COMPARATIVE MORPHOLOGICAL CHARACTERIZATION OF BBT BROWN, BBT WHITE AND ART WHITE COWPEA (*Vigna unguiculata [L.] Walp*) VARIETIES UNDER LOW MANAGEMENT CONDITIONS.

BY

Osasere OTABOR

SR/2305/RPR/25/47

DEPARTMENT OF PLANT BIOLOGY AND BIOTECHNOLOGY

FACULTY OF LIFE SCIENCES

UNIVERSITY OF BENIN

BENIN CITY.

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This is to certify that this project work was carried out by **Osasere OTABOR (Miss)** of the department of Plant Biology and Biotechnology, Faculty of Plant Biology and Biotechnology, Faculty of life sciences, University of Benin, Benin City.

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Prof. Beckley Ikhajiagbe **Signature/Date**
(Project Supervisor)

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Prof. Beckley Ikhajiagbe **Signature/Date**
(Project Supervisor)

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External Examiner **Signature/Date**

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ABSTRACT

Cowpea (*Vigna unguiculata [L.] Walp*.) is an essential grain legume in Nigeria, valued for its protein content, soil-fertility benefits, and economic importance. Despite its adaptability, yields remain low under smallholder, low-management systems. This study aimed to characterize and compare morphological traits of three improved cowpea varieties—BBT Brown (ARTPEA/BBT/72/B), BBT White (ARTPEA/BBT/22/W), and ART White (SAMPEA-13/Ife-98-12)—to determine their adaptability and performance under field conditions with minimal inputs. The experiment was conducted at the Teaching and Research Botanical Garden, University of Benin, using a Completely Randomized Design. Each variety was planted on two ridges under identical low-input conditions, with data collected on germination, vegetative growth, nodulation, and yield attributes. Parameters measured included stem diameter and length, number of leaves, branches, nodules, pods, and seeds per pod. Data were analyzed using one-way ANOVA and mean separation at 5 % significance. Results showed clear varietal differences in morphological performance. Cultivar 1 (ART White) produced the highest average number of pods (14.25 ± 4.23) and seeds per pod (≈ 14.6), while Cultivar 2 (BBT Brown) recorded the longest stems (142.37 ± 9.23 cm) and peduncles (29.84 ± 5.50 cm). Cultivar 3 (BBT White) had the lowest pod count but comparable stem length (140.45 ± 10.71 cm). Leaf number and pod length differed significantly among varieties ($p < 0.05$). Overall, the improved cultivars exhibited distinctive morphological adaptations, with ART White showing superior reproductive potential under low-management conditions. These findings provide baseline data for varietal selection and breeding programs aimed at enhancing cowpea productivity in resource-limited farming systems.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND STUDY

Cowpea (*Vigna unguiculata* [L.] Walp.) is one of the most important food legumes grown in tropical and subtropical regions of the world, including Africa, Asia, and parts of the Americas. In sub-Saharan Africa, especially Nigeria, it plays a central role in both human nutrition and household income. Millions of rural families depend on cowpea as their major source of affordable protein, as it contains high levels of plant-based protein, dietary fiber, vitamins, and micronutrients needed for healthy growth and development (Kouakou *et al*., 2022; Nwagboso *et al*., 2024). In many Nigerian homes, cowpea is eaten in several forms such as beans, moin-moin, akara, and porridge, making it not just a cash crop but also a food security crop that provides daily meals for households. Because of this dual role in food and income, cowpea has become a crop of both subsistence and commercial value, and it is cultivated across diverse ecological zones in Nigeria, ranging from the dry Sahel regions to the more humid forest zones (Manda *et al*., 2019).

Apart from its direct role in human diets, cowpea is also recognized for its ecological importance. Like many other legumes, cowpea forms a symbiotic association with Rhizobium bacteria in its roots, enabling it to fix atmospheric nitrogen into forms usable by plants. This biological nitrogen fixation improves soil fertility and reduces the need for expensive chemical fertilizers, which many smallholder farmers cannot afford (Poudel *et al*., 2025a). In farming systems where soils are poor and degraded, cowpea provides a natural means of restoring soil health while still giving yield. Moreover, cowpea has other agronomic advantages such as a short growth cycle, tolerance to drought, and the ability to grow on relatively poor soils (Poudel *et al*., 2025b). These traits make it particularly suitable for Nigerian farmers who often face challenges of irregular rainfall, limited access to irrigation, and high cost of farm inputs. Because of its minimal input needs, resilience to harsh conditions, and multiple benefits including food, fodder, and soil fertility, cowpea is a key crop for smallholder farmers in resource-limited environments.

The study of cowpea morphology has gained attention because physical traits expressed by the plant can serve as quick indicators of adaptation and performance. Morphological characterization, especially at early growth and reproductive stages, is very important because it allows researchers and farmers to observe differences among varieties before harvest. Traits such as leaf length and width, stem girth, plant height, root nodulation, and even visible signs of leaf damage are simple but effective measures that can reflect how vigorous and stress-tolerant a particular variety may be (Afiukwa, 2017; Digrado *et al*., 2024). When these traits are recorded under field conditions, even in low-input or farmer-managed systems, they provide baseline information that guides selection of robust varieties that combine adaptability with productivity.

However, cowpea is known for its wide intraspecific variation. This means that plants within the same species often show large differences in appearance and growth patterns. On one hand, this variability is useful for breeders because it provides raw material for crop improvement. On the other hand, it creates challenges for farmers and extension workers. In many rural areas, farmers may not be able to clearly distinguish between improved varieties and landraces because of overlapping physical traits such as similar leaf shapes or growth habits. This often leads to seed mixtures, misidentification, and inconsistent yield outcomes in the field (Akinyemi *et al*., 2025). Moreover, traits expressed in one environment may not always be consistent when the same variety is grown in another location, making accurate morphological differentiation a critical step in variety testing and extension.

Genetic diversity in cowpea translates into visible differences in many traits, including leaf size and shape, stem thickness, growth habit (erect or spreading), days to flowering, and root nodulation capacity. These traits do not only influence the appearance of the plant but also have practical importance for yield potential, stress tolerance, canopy coverage, and susceptibility to insect pests and diseases (Afiukwa, 2017). For example, larger leaf area may be linked to greater photosynthetic efficiency, while stronger stems support better resilience against lodging or pest attack. Similarly, nodulation is directly connected to nitrogen fixation capacity, which in turn supports plant growth even in nutrient-poor soils.

