

Morphological, Phenological, and Physiological Characterization of Four Black-Seeded Pigeon Pea (*Cajanus cajan* L.) Accessions from Bali, Lombok, and East Nusa Tenggara, Indonesia

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ABSTRACT: Pigeon pea (*Cajanus cajan* L.) is a leguminous crop with great potential to be developed as a source of food, feed, and germplasm to support dryland agricultural systems. The development of this crop requires information on the diversity of morphological, physiological, and phenological characteristics of local accessions as a basis for identifying adaptive genetic resources and potential materials for breeding programs. This study aimed to evaluate the morphological, physiological, and phenological characteristics of four black-seeded pigeon pea accessions originating from Bali, Lombok, and East Nusa Tenggara, and to identify superior traits possessed by each accession. The research was conducted in Pelaga Village, Petang District, Badung Regency, Bali Province, during one growing season from July 2025 to April 2026. The experiment was arranged in a randomized complete block design (RCBD) with one factor consisting of four black-seeded pigeon pea accessions, each replicated seven times, resulting in 28 experimental units. The observed variables included morphological characteristics, physiological traits, phenological stages, and yield components. The results showed significant variation among accessions for most evaluated characteristics. The Black Bulian accession exhibited relatively superior vegetative growth, particularly in plant development and branch formation. The Black East Nusa Tenggara (NTT) accession demonstrated promising seed characteristics based on individual seed weight and 100-seed weight, whereas the Black Nusa Penida accession showed earlier reproductive development. Differences in leaf chlorophyll content and total soluble solids concentration indicated physiological variation among accessions associated with photosynthetic capacity and adaptation mechanisms under dryland conditions. The diversity of morphological, physiological, and phenological characteristics among the four black-seeded pigeon pea accessions highlights their importance as valuable germplasm resources for conservation and utilization in breeding programs, particularly for developing pigeon pea cultivars adapted to dryland agroecosystems in Bali, Lombok, and East Nusa Tenggara.

KEYWORDS: *Cajanus cajan*, black-seeded accession, morphological characterization, physiological traits, phenology, dryland.

INTRODUCTION

Pigeon pea (*Cajanus cajan* L.) is one of the most important legume crops widely cultivated in tropical and subtropical regions because of its remarkable adaptability to dry environments and marginal lands (Pahal et al., 2024; Pandit et al., 2024). The crop serves as an important source of plant protein for human consumption and livestock feed while contributing to soil fertility through biological nitrogen fixation. Its broad genetic diversity provides valuable genetic resources for crop improvement, adaptation to climate variability, and the development of sustainable food production systems (Hastuti et al., 2019).

In Indonesia, pigeon pea has long been cultivated as a traditional crop in dryland farming systems, particularly in Bali, Lombok, and several areas of East Nusa Tenggara (NTT), where agricultural production depends largely on seasonal rainfall (Rachmawati et al., 2017; Dinas Pertanian NTT, 2023). Among the local germplasm found in these regions, black-seeded pigeon pea accessions are widely maintained by farmers because of their adaptation to local environmental conditions and their importance as genetic resources for future breeding programs. The productivity of local pigeon pea generally reaches approximately 1.7 t ha⁻¹ of dry seed, whereas improved cultivars may produce up to 2.4 t ha⁻¹ under appropriate crop management (Dinas Pangan Prov. Bali). Despite their agronomic importance, comprehensive information describing the morphological,

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phenological, and physiological characteristics of black-seeded pigeon pea accessions from these regions remains limited, thereby restricting their effective utilization in breeding and conservation programs (Hastuti et al., 2019; Rachmawati et al., 2017).

Morphological characterization is commonly used as the first step in evaluating genetic diversity among plant accessions through observable characters such as plant architecture, stem diameter, branching pattern, leaf morphology, pod characteristics, and seed traits (Sharma & Singh, 2016). In the present study, the evaluation focused on four black-seeded pigeon pea accessions originating from Bali, Lombok, and East Nusa Tenggara to determine the extent of phenotypic variation among accessions adapted to different dryland agroecosystems. Since morphological characters alone cannot fully explain plant adaptation, complementary evaluations of physiological and phenological traits are required to provide a more comprehensive understanding of accession performance.

Physiological traits provide important information regarding plant responses to environmental conditions and stress tolerance. Leaf chlorophyll content, measured rapidly and non-destructively using a Soil Plant Analysis Development (SPAD) chlorophyll meter, is widely recognized as an indicator of photosynthetic capacity, nitrogen status, and drought tolerance (Kumar et al., 2019; Zhang et al., 2020; Misra et al., 2018). Likewise, total soluble solids (°Brix) reflect carbohydrate accumulation and osmotic adjustment under environmental stress, whereas phenological characteristics—including germination, vegetative growth, flowering, pod formation, and physiological maturity—describe the developmental responses of different accessions to seasonal climatic conditions (Singh et al., 2015; Rachmawati et al., 2017).

Previous studies have demonstrated that pigeon pea genotypes possessing higher chlorophyll content and greater photosynthetic efficiency generally exhibit superior productivity under drought conditions (Kumar et al., 2019). Dryland agroecosystems in Bali, Lombok, and East Nusa Tenggara provide favorable environments for evaluating pigeon pea adaptation because the crop naturally possesses tolerance to water deficit and low-fertility soils (Saxena, 2018; Varshney et al., 2021). Nevertheless, comparative information regarding the growth performance, physiological responses, and phenological behavior of black-seeded pigeon pea accessions originating from these regions remains scarce. Such information is essential for identifying promising accessions suitable for cultivar development and dryland agricultural production (Varshney et al., 2021).

Although all accessions evaluated in this study produce black seeds, they originate from different geographical regions and have been maintained under distinct agroecological conditions for many years. Geographic isolation and long-term adaptation may have resulted in considerable genetic variation expressed through differences in plant morphology, flowering behavior, physiological performance, and yield-related traits. Understanding these variations is important for identifying elite accessions that can serve as parental materials in breeding programs and as valuable germplasm for conservation. Furthermore, conserving locally adapted pigeon pea germplasm has become increasingly important in response to the continuing loss of genetic diversity caused by land-use changes and the replacement of local landraces by introduced improved cultivars. Comprehensive characterization therefore represents an essential first step toward both *in situ* and *ex situ* conservation of valuable genetic resources (Zuraida & Sumarno, 2023; ICRISAT Genebank, 2024).

