ significantly in ANOVA, their near-perfect correlation (r = 0.96) and strong association with grain yield indicate that these traits were closely related to yield performance under the conditions of the study. This suggests that tiller number may be a useful trait to consider in selection for improved yield in adlay breeding programmes.

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Weight of 100 seeds varied significantly; seed size is a critical quality trait, often associated with better seedling vigour, market preference- and milling yield. Interestingly, Dwarf 2 did not translate its heavy seeds into the highest grain yield, suggesting that yield-component compensation may be occurring. The result indicates that greater seed weight alone did not correspond to higher grain yield in the evaluated genotypes, supporting the consideration of multiple yield components in selection.

Grain yield was negatively correlated with several phenological traits: days to flowering (r = -0.70), days to maturity (r = -0.73) and start of grain colour change (r = -0.66), indicating strong negative associations with days to flowering and maturity and a moderately strong negative association with the start of grain colour change. Thus, the negative correlations indicate that earlier flowering, maturity and grain colour change were associated with higher grain yield among the genotypes evaluated under the conditions of the study. These associations suggest that earlier phenological development was generally associated with better yield performance among the evaluated genotypes. However, days to maturity did not differ significantly among genotypes in the ANOVA, indicating that the observed correlation should be interpreted as an association rather than evidence of significant genotypic differences in maturity duration. Therefore, these trait associations should be validated across multiple environments and seasons before being considered as selection criteria for yield improvement in adlay breeding programmes. Similarly, Tapol was reported as the highest-yielding among 5 adlay varieties evaluated in Surigao del Sur, Mindanao (3). However, differences in genotype performance and ranking across studies may arise from variation in environmental conditions and genotype-by-environment interactions.

The observed variation provides baseline information for further evaluation of the germplasm under Musuan conditions. However, because the genotypes were evaluated at one site during a single growing season, the stability of their phenotypic performance and yield ranking remains uncertain. Multi-location and multi-season trials are therefore needed to assess genotype-by-environment interactions before promising genotypes are advanced for cultivar development or broader breeding applications.

Trait association and implications for yield improvement

The PPMC revealed several strong associations among traits related to yield in adlay. The strongest association was between the number of vegetative tillers and productive tillers (r = 0.96), indicating a strong relationship between tiller production and productive tiller formation. Grain yield showed strong significant positive correlations with both vegetative (r = 0.85) and productive tiller numbers (r = 0.82), indicating that higher tiller numbers were associated with higher grain yield under the conditions of the present study. However, neither vegetative nor productive tiller numbers differed significantly among genotypes in the ANOVA. Thus, the correlation results indicate an association between tiller number and grain yield, but do not establish a causal relationship or demonstrate that tiller number is responsible for genotypic differences in yield. This association is consistent with previous studies in cereals, where tiller number is recognised as an important component of yield potential (23–25). Therefore, tiller number may be considered a potentially useful trait for further evaluation, but its value as a selection criterion for high yield requires validation.

Grain yield was negatively correlated with several phenological traits: days to flowering (r = -0.70), days to maturity (r = -0.73) and start of grain colour change (r = -0.66). Thus, earlier phenological development was associated with higher grain yield among the genotypes evaluated. However, days to maturity did not differ significantly among genotypes in the ANOVA, indicating that the observed correlation should be interpreted as an association rather than evidence of significant genotypic differences in maturity duration. Therefore, these trait associations should be validated across multiple environments and seasons before being considered as selection criteria for yield improvement in adlay breeding programmes.

Plant architecture traits also showed coordinated development, as evidenced by positive correlations among plant height, internode length, leaf length and tiller number. These associations indicate coordinated variation among plant architecture traits and tiller numbers under the conditions of the present study. Their relevance to indirect selection for yield, however, requires further evaluation. The observed associations among traits also highlight the need to evaluate tiller number alongside other agronomic traits when considering its potential use in selection. Thus, tiller number may be considered as one of several traits to be evaluated for yield improvement rather than as a sole selection criterion.

The observed trait associations may provide a basis for identifying candidate traits for further evaluation in indirect selection. However, given that the correlations were derived from 15 genotype means under a single environmental condition, their consistency and utility as selection criteria require validation across multiple seasons and locations. The heritability of tillering traits should also be assessed to determine their potential usefulness for genetic selection.