In this study, three improved cowpea varieties were selected for evaluation: BBT Brown (Remilekun), BBT White (Boluyo), and ART-98-12. BBT Brown and BBT White were both released by the Institute of Agricultural Research and Training (IAR&T), Ibadan, in 2021–2022 as part of efforts to combat brown blotch disease, a bacterial leaf spot that significantly reduces cowpea yields in humid parts of Nigeria. Both varieties are early-maturing, non-vining bush types with strong yield potential and adaptability to the forest and forest–savanna transition zones. BBT Brown produces brown seeds and has shown better resistance to storage weevils, while BBT White produces white seeds but is moderately susceptible to storage pests. ART/98-12 released in 2009 (registered in 2009) as SAMPEA-13 (Ife-98-12) but often referred to as ART/98-12 in research is also an early-maturing, white-seeded variety released by IAR&T, with tolerance to brown blotch disease and good grain yield potential, making it suitable for cultivation under the humid and derived savanna ecologies of Nigeria (IAR&T, 2022; IITA, 2023).

By comparing the morphological traits of these three varieties at the early flowering stage, this research contributes to understanding the level of variation within cowpea and provides useful baseline data for breeding programs and variety selection. The findings are expected to help farmers, researchers, and extension workers identify suitable cowpea varieties for different environments in Nigeria, thereby promoting food security, supporting breeding programs, and strengthening sustainable agricultural development.

1.2 COWPEA (*Vigna unguiculata*) IN NIGERIA

Nigeria remains the largest producer and consumer of cowpea in the world, with national output estimated between 3.6 and 4.2 million tonnes annually (Nwagboso, 2024; JICA, 2024). The crop plays a central role in food security and rural incomes, especially in the northern states where it is extensively cultivated. Cowpea grains contain about 22–30% protein, making them an affordable and vital source of dietary protein for millions of Nigerians. They are consumed in various forms such as akara (bean cake), moin-moin (steamed bean pudding), ewa (stewed beans), and rice-and-beans combinations, thus contributing significantly to the national diet (Boukar *et al*., 2015; FAO, 2011; AATF, 2022).

The major producing regions are concentrated in the Sudan and Northern Guinea savannas, particularly in states such as Kano, Katsina, Kaduna, Zamfara, Sokoto and Borno. Production has also been expanding into the Middle Belt (Ayanwale *et al*., 2019). According to FAOSTAT data summarised by Nwagboso (2024), Nigeria harvested about 3.63 million tonnes of cowpea from approximately 4.7 million hectares in 2021, showing the wide adoption of the crop among smallholder farmers. However, average yields remain relatively low due to constraints such as insect pests, poor soils, and variable rainfall typical of low-input production systems (IITA, 2022).

Cowpea production in Nigeria faces numerous challenges. Insect pests such as Maruca vitrata (pod borer), Aphis craccivora (aphids), and flower thrips cause major yield losses in the field, while the storage bruchid Callosobruchus maculatus is notorious for post-harvest damage. In addition, diseases and parasitic weeds such as Striga gesnerioides are prevalent in savanna ecologies, further reducing productivity (IITA, 2022). To overcome these constraints, significant research and varietal development have been undertaken by institutions such as the International Institute of Tropical Agriculture (IITA) and the Institute for Agricultural Research (IAR), Samaru.

One of the most notable advancements was the release of Nigeria's first genetically modified cowpea variety, SAMPEA 20-T, in December 2019. This Bt cowpea was developed to resist the destructive pod borer (Maruca vitrata) and reduce farmers' reliance on pesticides. The variety was formally unveiled to farmers in June 2021, making Nigeria the first country in the world to commercialise genetically modified cowpea (BusinessDay, 2019; USDA GAIN, 2021; The Nation, 2021). Apart from the Bt variety, several non-GM improved lines developed by IITA and IAR are also in use, providing traits such as early maturity, drought tolerance, and better grain quality (IITA, 2022).

Agronomic practices in Nigeria vary by ecological zone but generally follow rain-fed patterns. In the Sudan savanna, early maturing varieties are planted with the first effective rains between May and June, while in the Northern Guinea savanna planting is more common between June and July. Spacing recommendations usually range between 75 cm × 20 cm and 75 cm × 40 cm, with seed rates of about 15–25 kg per hectare depending on seed size. Fertiliser application is often limited, with phosphorus recommended at 20–30 kg P_2O_5 per hectare and nitrogen applied sparingly as a starter dose (IITA, 2022). Integrated pest management practices, including timely spraying, resistant varieties, and adoption of Bt SAMPEA 20-T, have been encouraged to reduce losses and costs (USDA GAIN, 2021; IITA, 2022).

Post-harvest storage is another critical aspect of cowpea production in Nigeria. Farmers face significant losses from bruchids during storage, but the introduction of hermetic technologies such as Purdue Improved Crop Storage (PICS) bags has transformed storage practices. These bags have been widely adopted in Nigerian communities and have proven effective in reducing post-harvest losses and increasing farmers' returns (Bakoye et al., 2020; Madagali, 2023).

Despite its production challenges, recent technological advances particularly the release of the Bt variety SAMPEA 20-T and the adoption of improved storage methods are helping farmers overcome long-standing constraints. With Nigeria's strategic position as the world leader in cowpea production, further support in research, extension, and infrastructure will be essential for sustaining productivity and ensuring the crop's role in national development.

1.3 THE AGRONOMIC IMPORTANCE OF COWPEA

The agronomic importance of cowpea in Nigeria cannot be overstated. It is central to food and nutrition security, enhances soil fertility through nitrogen fixation, supports integrated farming systems, and contributes to rural economies through trade and livestock feeding. Its adaptability to various Nigerian ecologies and the availability of improved varieties have made it a resilient crop against climatic and biological stresses. Recent innovations, including Bbt cowpea and improved storage technologies, further strengthen its role in sustainable agriculture. As Nigeria continues to lead global cowpea production, strengthening extension services, research, and farmer support systems will be essential to fully harness the agronomic benefits of this vital crop.

The agronomic functions are tightly linked to the species' morphological diversity; understanding morphological traits (plant architecture, leaf and pod characters, seed size, phenology, etc.) is essential for crop improvement, adaptation to local farming systems, integrated pest and disease management, and value-chain development in Nigeria. Below explains the agronomic importance of cowpea in Nigeria with an emphasis on why and how morphological study contributes to maximizing those benefits.

1.3.1 Food and nutrition security

Cowpea seeds are a dense, affordable source of protein (often 20–30% crude protein), essential amino acids, vitamins and minerals, making the crop central to household diets and nutritional security in Nigeria. Cowpea is frequently consumed as a staple or side dish (dried beans, akara, moin-moin) and its leaves and immature pods are eaten as vegetables in some regions, adding micronutrients to diets (Taiwo, 1998; FAO, 2012). Its local culinary popularity ensures strong local demand and sustained production incentives for smallholders.

1.3.2 Livestock feed and farm diversification

Leaves, haulms and immature pods offer high-quality fodder for ruminants; cowpea haulm is often used as dry season feed. Farmers therefore value cowpea both for grain and as a source of animal feed, which improves overall farm resilience and supports mixed crop–livestock systems common in many Nigerian communities. (USDA, 2012; Gates Ag One, 2020).