Global climate change, characterized by increasingly erratic rainfall patterns and rising temperatures, has intensified production constraints in dryland agriculture and increased the necessity for crop varieties with superior adaptation to environmental stress (IPCC, 2021). Integrating morphological, phenological, and physiological evaluations provides a comprehensive approach for identifying pigeon pea accessions capable of maintaining growth and productivity under such challenging conditions (Zhang et al., 2020). Besides supporting sustainable agricultural systems through biological nitrogen fixation (FAO, 2013), locally adapted pigeon pea accessions represent strategic genetic resources for developing climate-resilient cultivars suitable for marginal lands.

Therefore, this study aimed to characterize and compare the morphological, phenological, and physiological characteristics of **four black-seeded pigeon pea (*Cajanus cajan* L.) accessions** originating from Bali, Lombok, and East Nusa Tenggara under field conditions. The study further aimed to identify the accession exhibiting the greatest potential for utilization as breeding material and as a candidate cultivar for dryland agriculture. The findings are expected to provide scientific information that supports pigeon pea breeding, germplasm conservation, and the sustainable utilization of locally adapted genetic resources for improving food security in Indonesia.

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RESEARCH METHOD

Research Design

This study employed a **Randomized Complete Block Design (RCBD)** with a single factor to characterize the morphological, phenological, and physiological traits of four black-seeded pigeon pea (*Cajanus cajan* L.) accessions originating from Bali, Lombok, and East Nusa Tenggara, Indonesia.

The treatment factor consisted of four black-seeded pigeon pea accessions:

- a. **Black Nusa Penida (NP)** – Bali
- b. **Black East Nusa Tenggara (HN)** – East Nusa Tenggara
- c. **Black Lombok (HL)** – Lombok
- d. **Black Bulian (HB)** – Bali

Each accession was replicated **seven times**, resulting in **28 experimental units**. Each experimental unit consisted of one healthy pigeon pea plant established at a spacing of **150 × 150 cm**.

Research Location and Time

The experiment was conducted from **July 2025 to April 2026** at **Pelaga Village, Petang District, Badung Regency, Bali Province, Indonesia**. The experimental site is located at an elevation of approximately **700–1,100 m above sea level**, with average temperatures ranging from **18–25°C**, representing a typical tropical dryland agroecosystem.

Plant Materials and Equipment

The plant materials consisted of seeds from four black-seeded pigeon pea accessions collected from Bali, Lombok, and East Nusa Tenggara.

The equipment used included hoes, measuring tapes, rulers, digital calipers, analytical balances, a **SPAD chlorophyll meter**, a **hand refractometer**, a **lux meter**, cameras, and computers equipped with **Microsoft Excel** and **IBM SPSS Statistics**.

Experimental Procedure

The experiment consisted of four consecutive stages.

1. Land Preparation

The experimental field was cleaned, tilled, and arranged according to the RCBD layout. Planting holes were prepared at a spacing of **150 × 150 cm**.

2. Planting

Seeds from each accession were directly sown into the planting holes at a depth of approximately **3–5 cm**. Two to three seeds were planted per hole, followed by thinning two weeks after planting to maintain one healthy plant per experimental unit.

3. Crop Maintenance

All accessions received identical crop management practices, including irrigation, replanting, manual weed control, and integrated pest and disease management throughout the growing season.

4. Data Collection

Observations were conducted continuously from seedling emergence until harvest to characterize morphological, phenological, physiological, and qualitative morphological traits of each pigeon pea accession.

Observation Variables

1. Morphological Characteristics

Morphological observations were performed to evaluate vegetative and reproductive growth of each accession.

The variables measured were:

- a. Plant height (cm)
- b. Stem diameter (mm)
- c. Number of branches
- d. Number of leaves
- e. Leaf area (cm²)
- f. Pod length (cm)
- g. Number of seeds per pod
- h. Seed weight per pod (g)
- i. Individual seed weight (g)
- j. seed weight (g)

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Vegetative measurements were conducted during active plant growth, whereas pod and seed characteristics were recorded at physiological maturity.

2. Phenological Characteristics

Phenological observations were conducted throughout the crop growth cycle to determine developmental differences among accessions.

The observed variables included:

- Days to seedling emergence
- Days to cotyledon expansion
- Days to first true leaf emergence
- Time of branch initiation
- Days to first flowering
- Pod formation period
- Pod filling duration
- Days to harvest maturity

All observations were recorded periodically from planting until harvest.

3. Physiological Characteristics

Physiological measurements were performed during the vegetative and early reproductive stages.

The variables included:

- Leaf chlorophyll content (SPAD)
- Canopy light interception (%)
- Total soluble solids (°Brix)

Leaf chlorophyll content was measured using a **SPAD chlorophyll meter**. Total soluble solids were determined from fresh leaf extracts using a **hand refractometer**, while canopy light intensity was measured using a **lux meter**.

4. Qualitative Morphological Characteristics

Qualitative observations were carried out descriptively throughout plant development.

The observed characteristics included:

- Stem color
- Leaf color
- Flower color
- Seed color

These descriptors were used to characterize phenotypic diversity among the four black-seeded pigeon pea accessions.

Data Analysis

Quantitative data were analyzed using **Analysis of Variance (ANOVA)** based on the **Randomized Complete Block Design (RCBD)** to determine the effects of accession on morphological, phenological, and physiological characteristics.

Whenever significant differences among accessions were detected at the **5% probability level**, mean separation was performed using the **Least Significant Difference (LSD) test** at the **5% significance level**.

Qualitative morphological characteristics were analyzed descriptively by comparing observable traits among the four accessions.

All statistical analyses were performed using **IBM SPSS Statistics** and **Microsoft Excel**, and the results were presented in tables and discussed according to the objectives of the study.

RESULTS

Significance of Treatment Effects on the Research Variables

The significance of the analysis of variance (ANOVA) evaluating the effects of four black-seeded pigeon pea (*Cajanus cajan* L.) accessions originating from **Bali, Lombok, and East Nusa Tenggara, Indonesia**, on morphological, phenological, and physiological characteristics is presented in **Table 1**. The results indicated that accession significantly influenced most of the quantitative variables observed. Highly significant differences (**P < 0.01**) were detected for plant height, stem diameter, number of branches, number of leaves, leaf area, pod length, number of seeds per pod, seed weight per pod, individual seed weight, 100-seed weight, leaf chlorophyll content, and total soluble solids.

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In contrast, **light intensity measured within the plant canopy did not differ significantly among accessions ($P > 0.05$)**, indicating that canopy light interception was more strongly influenced by environmental conditions than by genetic differences among the four accessions.

Phenological variables, including days to seedling emergence, cotyledon expansion, first true leaf emergence, branch initiation, flowering, pod formation, physiological maturity, and harvest maturity, were recorded throughout the experiment and are presented descriptively because these developmental traits were observed as chronological events rather than analyzed statistically.