Phenotypic diversity among adlay genotypes

The SSWDI revealed substantial phenotypic diversity among the evaluated adlay genotypes, with an overall mean of 0.75, indicating moderate diversity across morpho-agronomic traits. This reflects considerable phenotypic variation within the evaluated germplasm and provides a basis for further characterisation and evaluation of the genotypes. Comparable levels of diversity have been reported in Philippine *C. lacryma-jobi* germplasm, underscoring the value of conserving and utilising local genetic resources for crop improvement (5, 7).

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Traits exhibiting high diversity (H′ = 0.76–0.99) were primarily associated with germination, tillering ability, phenological development, panicle characteristics and grain yield. The diversity observed in these traits demonstrates variability for several agronomically relevant characteristics among the evaluated genotypes. Similar patterns of significant variation in key agronomic traits, including flowering time, plant height, grain yield and seed weight, have been reported in previous evaluations of adlay breeding lines, highlighting their importance in characterising variation within adlay germplasm (12).

Principal component analysis of morpho-agronomic traits

Principal component analysis (PCA) based on the mean values of the 15 adlay genotypes (n = 15) revealed multivariate patterns of variation among genotypes, with the first 2 principal components accounting for 54.9 % of the total variation. This proportion indicates that more than half of the observed multivariate variation was represented by the first two principal components. The value was comparable to a previous report, where the first two principal components accounted for approximately 47.5 % of the total morphological variation among 94 Job's-tears accessions (9). Similar phenotypic diversity has also been reported in Philippine adlay germplasm (5).

The strong contributions of plant growth and structural traits to PC1 indicate that differences in plant architecture and vegetative development were major components of genotype differentiation. Plant height, leaf length, leaf width, number of nodes, length of internodes and number of vegetative tillers were among the major contributors to this component, together with duration of flowering and grain yield. In contrast, PC2 was dominated by phenological traits, particularly days to flowering, start of grain colour change and days to maturity. Genotypes located in the positive region of PC2, including Dwarf 1, Pulot 2, Ginampay and Gulian 3, were positioned toward maturity-related traits, whereas the Tapol groups and Gulian 2 were positioned toward yield-related traits, including grain yield, number of productive tillers and number of grains per panicle. This positioning indicates contrasting trait associations among the genotypes along the second principal component. Their performance and stability across environments, however, require further evaluation through multi-season and multi-location trials.

The dispersion of genotypes across the PCA biplot further demonstrates the presence of diverse combinations of morpho-agronomic traits among the evaluated materials. Such variability provides opportunities for identifying genotypes with desirable trait combinations for further evaluation in breeding programmes. The observed phenotypic diversity may be partly related to the natural outcrossing system and human activities, which have been reported to influence genetic diversity and population structure in Coix populations (10).

Conclusion

This study demonstrated morpho-agronomic variability among 15 adlay genotypes under the environmental conditions of Musuan, Bukidnon, with significant differences observed in grain yield, plant architecture and phenological traits, providing baseline information for adlay improvement. The Tapol genotypes recorded the highest grain yields in the present single-site, single-season evaluation and may be considered promising for further testing, although their performance remains preliminary because genotype-by-environment interactions were not assessed. Grain yield was positively associated with tiller production, but because vegetative and productive tiller numbers did not differ significantly among genotypes in the ANOVA, these relationships represent associations rather than causal effects on yield. Negative associations between grain yield and phenological traits suggested that earlier phenological development was associated with higher grain yield. These trait associations and the performance of promising genotypes require validation across multiple locations and growing seasons to determine their consistency, stability and usefulness for breeding and cultivar development.

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Authors' contributions

JVRA conceptualised and designed the study, conducted the experimental procedures, collected and analysed the data, prepared the original manuscript draft and revised the manuscript. NBB, JMJ and HLVE contributed to the study design, provided technical and academic guidance, critically revised the manuscript for important intellectual content and performed the final editing. All authors have 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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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used Grammarly and ChatGPT to assist with language editing and improve the clarity of the text. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the final content of the manuscript.

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