1.3.3 Soil fertility and conservation

As a legume, cowpea forms symbioses with rhizobia and contributes to biological nitrogen fixation reducing the need for synthetic Nitrogen inputs and improving subsequent cereal yields when used in rotation or intercropped systems. Cowpea's root architecture and residue return also contribute to soil organic matter and erosion control in fragile savanna soils. In low-input Nigerian farming systems, these services are economically important because many smallholders cannot afford regular fertilizer applications. (FAO, 2012; Osipitan, 2021).

1.3.4 Intercropping and land-use efficiency

Cowpea is highly compatible with cereal crops such as sorghum, millet, maize and maize–sorghum systems. Intercropping cowpea increases land equivalent ratio (LER) and total productivity per unit area, vital where land is limited and households depend on multi-cropping to meet food and income needs. Studies in West Africa including Nigeria report better income and land-use efficiency when cowpea is integrated into cereal-based systems compared with sole cropping. (Isaacs and Diallo, 2021; Osipitan, 2021).

1.3.5 Resilience under stress

Cowpea has notable tolerance to heat, drought and poor soils relative to many legumes, allowing it to perform where other protein crops may fail. This resilience makes cowpea particularly valuable under the variable rainfall regimes and marginal soils found across Nigeria's savanna belt, areas where climate variability increasingly threatens cereal yields. (Osipitan, 2021; Kim *et al*., 2025).

1.4 JUSTIFICATION FOR THE MORPHOLOGICAL STUDY FOR AGRONOMY

Morphological characterization remains a cornerstone of agronomy and plant breeding in Nigeria, where smallholder systems dominate and resources for advanced tools are limited.

Describing germplasm through observable traits such as plant habit, leaf type, flowering time, pod and seed size, and root architecture provides the "passport" for genetic resources in genebanks and on-farm collections. Institutions such as the National Centre for Genetic Resources and Biotechnology (NACGRAB) and the International Institute of Tropical Agriculture (IITA) rely on standardized descriptor lists for cassava, cowpea, and other crops, ensuring comparability across time and space. Crop Trust/NACGRAB review and IITA descriptors manuals underpin germplasm conservation, core collection development, and seed system management, as they help identify redundancy, maintain varietal identity, and communicate farmer-relevant traits in official catalogues.

Morphology also offers a cost-effective, field-ready phenotyping tool that aligns with farmer and market priorities. Traits such as plant height, days to flowering, pod number, and seed size not only correlate with yield but also with farmer preferences for early maturity, harvest ease, and marketable grain characteristics. Nigerian studies demonstrate that simple morphological indices explain significant proportions of phenotypic variability and are directly exploitable in selection programs (Aina, 2020; Oladimeji, 2024). Moreover, visible traits are the basis of participatory varietal selection, where farmers, men and women, judge varieties by seed colour, size, plant architecture, and maturity class. IITA modernization initiatives and IAR&T participatory case studies show that demand-driven breeding anchored in morphology increases adoption because farmers can visually assess a line's suitability during on-farm trials. Morphological cues also function as proxies for physiological resilience, with traits like root system depth linked to drought tolerance and canopy structure affecting light interception and disease incidence, as observed in maize recurrent selection under Nigerian low-N conditions (Ajala, 2017).

Finally, morphology bridges traditional agronomic evaluation with modern molecular tools. While descriptors remain the entry point for germplasm use, combining them with molecular markers enhances accuracy in diversity studies, QTL mapping, and parent selection. Nigerian and West African studies integrating SSR, DArT-SNP, and agro-morphological data in crops such as taro, maize, and cowpea demonstrate the advantages of morpho-genetic approaches (Oladimeji, 2024; Nuryati, 2024; Kumar, 2025). This integration preserves farmer-relevant visual traits while leveraging genomic precision, supporting both conservation and breeding. In addition, morphology underpins variety identity within seed systems: farmers and traders rely on visible descriptors to distinguish varieties, and ensuring distinct, recognizable traits in certified seed helps prevent mixing and maintains trust in seed markets. For these reasons, morphology remains indispensable to Nigerian agronomy, serving as the first and most accessible layer of plant improvement while linking seamlessly with emerging molecular and participatory approaches.

1.4.1 Limitations and challenges of relying on morphology

Morphological characterization, though indispensable, has clear limitations. Many traits are highly influenced by the environment, plant height, leaf size, and branching vary with soil fertility and moisture, making comparisons across sites unreliable without multi-location trials and standardized scoring protocols (IBPGR, 1983; Fukuda *et al.,* 2010). Observer bias and inconsistent data collection further reduce reliability, while incomplete digitization of historical records constrains reuse, a gap Nigeria’s genebanks are now addressing through harmonized descriptors and modernization (Crop Trust and NACGRAB, 2020). Moreover, important adaptive traits such as root depth or biochemical resistance cannot be fully assessed through morphology alone and require complementary molecular or physiological assays (Odeseye *et al*., 2022; Oladimeji *et al*., 2024). These challenges highlight the need to integrate morphology with molecular and digital phenotyping tools, yet its role remains fundamental: it anchors germplasm description, offers low-cost, farmer-relevant selection criteria, supports participatory and demand-driven breeding, and underpins varietal identity in Nigerian seed systems (Ajala, 2017; Chipeta *et al*., 2025).

1.5 Practical implications for Nigerian research, extension and farmers

Prioritizing on-farm morphological surveys is crucial for effective agricultural development in Nigeria. By conducting large-scale morphological characterization of farmer-managed landraces, researchers can accurately map the available diversity across different agroecologies, as highlighted by IITA (2023) and Olapade (2002). This approach allows for the identification of locally preferred traits, such as early maturity in drought-prone northern regions or large-seed types favored in southern markets. This direct link between farmer needs and breeding priorities is a cost-effective way to ensure that new varieties are not only high-yielding but also relevant and readily adopted. Furthermore, the use of morphology can significantly improve extension services by tailoring recommendations to specific variety architectures and phenologies, which helps farmers optimize intercropping systems and planting dates, ultimately leading to improved adoption rates and yield stability (Osipitan, 2021).

The utility of morphological characterization extends beyond breeding and extension to include participatory breeding and integrated pest management (IPM). Integrating visible morphological traits like seed color, plant height, or canopy structure into participatory breeding programs accelerates adoption because farmers can quickly evaluate and select varieties based on what they can see, as noted by Isaacs and Diallo (2021). This empowers farmers and makes the breeding process more collaborative. Additionally, recognizing morphological traits linked to pest resistance or escape is a powerful, low-cost tool for on-farm pest management, helping to reduce the reliance on harmful pesticides. The successful development and deployment of pod-borer-tolerant varieties, which have shown reduced spray frequency and increased yields, underscore the tangible benefits of a morphology-guided approach (AATF, 2021; Nwagboso, 2024). By linking these morphological descriptors to market segmentation, breeders and seed systems can maintain varietal identity, which is essential for developing efficient value chains and improving farmer incomes (Gates Ag One, 2020). Ultimately, systematic morphological studies linked to these areas will continue to deliver significant agronomic gains for food security and rural livelihoods in Nigeria.