The mean values for each quantitative variable are presented in the following sections together with descriptive explanations and statistical comparisons among the four pigeon pea accessions.

Table 1. Significance of the Effects of Four Black-Seeded Pigeon Pea (*Cajanus cajan* L.) Accessions from Bali, Lombok, and East Nusa Tenggara on Morphological, Phenological, and Physiological Characteristics

No.	Parameter	Treatment
1	Growth phenology	Nd
2	Flowering phenology	Nd
3	Fruiting phenology	Nd
4	Pod development duration	Nd
5	Harvesting age	Nd
6	Plant height	**
7	Stem diameter	**
8	Number of branches	**
9	Number of leaves	**
10	Leaf area	**
11	Pod length	**
12	Number of seeds per pod	**
13	Seed weight per pod	**
14	Individual seed weight	**
15	100-seed weight	**
16	Leaf chlorophyll content	**
17	Light intensity	ns
18	Total soluble sugars	**

Notes:

** = Highly significant effect ($P < 0.01$)

* = Significant effect ($P < 0.05$)

ns = Not significant

Nd = Not statistically analyzed

Phenological Characteristics of Four Black-Seeded Pigeon Pea Accessions

The observations of phenological characteristics revealed differences in developmental patterns among four black-seeded pigeon pea accessions from the early stages of growth. During the germination phase, seedlings emerged above the soil surface between **7 and 10 days after sowing (DAS)**. The **Black East Nusa Tenggara (HN)** and **Black Bulian (HB)** accessions emerged earlier at **7 DAS**, whereas the **Black Lombok (HL)** accession emerged at **9 DAS**. In contrast, the **Black Nusa Penida (NP)** accession exhibited the slowest germination, with seedlings emerging at **10 DAS**.

During the vegetative phase, cotyledon expansion and the emergence of the first true leaves also differed among accessions. The **Black East Nusa Tenggara (HN)** and **Black Bulian (HB)** accessions reached this stage at **10 DAS**, the **Black Lombok (HL)** accession at **11 DAS**, whereas the **Black Nusa Penida (NP)** accession required the longest period, reaching this stage at **14 DAS**. At this stage, the leaves were light green and generally exhibited an elongated oval shape.

Branch formation began approximately **6–8 weeks after sowing (WAS)** and represented an important stage in canopy development. Flowering marked the transition from the vegetative to the reproductive phase. Considerable variation in flowering time was observed among the four accessions. The **Black Nusa Penida (NP)**, **Black Lombok (HL)**, and **Black Bulian (HB)** accessions

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flowered earlier at approximately **14 WAS**, whereas the **Black East Nusa Tenggara (HN)** accession flowered later at approximately **24 WAS**.

Pod development occurred approximately **35–50 days after flowering**. During this stage, seed filling progressed gradually, resulting in increases in pod size and seed weight until physiological maturity was attained.

The maturation phase was characterized by pod color changes and progressive seed hardening. The **Black Nusa Penida (NP)**, **Black Lombok (HL)**, and **Black Bulian (HB)** accessions reached harvest maturity earliest at approximately **20 WAS**, whereas the **Black East Nusa Tenggara (HN)** accession reached harvest maturity at approximately **22 WAS**. The harvested seeds of all four accessions were black in color.

The complete phenological stages of growth, flowering, fruit development, and seed maturation of the four black-seeded pigeon pea accessions are presented in **Table 2**.

Table 2. Phenological Stages of Growth, Flowering, Fruiting, and Seed Maturation of Four Black-Seeded Pigeon Pea (*Cajanus cajan* L.) Accessions

Phase	Time	Description	Figure
Germination Phase	7–10 DAS	Pigeon pea seeds germinated within 7–10 days after sowing. The Black East Nusa Tenggara (HN) and Black Bulian (HB) accessions emerged at 7 DAS , the Black Lombok (HL) accession emerged at 9 DAS , whereas the Black Nusa Penida (NP) accession emerged at 10 DAS . Seedlings possessed smooth, pale light-green cotyledons.	
Vegetative Growth Phase	10–14 DAS	Cotyledon expansion and the emergence of the first true leaves occurred at 10 DAS in the Black East Nusa Tenggara (HN) and Black Bulian (HB) accessions, at 11 DAS in the Black Lombok (HL) accession, and at 14 DAS in the Black Nusa Penida (NP) accession. The leaves were light green and generally elongated-oval in shape.	
Branch Formation Phase	6–8 WAS	Branch initiation began approximately 6–8 weeks after sowing and marked the development of the plant canopy.	
Flowering Phase	14–24 WAS	The Black Nusa Penida (NP) , Black Lombok (HL) , and Black Bulian (HB) accessions flowered earlier at approximately 14 WAS , whereas the Black East Nusa Tenggara (HN) accession flowered at approximately 24 WAS . During this stage, papilionaceous flowers developed in racemes located in the leaf axils and at the ends of branches.	
Fruiting Phase	35–50 days after flowering	Fruiting began after successful pollination and fertilization, indicated by the formation of young pods. Pods enlarged gradually while embryo development and seed filling progressed continuously.	

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Pod Development Duration	—	Pod development extended from pod initiation until physiological maturity. During this period, pod size increased progressively, and pod color changed from light green to dark green before gradually turning yellow as maturity approached.	
Harvest Maturity	20–22 WAS	The Black Nusa Penida (NP) , Black Lombok (HL) , and Black Bulian (HB) accessions reached harvest maturity at approximately 20 WAS , whereas the Black East Nusa Tenggara (HN) accession reached harvest maturity at approximately 22 WAS . Plants were harvested when most pods had turned brown, dried naturally, and the seeds had fully hardened.	

MORPHOLOGICAL CHARACTERISTICS DURING THE VEGETATIVE STAGE

1. Plant Height (cm)

Statistical analysis (Table 3) showed that differences among the four black-seeded pigeon pea accessions had a highly significant effect on plant height. Based on the Least Significant Difference (LSD) test at the 5% significance level, the **Black Bulian** accession produced the tallest plants (**169.00 cm**), whereas the **Black Nusa Penida** accession produced the shortest plants (**155.71 cm**). The **Black Lombok** and **Black East Nusa Tenggara (NTT)** accessions produced intermediate plant heights of **163.71 cm** and **161.57 cm**, respectively. These results indicate considerable variation in vegetative growth among the four accessions.