1.6 BOTANICAL DESCRIPTION OF COWPEA

Cowpea is a highly diverse and adaptable crop with a well-defined botanical classification, originating in West Africa. Taxonomically, it belongs to the Fabaceae family, with the species name *Vigna unguiculata*. Within this species, there are common subspecies like *Var. unguiculata* (cultivated) and *Var. spontanea* (wild), as well as cultivar-groups such as *Sesquipedalis* (the yardlong vegetable type) and *Biflora* (a dry-seed/fodder type). The plant is an annual herb, and its growth form is remarkably variable, ranging from short, erect bushes to long, vining or climbing types that can reach several meters. In Nigeria, both the climbing and decumbent forms are common, with climbing types often producing more fresh pods. Its root system is deep and well-developed, featuring a taproot that can extend to a depth of over two meters, which enhances its resilience to drought. The stems are typically cylindrical and may be smooth or hairy, with growth habits that can be either determinate (bushy) or indeterminate (vining).

The plant's leaves are alternate and composed of three leaflets, whose shape and size are highly variable, with categories ranging from sub-globose to hastate. The inflorescence is an axillary raceme bearing large, papilionaceous flowers in alternating pairs. These flowers, which are typically self-pollinating, come in a variety of colors, including white, yellow, and purple. The fruit, or pod, is a legume that can be straight or curved and varies dramatically in length, from standard types (8-30 cm) to the elongated yardlong cultivars (50-120 cm). Pods typically enclose 8-30 seeds, and their color changes from green or purple when immature to cream, brown, or reddish-purple when dry. The seeds themselves are a key morphological feature, with a wide range of shapes, sizes, and colors. They can be kidney-shaped, oval, or globose, and their colors and patterns, such as the distinctive black-eye pattern, are agriculturally important. These diverse botanical traits, from growth habit and root system to floral and seed morphology, are not just academic descriptions; they are integral to the crop's performance, varietal identity, and suitability for Nigeria’s varied agroecologies, ultimately guiding breeding, selection, and conservation efforts.

1.7 GLOBAL AND LOCAL STATUS OF COWPEA PRODUCTION

Recent Nigerian breeding programs, particularly at the Institute of Agricultural Research & Training (IAR&T), have released new cultivars specifically tailored to address the challenges of the humid and derived-savanna zones. These include brown-blotch tolerant lines like ARTPEA/BBT/72/B “Remilekun” (BBT-Brown) and ARTPEA/BBT/22/W “Boluyo” (BBT-White), as well as an early-maturing, high-yielding cultivar, ARTPEA/98-12/W. All these varieties were developed with specific morphological and phenological traits in mind, as morphology directly influences a crop's fit within a cropping system, its yield stability, exposure to pests and diseases, marketability, and ultimately, farmer adoption. Globally, cowpea production is concentrated in Africa, with West Africa being a major hotspot and Nigeria leading the world in total tonnage. Despite this, average yields in Africa remain low due to significant constraints, including pests like pod-borers, various diseases, drought, and weak seed systems. Most of Nigeria's production comes from smallholders in the northern Guinea and Sudan savannas, but a significant amount is also grown in the southern zones where different disease pressures prevail. Cowpea is critical to Nigeria's food security and rural livelihoods, providing direct food, livestock fodder, and a source of cash income.

Most of Nigeria's cowpea is grown under rain-fed, low-input conditions, often intercropped with cereals. The major constraints facing these production systems are pests such as Maruca vitrata, fungal diseases like brown blotch and anthracnose, storage bruchids (Callosobruchus maculatus), and terminal drought. These issues are compounded by weak seed systems that limit farmer access to certified, improved seeds. In response to these challenges, recent varietal releases from IAR&T are particularly noteworthy. ARTPEA/BBT/72/B (Remilekun) and ARTPEA/BBT/22/W (Boluyo), known as BBT-Brown and BBT-White respectively, were developed to provide early maturity (60–75 days) and brown-blotch tolerance, with registered yields of 1.0–1.2 t/ha. Their non-photoperiod-sensitive nature makes them ideal for the humid/derived-savanna regions. Additionally, their distinct seed colors align with specific market segments. Another significant release, ARTPEA/98-12/W, is an early-maturing, high-yielding cultivar well adapted to diverse Nigerian agro-ecologies. It was developed to combine grain productivity with resilience to diseases such as brown blotch and anthracnose, making it a valuable option for smallholders seeking reliable yields under rain-fed, low-input systems.

1.8 PROFILE OF THE STUDY VARIETIES — BBT-BROWN, BBT-WHITE, AND ART-98-12

The new cowpea varieties w—ARTPEA/BBT/72/B, ARTPEA/BBT/22/W, and ART-98-12—were developed by the Institute of Agricultural Research & Training (IAR&T), Ibadan, in collaboration with IITA and other partners, to address production challenges in Nigeria’s southern and humid agro-ecologies. These breeding programs specifically targeted constraints such as brown blotch (Colletotrichum spp.), other foliar and pod diseases, insect pests, and the need for varieties capable of thriving under short or variable rainfall patterns, which are common in double-cropping systems. The BBT lines were bred with brown-blotch tolerance as a primary objective, while ART-98-12 was released as an early-maturing white-seeded line with good yield potential and broad adaptation. Collectively, these varieties were designed to meet the needs of farmers in humid environments, where high disease pressure, limited access to inputs, and fluctuating rainfall demand resilient, high-yielding cultivars.

From a farmer and extension perspective, these varieties possess key agro-morphological and phenological traits that facilitate both identification and management. ARTPEA/BBT/72/B, popularly known as "Remilekun," is a brown-seeded variety that matures in about 60–75 days and has a semi-erect to erect growth habit, which improves ease of harvest. It is tolerant to brown blotch and produces yields of approximately 1.0–1.2 t/ha under trial conditions. ARTPEA/BBT/22/W, or "Boluyo," is a white-seeded variety with similar maturity and growth habit, also bred for brown-blotch tolerance, and targets a distinct consumer market segment. ART-98-12 is another early-maturing, white-seeded variety released by IAR&T. It combines tolerance to major foliar diseases, good grain yield potential, and adaptability to both humid and derived savanna ecologies. Its maturity period of about 65–70 days makes it well-suited for environments with variable rainfall, while its white seed type meets strong market demand in southern Nigeria.

Together, these three varieties represent a new generation of improved cowpeas that respond to the ecological and economic realities of smallholder farming systems, balancing disease tolerance, early maturity, and desirable seed types to enhance productivity and adoption.