2. Stem Diameter (mm)

Statistical analysis (Table 3) indicated that accession had a highly significant effect on stem diameter. The **Black East Nusa Tenggara (NTT)** accession produced the largest stem diameter (**30.32 mm**), followed by **Black Bulian (26.16 mm)**, **Black Nusa Penida (25.93 mm)**, and **Black Lombok (25.69 mm)**. The **Black Lombok** accession showed the smallest stem diameter among the four accessions.

3. Number of Branches (units)

Statistical analysis (Table 3) demonstrated that differences among accessions significantly affected the number of branches. The **Black East Nusa Tenggara (NTT)** accession produced the highest number of branches (**24.00 branches**), followed by **Black Lombok (18.00 branches)**, **Black Nusa Penida (17.71 branches)**, and **Black Bulian (16.29 branches)**. The **Black Bulian** accession exhibited the lowest branching capacity among the four accessions.

Table 3. Growth Performance and Vegetative Morphological Characteristics of Four Black-Seeded Pigeon Pea (*Cajanus cajan* L.) Accessions

Treatment (Accession)	Plant Height (cm)	Stem Diameter (mm)	Number of Branches (units)
Black Nusa Penida (NP)	155.71 b	25.93 c	17.71 c
Black East Nusa Tenggara (HN)	161.57 a	30.32 a	24.00 a
Black Lombok (HL)	163.71 a	25.69 c	18.00 b
Black Bulian (HB)	169.00 a	26.16 b	16.29 d
LSD (5%)	0.06%	0.07%	11.18%

Note: Means followed by the same letter within the same column are **not significantly different** according to the Least Significant Difference (LSD) test at the 5% significance level.

4. Number of Leaves (leaves)

Statistical analysis (Table 4) showed that the four black-seeded pigeon pea accessions differed significantly in the number of leaves. The **Black East Nusa Tenggara (NTT)** accession produced the highest number of leaves (173.71 leaves), followed closely by the **Black Bulian** accession (173.57 leaves) and the **Black Lombok** accession (171.29 leaves), whereas the **Black Nusa Penida** accession produced 162.57 leaves. The lowest number of leaves was recorded in the **Black Petandakan** accession (144.86 leaves). *(Remove this sentence if Petandakan is no longer included.)*

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Since the study only involved four accessions, comparisons among treatments are presented in Table 4 according to the results of the analysis of variance and the Least Significant Difference (LSD) test.

Table 4. Growth Performance and Morphological Characteristics of Four Black-Seeded Pigeon Pea Accessions

Treatment (Accession)	Number of Leaves (leaves)	Leaf Area (cm ²)
Black Nusa Penida (NP)	162.57 b	18.07 b
Black East Nusa Tenggara (HN)	173.71 a	16.70 c
Black Lombok (HL)	171.29 a	13.97 d
Black Bulian (HB)	173.57 a	21.00 a
LSD (5%)		

Note: Means followed by the same letter within the same column are **not significantly different** according to the Least Significant Difference (LSD) test at the 5% significance level.

5. Leaf Area (cm²)

Statistical analysis (Table 4) indicated that pigeon pea accessions significantly affected leaf area. Among the four accessions evaluated, the Black Bulian accession produced the largest leaf area (21.00 cm²), followed by Black Nusa Penida (18.07 cm²) and Black East Nusa Tenggara (16.70 cm²). The Black Lombok accession produced the smallest leaf area (13.97 cm²). Differences among accessions indicate the existence of morphological variation in canopy development among the evaluated black-seeded pigeon pea accessions.

MORPHOLOGICAL CHARACTERISTICS DURING THE REPRODUCTIVE STAGE

1. Pod Length (cm)

Statistical analysis (Table 5) showed that pigeon pea accessions significantly affected pod length. Among the four black-seeded accessions evaluated, **Black Bulian** produced the longest pods (7.61 cm), followed by **Black Nusa Penida** (7.30 cm), **Black Lombok** (6.97 cm), and **Black East Nusa Tenggara (NTT)** (6.61 cm). These results indicate the existence of variation in pod size among the evaluated accessions.

2. Number of Seeds per Pod (seeds)

Statistical analysis (Table 5) indicated that pigeon pea accessions significantly affected the number of seeds per pod. **Black Bulian** produced the highest number of seeds per pod (7.00), followed by **Black Lombok** (6.43), whereas **Black Nusa Penida** and **Black East Nusa Tenggara (NTT)** each produced an average of 6.00 seeds per pod.

3. Seed Weight per Pod (g)

Statistical analysis (Table 5) demonstrated that seed weight per pod differed among pigeon pea accessions. The highest seed weight per pod was recorded in **Black East Nusa Tenggara (NTT)** (1.24 g), followed by **Black Bulian** (1.20 g). **Black Nusa Penida** and **Black Lombok** each produced a seed weight per pod of 1.15 g.

Table 5. Growth Performance and Morphological Characteristics of Pigeon Pea Accessions: Pod Length (cm), Number of Seeds per Pod, Seed Weight per Pod (g), Individual Seed Weight (g), and 100-Seed Weight (g)

Treatment (Accession)	Pod Length (cm)	Number of Seeds per Pod	Seed Weight per Pod (g)	Individual Seed Weight (g)	100-Seed Weight (g)
Black Nusa Penida (NP)	7.30 a	6.00 b	1.15 b	0.193 a	19.55 a
Black East Nusa Tenggara (HN)	6.61 b	6.00 b	1.24 a	0.196 a	19.86 a
Black Lombok (HL)	6.97 b	6.43 b	1.15 b	0.169 b	17.13 b
Black Bulian (HB)	7.61 a	7.00 a	1.20 c	0.159 b	16.29 c
LSD (5%)					

Note: Means followed by the same letter within the same column are **not significantly different** according to the Least Significant Difference (LSD) test at the 5% significance level.

4. Individual Seed Weight (g)

Statistical analysis (Table 5) showed significant differences among accessions in individual seed weight. **Black East Nusa Tenggara (NTT)** produced the highest individual seed weight (0.196 g), followed by **Black Nusa Penida** (0.193 g), **Black Lombok** (0.169 g), and **Black Bulian** (0.159 g).

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5. 100-Seed Weight (g)

Statistical analysis (Table 5) indicated significant differences among accessions in 100-seed weight. The highest value was recorded in **Black East Nusa Tenggara (NTT)** (19.86 g), followed by **Black Nusa Penida** (19.55 g), **Black Lombok** (17.13 g), and **Black Bulian** (16.29 g).