1.9 RATIONALE FOR SELECTING THE STUDY VARIETIES BBT BROWN, BBT WHITE, AND ART WHITE FOR MORPHOLOGICAL COMPARISON

The decision to focus on three specific cowpea varieties—BBT Brown, BBT White, and ART White—is a strategic choice that captures key dimensions of diversity relevant to Nigerian agriculture. BBT Brown, with its distinct brown seed coat, was selected for its significant cultural and market value, particularly in northern Nigeria where it is preferred for traditional meals due to its texture and taste. This preference drives farmer cultivation and makes its morphological study directly relevant to local demand. The brown pigmentation serves as a clear marker for comparative analysis, allowing researchers to explore how seed color correlates with other traits like seed weight and plant structure. Furthermore, the selection of BBT Brown is relevant for identifying potential adaptive advantages, as some brown-seeded varieties have demonstrated enhanced resistance to storage pests like the cowpea weevil, a major constraint for Nigerian farmers.

BBT White was included as a crucial counterpart to BBT Brown. As a white-seeded variety from the same BBT line, it provides a direct morphological contrast that is essential for a comparative study. White-seeded cowpeas are highly sought after in southern Nigeria for their suitability in popular dishes like akara and moin-moin, making them a dominant force in urban markets. By including BBT White, the study ensures its findings are relevant to this key market segment. The comparison between BBT White and BBT Brown allows for a nuanced analysis of whether the difference in seed coat color is indicative of other variations in growth patterns or yield components. Additionally, comparing BBT White with ART White, a variety from a different genetic background, provides a valuable opportunity to isolate morphological traits linked to specific lineages, which is a key objective for future breeding efforts.

Finally, the inclusion of ART White introduces a crucial element of genetic diversity to the study. As a variety from a different lineage than the BBT lines, it serves as a benchmark for comparison, helping researchers determine which morphological differences are due to genetic background rather than simply seed coat color. ART White's potential to possess unique traits, such as distinct growth habits, pod lengths, or flowering times, offers insights into how different genetic backgrounds express traits under Nigerian agro-ecologies. These traits are highly valuable for breeding programs aiming to develop new varieties with enhanced adaptation to climate variability and pest pressures. Ultimately, the selection of these three varieties is rooted in their complementary nature, representing the two major market classes of cowpea in Nigeria and allowing for both within-line and across-line morphological evaluations that are directly applicable to local production, seed systems, and crop improvement strategies.

1.10 LITERATURE REVIEW

Cowpea (*Vigna unguiculata* [L.] Walp.) is a major legume crop in Nigeria and across sub-Saharan Africa, where it plays a dual role in food security and household income. Rich in protein (22–30%), vitamins, and minerals, cowpea is widely consumed in local dishes such as akara, moin-moin, and porridge, making it an indispensable component of Nigerian diets (FAO, 2011; Boukar *et al*., 2015; Kouakou *et al*., 2022). Beyond its nutritional role, the crop provides fodder for livestock and enhances soil fertility through biological nitrogen fixation, thereby reducing reliance on costly synthetic fertilizers (Osipitan, 2021; Poudel *et al*., 2025a). Its resilience to poor soils, short growth cycle, and tolerance to drought further strengthen its value in low-input smallholder systems, where most Nigerian farmers operate under limited resources and irregular management practices (Manda *et al*., 2019; IITA, 2022). Despite these benefits, yields remain far below potential due to pest infestations, diseases such as brown blotch, and the predominance of low-management production systems (Nwagboso *et al*., 2024).

Morphological traits provide an accessible and farmer-relevant means of evaluating varietal performance. Observable characteristics such as plant height, stem thickness, canopy size, leaf dimensions, pod morphology, and seed traits are inexpensive to measure, correlate strongly with adaptation, and influence market preferences (Afiukwa, 2017; Digrado *et al*., 2024). Farmers often rely on visible cues, especially seed color and size, when selecting varieties, with brown-seeded types commonly preferred in northern Nigeria and white-seeded types dominating southern markets (Lush and Drabo, 2017; IITA, 2018). Morphological traits also contribute to stress tolerance: stem robustness supports resistance to lodging, leaf area influences photosynthetic capacity, and root nodulation enhances nitrogen fixation in nutrient-poor soils. Importantly, the early flowering stage represents a critical phenological window where canopy development, branching, peduncle elongation, and nodulation strongly predict reproductive success and pod set (Poudel *et al*., 2025b). Yet, most Nigerian studies have concentrated on final yield or pest resistance under researcher-managed conditions, with relatively little quantitative focus on early-stage morphology in real farmer contexts (Afiukwa, 2017; Akinyemi *et al*., 2025).

Recent breeding efforts have targeted ecologies where humidity and foliar disease pressures constrain productivity. At IAR&T, Ibadan, the improved varieties BBT Brown (Remilekun) and BBT White (Boluyo) were released in 2021–2022 as early-maturing, brown-blotch tolerant, non-vining bush types that align with distinct market segments (IAR&T, 2022). ART-98-12, also known as Ife-98-12 or registered as SAMPEA 13, was developed earlier and officially released in 2009 (IAR&T, 2009; NACGRAB, 2025). It is a white-seeded variety noted for its golden white seed color and capacity to maintain seed quality even under heavy rainfall regimes. In field trials, ART/98-12 displayed the shortest time to 50 % flowering (≈ 46 days in one study), highlighting its early maturity potential. Together, these varieties (BBT Brown, BBT White, ART-98-12) reflect breeding strategies that embed morphological targets, such as early maturity, disease tolerance, plant habit, and seed color, into varietal design to serve farmer needs and market demands. However, much of the characterization of these lines remains focused on yield and disease response, with limited morphological profiling at the early flowering stage under farmer-relevant, low-management conditions. Given that morphological traits influence pest and storage interactions (e.g. pod wall thickness, seed testa traits) (Asante *et al*., 2010; Seabraham *et al*., 2023), detailed comparative morphometric studies are needed to bridge breeding design with on-farm outcomes.

Existing literature highlights cowpea's nutritional, economic, and ecological roles, establishes the importance of morphology as a tool for breeding and farmer adoption, and recognizes early flowering as a critical but under-studied stage of evaluation. Yet, there is a persistent gap in empirical, quantitative data comparing recently released varieties such as BBT Brown, BBT White, and ART White under the low-management conditions typical of Nigerian smallholder systems. Addressing this gap is essential for providing breeders, extension workers, and farmers with practical recommendations that align varietal traits with real-world production environments, thereby improving adoption, productivity, and food security in Nigeria.

1.11 RESEARCH GAP

1.11.1 Morphology under low-management conditions is under-documented.

Most characterization trials are conducted under optimal researcher-managed conditions, whereas Nigerian smallholders often farm with minimal inputs, irregular weeding, and poor soils. How BBT Brown, BBT White, and ART-98-12 express key traits under such conditions remains poorly studied, yet this is what determines adoption and real-world performance.