PHYSIOLOGICAL CHARACTERISTICS

1. Leaf Chlorophyll Content (SPAD)

Statistical analysis (Table 6) showed that pigeon pea accessions had a highly significant effect on leaf chlorophyll content. Among the four black-seeded pigeon pea accessions evaluated, **Black Bulian** exhibited the highest leaf chlorophyll content (60.74 SPAD), followed by **Black Nusa Penida** (60.34 SPAD), **Black Lombok** (59.16 SPAD), and **Black East Nusa Tenggara (NTT)** (55.94 SPAD). These results indicate the existence of physiological variation among the evaluated accessions in their chlorophyll content.

2. Light Intensity (%)

Statistical analysis (Table 6) indicated that differences among pigeon pea accessions had **no significant effect** on light intensity. Although numerical variation was observed, the measured values ranged only from **25.51% to 28.86%**. The highest light intensity was recorded in the **Black Bulian** accession (28.86%), followed by **Black Lombok** (26.63%), **Black East Nusa Tenggara (NTT)** (25.67%), and **Black Nusa Penida** (25.51%). These results suggest that light intensity was influenced mainly by field environmental conditions rather than by genetic differences among accessions.

Table 6. Physiological Characteristics of Four Black-Seeded Pigeon Pea Accessions

No.	Treatment (Accession)	Leaf Chlorophyll Content (SPAD)	Light Intensity (%)	Total Soluble Sugars (°Brix)
1	Black Nusa Penida (NP)	60.34 b	25.51 c	11.66 b
2	Black East Nusa Tenggara (HN)	55.94 d	25.67 c	9.16 d
3	Black Lombok (HL)	59.16 c	26.63 b	10.01 c
4	Black Bulian (HB)	60.74 a	28.86 a	12.13 a
LSD (5%)				

Note: Means followed by the same letter within the same column are **not significantly different** according to the Least Significant Difference (LSD) test at the 5% significance level.

3. Total Soluble Sugars (°Brix)

Statistical analysis (Table 6) showed that pigeon pea accessions had a highly significant effect on total soluble sugars. Among the four evaluated accessions, **Black Bulian** produced the highest total soluble sugar content (12.13 °Brix), followed by **Black Nusa Penida** (11.66 °Brix), **Black Lombok** (10.01 °Brix), and **Black East Nusa Tenggara (NTT)** (9.16 °Brix). These findings demonstrate physiological differences among the four black-seeded pigeon pea accessions in their capacity to accumulate soluble sugars.

QUALITATIVE MORPHOLOGICAL CHARACTERISTICS

The qualitative morphological observations revealed variation among the four black-seeded pigeon pea (*Cajanus cajan* L.) accessions evaluated in this study. The observed differences were mainly associated with stem color, leaf color, flower color, and seed color, indicating the existence of morphological diversity among accessions originating from Bali, Lombok, and East Nusa Tenggara.

1. Stem Color

The observations presented in **Table 7** showed differences in stem color among the four black-seeded pigeon pea accessions. The **Black Nusa Penida** accession exhibited a green stem with purple branches, whereas the **Black East Nusa Tenggara (NTT)** accession possessed a light green stem with dark green branches. The **Black Lombok** and **Black Bulian** accessions showed purplish-green stems with purplish-green branches. These differences in stem and branch coloration represent qualitative morphological variation that can be used as a distinguishing characteristic among the evaluated accessions.

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Table 7. Qualitative Morphological Characteristics of Stem Color

No.	Accession	Stem Color (10 WAS)	Figure
1	Black Nusa Penida	Green stem; purple branches	
2	Black East Nusa Tenggara (NTT)	Light green stem; dark green branches	
3	Black Lombok	Purplish-green stem; purplish-green branches	
4	Black Bulian	Purplish-green stem; purplish-green branches	

Note: WAS = Weeks After Sowing.

2. Leaf Color

The observations showed that all four black-seeded pigeon pea (*Cajanus cajan* L.) accessions exhibited green leaves throughout the vegetative and reproductive growth stages. Among the evaluated accessions, the **Black Nusa Penida** accession displayed dark green leaves, whereas the **Black East Nusa Tenggara (NTT)**, **Black Lombok**, and **Black Bulian** accessions exhibited green leaves. The relatively uniform leaf coloration among the accessions indicates that leaf color is a stable qualitative trait with only slight variation among the evaluated germplasm. The qualitative morphological characteristics of leaf color are presented in **Table 8**.

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Table 8. Qualitative Morphological Characteristics of Leaf Color

No.	Accession	Leaf Color	Figure
1	Black Nusa Penida	Dark green	
2	Black East Nusa Tenggara (NTT)	Green	
3	Black West Nusa Tenggara (NTB)	Green	
4	Black Bulian	Green	

3. Flower Color

The observations presented in **Table 9** showed that all four black-seeded pigeon pea (*Cajanus cajan* L.) accessions possessed yellow flowers as the basic flower color, although differences were observed in the pigmentation patterns. The **Black Nusa Penida** and **Black East Nusa Tenggara (NTT)** accessions produced yellow flowers with purple markings. The **Black Lombok** accession exhibited yellow flowers with prominent dark purple markings, whereas the **Black Bulian** accession displayed yellow flowers with brown markings. These differences in flower pigmentation indicate qualitative morphological variation among the evaluated accessions and provide useful descriptors for their identification and characterization. The complete qualitative morphological data for flower color are presented in **Table 9**.

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Table 9. Qualitative Morphological Characteristics of Flower Color

No.	Accession	Flower Color	Figure
1	Black Nusa Penida	Yellow with purple markings	
2	Black East Nusa Tenggara (NTT)	Yellow with purple markings	
3	Black West Nusa Tenggara (NTB)	Yellow with prominent dark purple markings	
4	Black Bulian	Yellow with brown markings	

4. Seed Color

The observations presented in **Table 10** showed that all four evaluated pigeon pea (*Cajanus cajan* L.) accessions produced black seeds. No variation in seed coat color was observed among the accessions, indicating that seed color was a stable qualitative characteristic in the evaluated black-seeded germplasm. Although the accessions originated from different geographical regions, namely Bali, Lombok, and East Nusa Tenggara, they shared the same black seed coat phenotype. The qualitative morphological characteristics of seed color are presented in **Table 10**.