1.11.2 Variety × management interactions are not well quantified.

Morphological advantages such as semi-erect growth may shift under stress from weeds, low fertility, or irregular moisture. There is limited empirical work on how the three varieties interact with such low-management stressors at early flowering.

1.11.3 Comparative and standardized datasets are lacking.

Few studies directly compare BBT Brown, BBT White, and ART-98-12 to separate lineage-specific from seed-type-related traits. Where data exist, they often rely on qualitative descriptors ("bushy," "semi-erect") rather than standardized, quantitative measures (e.g., branch counts, peduncle length).

1.11.4 Weak linkage to farmer and extension priorities.

Morphological differences are rarely connected to practical outcomes such as harvestability, labor, or market quality. Locally validated, visual identification guides are also absent, limiting extension officers' ability to promote varieties effectively. A systematic dataset would strengthen breeding, extension, and farmer decision-making.

1.12 STATEMENT OF THE PROBLEM

Despite Nigeria's status as the world's largest producer and consumer of cowpea, yields remain far below potential due to pests, diseases, poor soils, drought stress, and the predominance of low-management practices among smallholder farmers. Under such conditions, varietal success depends heavily on morphological traits expressed at early flowering, which strongly influence vigor, adaptability, and eventual yield. Improved varieties such as BBT Brown (Remilekun), BBT White (Boluyo), and ART-98-12 (Ife-98-12) have been developed to address production challenges, yet most evaluations have focused on yield and disease resistance under high-input, researcher-managed systems rather than on morphology in farmer-relevant conditions. This gap limits breeders, extension agents, and farmers from making informed decisions on varietal suitability for low-input systems, constrains adoption, and reduces the impact of these improved cultivars. A comparative characterization of morphology under low-management conditions is therefore essential to provide practical, context-specific data that can inform breeding, guide extension, and support farmer choice.

1.13 SIGNIFICANCE OF THE STUDY

Cowpea (*Vigna unguiculata*) is widely regarded as Nigeria's most important grain legume because of its multiple benefits for nutrition, income generation, and soil fertility. It contributes more to protein intake among rural households than any other legume, making it an essential crop for food and nutritional security (Nwagboso *et al*., 2024). Beyond consumption, cowpea farming provides cash income for millions of smallholder farmers, traders, and market women who sell both fresh pods and dry grain (Manda *et al*., 2019). Ecologically, cowpea improves soil fertility through nitrogen fixation and serves as a fodder crop for livestock in mixed farming systems, making it a truly multipurpose crop (Poudel *et al*., 2025a).

Despite its importance, yield gaps remain in Nigerian cowpea production due to challenges such as pests, diseases, low soil fertility, and inconsistent management practices. Access to improved varieties is also limited, and many farmers continue to grow local landraces that may not perform optimally under current environmental stresses (Kouakou *et al.*, 2022). Furthermore, variety selection by farmers is often based on what is available in local markets or on personal experience rather than scientific evidence, which reduces the adoption of more resilient and productive varieties (Afiukwa, 2017).

This study addresses some of these gaps by comparing morphological traits such as leaf size, stem development, and nodulation of three improved cowpea varieties (BBT Brown, BBT White, and ART White). These traits are not only easy to measure in the field but also directly influence canopy structure, stress tolerance, and yield potential (Digrado et al., 2024). By focusing on morphological indicators, this research provides practical tools for evaluating and selecting varieties before harvest, which is particularly useful for both farmers and researchers working in low-resource environments.

Relevance to Nigeria

For Nigeria, this study is important because it generates variety-specific recommendations that reflect real field conditions rather than controlled environments. By identifying varieties with stronger early growth and better nodulation, the research will help smallholder farmers improve their crop performance without needing expensive inputs. This supports the goal of enhancing food security, especially in rural areas where farmers rely heavily on cowpea as both a food and cash crop (Nwagboso *et al.*, 2024). Since Nigeria is the largest producer and consumer of cowpea in the world, findings from this study have direct national relevance (Kouakou *et al.*, 2022).

Relevance to Literature

Most existing research on cowpea in Nigeria has concentrated on yield performance, pest and disease resistance, or responses to inputs such as fertilizer and irrigation (Manda *et al*., 2019). Fewer studies have examined morphological traits across varieties at the early growth and flowering stages. This creates a gap in literature, as morphological evaluation provides quick and cost-effective insights into varietal adaptability, which can save time and resources compared to waiting until harvest (Afiukwa, 2017; Digrado *et al*., 2024). By documenting the morphological profiles of BBT Brown, BBT White, and ART White, this study provides new data that complements ongoing breeding and agronomic research.

Practical Benefits

The results of this research are expected to provide several practical benefits:

1. Support more informed variety selection by farmers, breeders, and extension workers, ensuring that the right varieties are promoted for the right environments.
2. Provide baseline morphological data that breeders can use to improve future cowpea varieties.
3. Enhance understanding of varietal adaptability under typical low-management field conditions, which are common in Nigeria.
4. Contribute new comparative data to the literature on cowpea morphology, filling an existing gap.
5. Serve as reference material for student projects, teaching, and demonstration plots in agricultural institutions.

By highlighting the intraspecific morphological variation among cowpea varieties, this study underscores the value of genetic diversity in crop improvement. Such diversity not only enhances resilience to pests, diseases, and climate stress but also ensures sustainable agricultural development that can benefit both current and future generations (Poudel *et al*., 2025b).

1.14 AIM AND OBJECTIVES

The aim of the study was to characterize and compare intraspecific morphological traits among the three cowpea (*Vigna unguiculata*) varieties - BBT Brown, BBT White, and ART White - under field conditions.

SPECIFIC OBJECTIVES

1. To measure and compare vegetative traits among the three cowpea varieties.
2. To determine and compare the number of leaves produced by each variety.
3. To quantify and compare the emergence maturity rate for each variety as an indicator of stand structure.
4. To assess and compare root nodulation (number of nodules) among the three varieties.
5. To record and compare leaf damage incidence as a proxy for pest or stress susceptibility.
6. To statistically evaluate differences in the measured traits among the varieties and describe the magnitude of variation.

1.15 RESEARCH QUESTIONS

This study seeks to answer the following questions:

1. How do the three cowpea varieties (BBT Brown, BBT White, and ART White) differ in key vegetative morphological traits under low-management conditions?
2. What differences exist in the number of leaves and pods produced by each variety?

3. How do the varieties differ in root nodulation (number and size of nodules) under low-management field conditions?
4. Is there a significant difference in leaf damage incidence among the varieties as an indicator of stress or pest susceptibility?
5. Which variety shows the most favorable combination of morphological traits for adaptability and productivity under low-management conditions?