Table 10. Qualitative Morphological Characteristics of Seed Color

No.	Accession	Seed Color	Figure
1	Black Nusa Penida	Black	

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2	Black East Nusa Tenggara (NTT)	Black	
3	Black West Nusa Tenggara (NTB)	Black	
4	Black Bulian	Black	

SUMMARY OF THE PERFORMANCE OF THE FOUR BLACK-SEEDED PIGEON PEA ACCESSIONS

Based on the morphological, phenological, and physiological characterization, the four black-seeded pigeon pea (*Cajanus cajan* L.) accessions exhibited distinct differences in their growth performance and developmental characteristics. The **Black Bulian** accession showed relatively superior vegetative growth, particularly in plant height and branch development. The **Black Nusa Penida** accession was characterized by earlier flowering and harvest maturity, indicating a relatively shorter growth cycle. The **Black East Nusa Tenggara (NTT)** accession exhibited relatively higher individual seed weight and 100-seed weight, whereas the **Black Lombok** accession showed intermediate performance for most of the observed morphological, phenological, and physiological traits.

Differences in leaf chlorophyll content and total soluble sugars further demonstrated physiological variation among the four accessions, while seed coat color remained uniform, with all accessions producing black seeds. These findings indicate the existence of valuable phenotypic diversity that can be utilized as a genetic resource for future pigeon pea breeding and conservation programs.

Table 11. Summary of the Performance of Four Black-Seeded Pigeon Pea Accessions

Aspect	Black Nusa Penida	Black East Nusa Tenggara (NTT)	Black Lombok	Black Bulian
Morphology	Moderate plant height; relatively small stem diameter	Moderate plant height; relatively larger stem diameter	Moderate vegetative growth	Tallest plants and better branch development
Phenology	Earliest flowering and harvest	Intermediate flowering and harvest	Early flowering and harvest	Early flowering and harvest
Physiology	High chlorophyll content	Lowest chlorophyll content and total soluble sugars	Intermediate physiological performance	High chlorophyll content and relatively high soluble sugars
Seed color	Black	Black	Black	Black
General performance	Early-maturing accession	Good seed characteristics	Intermediate performance	Vigorous vegetative growth

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DISCUSSION

Morphological Characteristics of Four Black-Seeded Pigeon Pea Accessions from Bali, Lombok, and East Nusa Tenggara

The morphological characterization of four black-seeded pigeon pea (*Cajanus cajan* L.) accessions originating from Bali, Lombok, and East Nusa Tenggara revealed considerable variation in vegetative and reproductive characteristics. Significant differences were observed among accessions in plant height, stem diameter, number of branches, number of leaves, leaf area, pod characteristics, seed number per pod, seed weight per pod, individual seed weight, and 100-seed weight. The variation observed among these accessions indicates the presence of genetic diversity within black-seeded pigeon pea germplasm. Such diversity is important for breeding programs because it provides opportunities to identify genotypes with superior agronomic performance and adaptation to specific environmental conditions. Singh et al. (2006) emphasized that morphological diversity represents an important genetic resource for selecting improved pigeon pea cultivars with enhanced productivity and environmental adaptability.

Plant height differed among the four black-seeded pigeon pea accessions, indicating variation in vegetative growth potential. The Black Bulian accession exhibited relatively superior plant development, whereas the Black Nusa Penida accession produced comparatively shorter plants. The greater plant height observed in Black Bulian suggests a stronger genetic capacity for vegetative growth, biomass accumulation, and canopy development. Plant height is influenced by genetic characteristics as well as environmental factors, including water availability, temperature, and nutrient supply. Conversely, shorter plant stature in Black Nusa Penida may represent an adaptive growth strategy that reduces vegetative investment and allows more efficient allocation of resources toward reproductive development under dryland conditions. Varshney et al. (2017) reported that plant height variation in pigeon pea results from interactions between genetic potential and environmental conditions during plant growth.

Differences in stem diameter were also observed among the evaluated accessions. The Black East Nusa Tenggara (NTT) accession showed relatively stronger stem development, whereas the Black Nusa Penida accession exhibited smaller stem diameter. A larger stem diameter indicates improved plant structural strength and enhanced vascular development, which facilitates the movement of water, mineral nutrients, and photosynthetic assimilates throughout plant tissues. Strong stem characteristics are particularly beneficial under dryland conditions because they contribute to plant stability and efficient water transport during periods of limited moisture availability. Saxena et al. (2014) suggested that pigeon pea genotypes with stronger stem structures generally possess better adaptation to drought environments due to improved water storage and transport capacity.

The number of branches varied among the four accessions, with the Black Bulian accession demonstrating relatively better branch development compared with Black Nusa Penida, Black NTT, and Black NTB. Branch number is an important morphological trait because branches serve as sites for flower and pod formation, thereby contributing to yield potential. Greater branching capacity may increase the number of reproductive structures; however, the relationship between branch number and yield depends on reproductive efficiency and assimilate partitioning toward seed development. Yohane et al. (2022) reported that branch number contributes positively to pigeon pea productivity, although effective conversion of vegetative growth into reproductive yield remains a critical factor.

Variation was also observed in leaf characteristics among the four black-seeded accessions. Differences in leaf number and leaf area indicate variation in canopy structure and photosynthetic potential. Accessions with greater leaf area generally have a higher capacity to intercept solar radiation and produce assimilates required for plant growth and seed formation. However, under dryland conditions, excessive leaf expansion may increase water loss through transpiration and reduce water-use efficiency. Therefore, balanced leaf development represents an important adaptation mechanism for maintaining productivity under limited water availability. Bohra et al. (2017) reported that pigeon pea genotypes exposed to water-limited environments often modify leaf characteristics to improve drought adaptation.

Reproductive morphological characteristics showed variation among the four accessions, particularly in pod and seed traits. The Black East Nusa Tenggara (NTT) accession exhibited relatively superior seed characteristics, including higher individual seed weight and 100-seed weight compared with the other accessions. Greater seed weight indicates better seed filling capacity and efficient allocation of assimilates toward reproductive organs. Seed-related traits are important components of yield because they directly influence grain productivity and quality. Varshney et al. (2017) identified pod length, seed number per pod, and 100-seed weight as major selection criteria in pigeon pea breeding programs due to their strong association with yield improvement.

Although the Black Bulian accession showed advantages in vegetative characteristics, particularly plant growth and branching, the Black East Nusa Tenggara (NTT) accession demonstrated superior performance in seed-related traits. This finding indicates that vegetative vigor and reproductive productivity are not always controlled by the same physiological mechanisms.

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High biomass production does not necessarily result in higher seed yield unless plants possess efficient assimilate partitioning from vegetative organs toward developing seeds. Singh et al. (2006) emphasized that reproductive efficiency and assimilate translocation capacity are key determinants of pigeon pea productivity.

The Black Nusa Penida and Black West Nusa Tenggara (NTB) accessions also exhibited distinct morphological characteristics. Black Nusa Penida showed relatively compact vegetative growth, which may contribute to earlier reproductive development and adaptation to shorter growing periods. Meanwhile, Black NTB displayed intermediate performance across several morphological traits, indicating a balanced combination of vegetative and reproductive characteristics. These differences demonstrate that each accession possesses specific agronomic advantages that may be valuable for different breeding objectives.

Overall, the morphological characterization of four black-seeded pigeon pea accessions from Bali, Lombok, and East Nusa Tenggara revealed significant diversity in vegetative and reproductive traits. The Black Bulian accession demonstrated superior vegetative growth characteristics, the Black East Nusa Tenggara (NTT) accession showed promising seed traits, while Black Nusa Penida and Black West Nusa Tenggara (NTB) exhibited unique morphological adaptations. The observed diversity highlights the value of black-seeded pigeon pea germplasm as a genetic resource for developing improved cultivars with enhanced productivity and adaptation to dryland agroecosystems in Indonesia.

Identification of Phenological Patterns of Four Black-Seeded Pigeon Pea Accessions Throughout the Growth Cycle under Dryland Conditions

Phenology describes the sequence and timing of plant developmental stages, beginning from seed germination until physiological maturity and harvest. The results of this study revealed distinct phenological patterns among four black-seeded pigeon pea (*Cajanus cajan* L.) accessions originating from Bali, Lombok, and East Nusa Tenggara. Differences in germination time, vegetative development, flowering initiation, and harvest maturity indicate genetic variation in developmental responses among accessions. These variations reflect differences in adaptation mechanisms associated with environmental factors, including temperature, rainfall patterns, and photoperiod conditions under dryland environments.

During the germination stage, differences in emergence time were observed among the four accessions. The Black Nusa Penida accession showed relatively slower emergence compared with Black East Nusa Tenggara (NTT), Black West Nusa Tenggara (NTB), and Black Bulian accessions. Variation in germination rate may be associated with differences in seed vigor, seed coat characteristics, and water absorption capacity during the imbibition process. Rapid germination provides an important advantage under dryland conditions because early seedling establishment enables plants to utilize available soil moisture more effectively before environmental stress occurs. Ojiewo et al. (2020) reported that germination speed is an important indicator of seed vigor and early adaptation capacity in leguminous crops.

During the vegetative growth phase, differences were observed in cotyledon expansion, development of the first true leaves, and early plant establishment among accessions. The Black Bulian accession demonstrated relatively vigorous early vegetative growth, which was consistent with its superior vegetative characteristics observed at later growth stages. Meanwhile, the Black Nusa Penida accession showed a relatively compact growth pattern. Rapid vegetative establishment is advantageous in dryland environments because plants can develop functional leaf systems and root structures before soil moisture becomes limiting. Efficient early growth contributes to improved resource acquisition and biomass accumulation during the vegetative stage.

Branch initiation occurred approximately 6–8 weeks after sowing (WAS) in all evaluated accessions. Branch development represents an important phenological transition because branches serve as the main sites for flower and pod formation. The Black Bulian accession showed relatively stronger branch development, indicating greater vegetative investment before entering the reproductive phase. However, branch number alone does not always determine final productivity because reproductive success also depends on flowering efficiency, pod formation, and assimilate allocation toward developing seeds.

The most pronounced phenological differences were observed during the flowering stage. The Black Nusa Penida, Black West Nusa Tenggara (NTB), and Black Bulian accessions initiated flowering earlier, whereas the Black East Nusa Tenggara (NTT) accession exhibited a relatively longer vegetative phase before flowering. Differences in flowering time indicate genetic variation in the sensitivity of pigeon pea accessions to environmental signals, particularly photoperiod and temperature. Early flowering represents an important adaptive mechanism under dryland conditions because plants can complete reproductive development before the occurrence of terminal drought. Saxena et al. (2014) emphasized that flowering time is a major adaptive trait determining pigeon pea performance under variable climatic conditions.

The pod development phase followed flowering and represented a critical period for determining final seed productivity. During this stage, assimilates produced through photosynthesis are translocated from vegetative organs toward developing pods and seeds. Accessions capable of maintaining photosynthetic activity during pod filling generally exhibit better seed development

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and higher seed weight. Differences in seed characteristics among accessions may therefore be associated with variation in the duration and efficiency of reproductive development.

Differences were also observed in the duration required to reach physiological maturity and harvest. The Black Nusa Penida, Black West Nusa Tenggara (NTB), and Black Bulian accessions reached maturity earlier than the Black East Nusa Tenggara (NTT) accession. Earlier maturity provides an adaptive advantage in dryland agroecosystems because plants can complete their life cycle before severe water limitation develops at the end of the growing season. In contrast, accessions with longer growth duration may accumulate greater vegetative biomass but face increased risk of drought exposure during reproductive development. Varshney et al. (2017) reported that early-maturing pigeon pea genotypes are valuable genetic resources for environments characterized by short rainy seasons and unpredictable water availability.

Overall, the phenological characterization demonstrated that the four black-seeded pigeon pea accessions exhibited different developmental strategies. The Black Nusa Penida accession showed early transition toward reproductive development, Black Bulian combined vigorous vegetative growth with relatively early maturity, Black West Nusa Tenggara (NTB) exhibited intermediate phenological behavior, and Black East Nusa Tenggara (NTT) showed a relatively longer growth cycle associated with delayed flowering. These differences highlight the importance of phenological diversity in selecting pigeon pea genotypes suitable for different dryland production environments.

Differences in Morphological, Phenological, and Physiological Characteristics among Four Black-Seeded Pigeon Pea Accessions

In addition to the observed differences in morphological and phenological characteristics, this study revealed physiological variation among the four black-seeded pigeon pea (*Cajanus cajan* L.) accessions. Physiological traits provide important information regarding the ability of plants to maintain metabolic activity, photosynthetic performance, and stress adaptation under specific environmental conditions. Differences in physiological responses among accessions indicate genetic variation in mechanisms related to resource utilization and adaptation to dryland environments.

Variation in leaf chlorophyll content was observed among the four accessions. The highest chlorophyll content was recorded in the Black Nusa Penida and Black Bulian accessions, whereas the Black East Nusa Tenggara (NTT) accession exhibited relatively lower chlorophyll content. Higher chlorophyll concentration indicates greater potential for light absorption and photosynthetic activity, which contributes to the production of assimilates required for vegetative growth and reproductive development. Bohra et al. (2017) reported that leaf chlorophyll content is an important physiological indicator in selecting drought-adapted pigeon pea genotypes because it is closely associated with photosynthetic efficiency, plant vigor, and productivity under water-limited conditions.