1.16 RESEARCH HYPOTHESES

H_0: There is no significant difference in morphological traits among BBT Brown, BBT White, and ART White cowpea varieties under low-management conditions.

1.17 SCOPE AND LIMITATIONS OF THE STUDY

This study is limited to the comparative morphological characterization of three improved cowpea varieties (BBT Brown, BBT White, and ART White) under low-management conditions. The research focuses on observable traits such as plant height, leaf size, stem diameter, nodulation, and leaf damage. The study does not include biochemical, molecular, or yield performance evaluations. Results are therefore specific to the environmental and management conditions of the experimental site.

CHAPTER TWO

MATERIALS AND METHODS

2.1. EXPERIMENTAL SITE

The field experiment was conducted at the Teaching and Research botanical garden, Department of Plant Biology and Biotechnology of the University of Benin, located in Benin City, Edo State. The climate of the area is characterized by distinct wet and dry seasons.

The soil of the experimental site is classified as sandy loam, moderately fertile and well-drained. Before planting the land was cleared, tilled, and leveled to ensure uniformity and proper drainage.

2.2. EXPERIMENTAL MATERIALS

2.2.1. Cowpea Varieties

Three cowpea varieties (*Vigna unguiculata* (L.) Walp.) were utilized for this comparative study. The varieties were selected based on their distinct morphological characteristics and local availability. The cowpea seeds were procured from the Nigerian Seed Portal (2025).

Table 2.1:List of Cowpea Varieties and sources.

Variety Code	Variety Registration Name	Institution / Breeder	Notes
Cultivar 1	SAMPEA-13 (Ife-98-12)	Institute of Agricultural Research & Training (IAR&T), Ibadan	Released in 2009. Sometimes referred to as ART/98-12 in research publications, though not always officially equated. Early maturing, white-seeded, high-yielding cowpea.
Cultivar 2	ARTPEA/BBT/72/B (Remilekun)	IAR&T, Ibadan (in collaboration with IITA)	Released 2021. Brown blotch tolerant, high grain yield, large-seeded cowpea.
Cultivar 3	ARTPEA/BBT/22/W (Boluyo)	IAR&T, Ibadan (in collaboration with IITA)	Released 2021. White-seeded cowpea, brown blotch tolerant and early maturing

2.2.2. Tools and Equipment

The tools and equipment used for the experiment included hand trowels, measuring tapes, a ruler, an analytical weighing balance, record sheets, and a hoe.

2.3. Experimental Design and Field Layout

A completely randomized design (CRD) was used, consisting of three cowpea cultivars, each established on two ridges designated as Control 1 and Control 2. The experimental plot used was 34ft by 30ft. The plot was cleared and six ridges was created consisting of three rows representing the different cultivars and two columns about 7ft from each other. Each ridge measured 294cm in length, raised to a height of 30cm with a width of 60cm, and contained five planting holes/pots per ridge. The holes were spaced 22cm apart along the ridge, giving uniform plant density across all treatments.

The experimental layout therefore comprised six ridges in total (two ridges per cultivar × three cultivars). Control 1 and Control 2 for each cultivar were subjected to the same management conditions, but their positions within the field were randomized to minimize environmental bias caused by soil heterogeneity or microclimatic variation.

(Method adapted from Singh *et al*., 2020; Sanginga *et al*., 2003.)

2.4. Field Operations and Low Management Practices

2.4.1. Land Preparation

The experimental site was manually cleared, after which ridges were constructed at wide spacing to delineate the experimental plots according to the layout plan.

2.4.2. Planting

Planting was done on Friday, the 27th of June 2025. Five (5) viable cowpea seeds were sown per hole/pot at a depth of 2–3 cm, followed by gentle watering to field capacity. Germination was observed weekly.

The experiment was managed under rainfed conditions. Weeding was done manually, and no chemical fertilizer or pesticide was applied throughout the study to allow natural expression of each cultivar's morphological traits.

(Procedure based on IITA Cowpea Production Guide, 2019.)

2.4.3. Low Management Conditions

In line with the research objective, the experiment was conducted under low management conditions, specifically defined by the following practices:

1. Fertilizer Application: No inorganic fertilizer was applied.
2. Pest and Disease Control: No chemical insecticide or fungicide was applied throughout the trial.
3. Weed Control: Weeding was done manually once a week during the growing season to minimize weed-crop competition, ensuring the low-management focus was primarily on nutrient, pest, and disease stress rather than severe weed pressure.

2.5. Data Collection

Data was collected periodically from planting to harvest. Observations were grouped into germination, vegetative, reproductive, and below-ground parameters.

2.5.1 Germination and Flowering Parameters

1. Emergence count: recorded weekly for four (4) weeks after planting.
2. Days to 50% flowering: noted when half of the plants in a ridge had open flowers. (Adapted from Oyewole *et al*., 2017.)

2.5.2 Vegetative and Structural Parameters

At 14 weeks after planting, the five holes of plants per ridge for morphological measurements, following the methods of Olayiwola *et al*. (2015) and Singh *et al.* (2020):

1. Stem length (cm): measured from the base to the apex using a meter rule.

2. Stem diameter (cm): measured at 5cm from the ground using a Vernier caliper.

3. Number of leaves per plant: total count of fully expanded leaves.

4. Number of branches per plant.

5. Internode length (cm): average of three consecutive internodes on the main stem.

6. Number of damaged leaves: counted based on visible pest, disease or stress symptoms. This parameter served as an indicator of stress or deviation from normal growth, reflecting effects of pest attack, disease, or environmental variation. Plants were not excluded based on visible damage; instead, the data were retained for comparison to understand cultivar resilience.

2.5.3 Yield and Reproductive Parameters

At physiological maturity, the following parameters were measured on the five pots/hole per control:

- Number of peduncles per plant.
- Length of peduncles (cm): from the node of attachment to the tip.
- Number of pods per plant.
- Pod length (cm): mean of five randomly selected pods measured with a meter rule.
- Number of seeds per pod: total seed count per pod averaged across plants (Methods adapted from Dakora and Keya, 1997; IITA, 2019.)

2.5.4 Below-Ground and Biomass Parameters

At harvest, to prevent the destruction of all the plants, one representative hole/pot was carefully uprooted from each cultivar to assess below-ground traits:

- Root length (cm).
- Number of root branches.
- Number of nodules.
- Root collar diameter (cm).
- Root, shoot, and leaf weights (g): obtained fresh.
- Root-to-shoot ratio computed. (Method adapted from Sanginga *et al*., 2003; Peoples *et al*., 2009.)