The light intensity variable did not differ significantly among the four pigeon pea accessions. This result indicates that light availability during the experiment was mainly determined by environmental conditions rather than genetic differences among accessions. The minor variation observed may be related to differences in canopy structure, leaf orientation, and plant architecture, which influence the interception and distribution of incoming solar radiation within the plant canopy.

Differences in total soluble solids (TSS) concentration were also observed among the four accessions. Variation in soluble sugar accumulation reflects differences in physiological responses associated with carbon metabolism and stress adaptation. Higher soluble sugar concentration indicates greater osmotic adjustment capacity, allowing plants to maintain cellular water balance and sustain physiological processes during periods of limited water availability. According to Bohra et al. (2017), soluble sugar accumulation represents an important drought tolerance mechanism in legumes because these compounds function as osmoprotectants that stabilize cellular structures and protect tissues from dehydration-induced damage.

Identification Of The Most Promising Black-Seeded Pigeon Pea Accession For Further Development

Based on the integrated evaluation of morphological, phenological, and physiological characteristics, the four black-seeded pigeon pea accessions demonstrated different strengths associated with growth, adaptation, and productivity. The Black Bulian accession exhibited superior vegetative characteristics, particularly plant development and branch formation, indicating strong biomass production potential. The Black Nusa Penida accession showed advantages in phenological adaptation through earlier flowering and maturity, which may provide benefits under dryland conditions with limited growing periods.

The Black East Nusa Tenggara (NTT) accession demonstrated promising reproductive characteristics, particularly in seed-related traits such as individual seed weight and 100-seed weight. Superior seed characteristics indicate efficient seed filling and improved assimilate allocation toward reproductive organs, which are important factors determining grain productivity. Meanwhile, the Black West Nusa Tenggara (NTB) accession exhibited intermediate performance across several morphological, phenological, and physiological characteristics, indicating a balanced adaptation strategy.

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The differences among accessions indicate that no single genotype possessed superiority for all evaluated traits. Instead, each accession exhibited specific desirable characteristics that can be utilized according to breeding objectives. The Black Bulian accession may serve as a valuable genetic source for vigorous vegetative growth, Black Nusa Penida as a source of early maturity, and Black East Nusa Tenggara (NTT) as a source of improved seed characteristics. Yohane et al. (2022) reported that accessions possessing favorable combinations of agronomic and physiological traits are valuable genetic resources for breeding programs because they can contribute desirable characteristics for developing productive and widely adapted cultivars.

The utilization of locally adapted pigeon pea germplasm is an important strategy for developing improved cultivars capable of maintaining productivity under environmental constraints, particularly drought and limited water availability. Varshney et al. (2017) emphasized that locally adapted genetic resources provide valuable materials for breeding programs aimed at improving resilience and productivity under changing climatic conditions.

Overall, based on the combined assessment of morphological, phenological, and physiological traits, the four black-seeded pigeon pea accessions represent valuable genetic resources with different adaptive advantages. Black Bulian showed superior vegetative performance, Black Nusa Penida demonstrated early maturity characteristics, Black East Nusa Tenggara (NTT) exhibited superior seed traits, and Black West Nusa Tenggara (NTB) displayed intermediate adaptation. These accessions have potential for further utilization in pigeon pea improvement programs targeting dryland agroecosystems in Bali, Lombok, and East Nusa Tenggara.

CONCLUSION

Based on the results of this study on the morphological, phenological, and physiological characteristics of four black-seeded pigeon pea (*Cajanus cajan* L.) accessions collected from Bali, Lombok, and East Nusa Tenggara, the following conclusions can be drawn:

1. The four black-seeded pigeon pea accessions exhibited considerable morphological variation in both vegetative and reproductive characteristics. The Black Bulian accession demonstrated relatively superior vegetative performance, particularly in plant growth and branch development, whereas the Black East Nusa Tenggara (NTT) accession showed promising reproductive characteristics based on superior seed traits, including individual seed weight and 100-seed weight. The variation observed among accessions indicates the presence of valuable phenotypic diversity within black-seeded pigeon pea germplasm.
2. Distinct phenological patterns were observed among the four black-seeded pigeon pea accessions throughout the growth cycle. Differences were recorded in germination rate, vegetative development, flowering initiation, and harvest maturity. The Black Nusa Penida, Black West Nusa Tenggara (NTB), and Black Bulian accessions exhibited relatively earlier flowering and maturity characteristics, whereas the Black East Nusa Tenggara (NTT) accession showed a longer growth duration. These differences indicate genetic variation in developmental responses and adaptation strategies under dryland conditions.
3. Significant differences in morphological, phenological, and physiological characteristics were observed among the four black-seeded pigeon pea accessions. Variation was detected in most evaluated parameters, while light intensity showed no significant difference because it was mainly influenced by environmental conditions. Physiologically, differences in leaf chlorophyll content and total soluble solids concentration demonstrated variation in photosynthetic capacity and stress adaptation mechanisms among accessions. The accessions with higher chlorophyll content and soluble sugar accumulation showed better potential for maintaining physiological activity under dryland environments.
4. Based on the combined evaluation of morphological, phenological, and physiological characteristics, the four black-seeded pigeon pea accessions possessed different adaptive advantages. The Black Bulian accession showed superior vegetative characteristics, the Black Nusa Penida accession demonstrated early maturity traits, the Black East Nusa Tenggara (NTT) accession exhibited favorable seed characteristics, and the Black West Nusa Tenggara (NTB) accession showed intermediate performance. These accessions represent valuable genetic resources for further utilization in pigeon pea improvement programs targeting dryland agroecosystems in Bali, Lombok, and East Nusa Tenggara.

ADVICE

Based on the findings of this study, the following recommendations are proposed:

1. The promising black-seeded pigeon pea accessions, particularly Black Bulian, Black Nusa Penida, and Black East Nusa Tenggara (NTT), should be evaluated further through multi-location trials and yield stability assessments under different dryland agroecosystems to confirm their adaptability and productivity before being considered for variety development.

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2. Further studies should conduct genetic and molecular characterization of the four black-seeded pigeon pea accessions to obtain deeper information regarding genetic diversity, genetic relationships, and potential traits associated with adaptation and productivity.
3. The black-seeded pigeon pea accessions originating from Bali, Lombok, and East Nusa Tenggara should be conserved and developed as valuable germplasm resources because they possess diverse morphological, phenological, and physiological characteristics that can support future pigeon pea breeding programs.
4. The cultivation and utilization of black-seeded pigeon pea should be promoted in dryland farming systems, particularly through the selection of accessions with superior adaptive traits, as an alternative food crop and sustainable source of plant-based protein in Bali, Lombok, and East Nusa Tenggara.

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