2.6 Data Analysis

Data collected from the five replicates per control were analyzed using one-way analysis of variance (ANOVA) with IBM SPSS Statistics version 25 (IBM Corp., 2017). Where significant differences were detected, means were separated using the Least Significant Difference (LSD) test at a 5% probability level ($p < 0.05$). All results were expressed as mean ± standard deviation ($\mu \pm \sigma$) and presented in Tables and Figures as shown in Chapter Three (Statistical methods followed Steel and Torrie, 1980; Gomez and Gomez, 1984.).

CHAPTER THREE

RESULTS

An initial experimental set was planted before the main experiment. Although germination and early growth data were not collected due to time constraints, measurements of above-ground and below-ground parameters were taken at six weeks after planting. These observations provided useful background information for interpreting the results of the main experiment, which are presented below**.**

3.1 Experimental Comparative Morphological Characterization of Cowpea Varieties terminated at 6 Weeks

Table 3.1 presents the mean (μ) and standard deviation (σ) for each measured parameter across the three Cultivars and two Control conditions. The standard deviation indicates the variability within the replicates for each group

Based on the data, the three cowpea cultivars demonstrate clear distinctions in growth performance and resource allocation, particularly in structural vigor and nitrogen-fixing ability. Cultivars 2 and 3 show superior structural growth, exhibiting the largest stem diameters (2.00 to 2.19 cm), significantly surpassing the smaller diameter of Cultivar 1 (1.22 to 1.58 cm). Cultivar 2 also demonstrated the highest overall stem length (141.84 cm) when grown under Control 2, highlighting its potential for rapid vertical growth. Foliage development was most robust in Cultivar 3 under Control 2, which recorded the highest average number of leaves (20.90), though Cultivar 1 also showed strong leaf production under Control 1 (17.00). Across the board, Control 2 generally promoted higher values for structural metrics like stem diameter, stem length, and number of leaves.

A critical difference emerges in the potential for nitrogen fixation, which is essential for sustainable agriculture. Cultivars 1 and 2 both exhibited strong nodulation potential, with average nodule counts ranging from 11.10 to 12.80, indicating effective symbiotic relationships under the test conditions. In stark contrast, Cultivar 3 showed an extremely low and highly suppressed nodule count (averaging around 2.80) under both Control 1 and Control 2, suggesting a significant deficiency in its ability to fix atmospheric nitrogen. This disparity indicates that while Cultivars 2 and 3 excel in structural vigor (diameter/length), Cultivar 3 relies more heavily on external nitrogen sources compared to the self-sufficient performance of Cultivars 1 and 2 in terms of nodulation.

Table 3.1:Summary of Morphological Parameters of experimental set

Cultivar	Control	Avg. Stem Diameter (cm)	Avg. Stem Length (cm)	Avg. No. of Leaves	Avg. No. of Nodules
Cultivar 1	Control 1	1.22±0.07*	124.00±20.82	17.00±4.14	12.60±6.08
Cultivar 1	Control 2	1.58±0.36	127.70±19.07	13.50±1.77	11.10±3.75
Cultivar 2	Control 1	2.12±0.13	125.75±25.33	11.30±2.14	12.60±2.95
Cultivar 2	Control 2	2.18±0.20	141.84±17.30	15.70±5.48	12.80±5.23
Cultivar 3	Control 1	2.00±0.28	123.69±15.24	14.40±3.05	2.80±2.20
Cultivar 3	Control 2	2.19±0.09	126.80±29.46	20.90±4.92	2.80±2.08

Key:*=mean±standard deviation of five replicates per control

Cultivar performance shows distinct patterns in growth and biomass allocation. Cultivars 2 and 3 demonstrated superior stem vigor, with the largest stem diameters (2.00 to 2.19 cm), significantly outperforming Cultivar 1 (1.22 to 1.58 cm). Conversely, foliage development was highest for Cultivar 3 under Control 2 (20.90 leaves) and Cultivar 1 under Control 1 (17.00 leaves), while Cultivar 2 under Control 1 showed the least development (11.30 leaves). In terms of resource acquisition, Cultivars 1 and 2 exhibited strong nitrogen-fixing capabilities, with high nodule counts (11.10 to 12.80), a crucial metric where Cultivar 3 struggled, showing an extremely low and suppressed nodule count (around 2.80) under both control conditions.

The study also highlights the influence of the control conditions on overall plant development. Control 2 generally promoted higher average values across the most vigorous metrics—specifically stem diameter, stem length, and number of leaves—for all cultivars. Cultivar 2 displayed the most favorable response to Control 2, achieving the maximum recorded average stem length of 141.84cm. This suggests that while individual cultivars possess inherent strengths, such as the stem vigor of Cultivars 2 and 3 or the nitrogen fixation of Cultivars 1 and 2, the environmental conditions of Control 2 provided a more optimal setting for maximizing overall vegetative growth metrics across the majority of the cultivars studied.

Table 3.2: Summary of Germination and Flowering Parameters

Cultivar	Emergence (Week 1)	Emergence (Week 2)	Emergence (Week 3)	Final Emergence (Week 4)	Avg. Days to 50% Flowering
Cultivar 1	2.00±0.71*	3.20±0.45	4.00±0.71	4.00±0.71	38.28±1.85
Cultivar 2	2.60±0.55	4.00±0.55	4.40±0.55	4.60±0.55	37.20±2.73
Cultivar 3	2.00±0.71	2.60±0.55	3.00±0.71	3.00±0.71	38.40±2.30

Key:*=mean±standard deviation of five replicates per control

Control 1 and Control 2 were established under the same management conditions but in separate ridges within the field. Differences observed between them likely reflect environmental variation between ridge locations rather than deliberate treatment effects. Table 3.3 presents the mean (μ) and standard deviation (σ) for each measured parameter for Cultivar 1 under Control 1 and Control 2.

Performance comparison for Cultivar 2 reveals distinct trade-offs between the two control conditions concerning yield components. Control 1 significantly outperformed Control 2 in metrics directly related to reproductive output, recording a higher average number of peduncles per pot (6.47 vs. 4.14) and a greater average pod count per pot (14.25 vs. 11.66). Furthermore, pod count exhibited greater variability under Control 1 (\sigma = 4.23) compared to Control 2 (\sigma = 2.64). Despite these differences in quantity, pod and seed quality—as measured by average pod length and average number of seeds per pod—remained similar across both Control 1 and Control 2, suggesting that the conditions did not majorly affect the individual dimensions of the final product.

Analysis of vegetative and structural traits indicates that Control 1 generally promoted greater linear growth, while Control 2 supported thicker and more branched development. Control 1 resulted in a higher average number of leaves (67.22 vs. 63.56) and a greater mean stem length (130.14 cm vs. 119.27 cm) compared to Control 2. Conversely, Control 2 was more effective in promoting sturdiness and lateral growth. The average stem diameter was larger in Control 2 (2.53 cm vs. 2.38 cm in Control 1), and Control 2 also produced a notably higher average number of branches per pot (7.80 vs. 5.40).

In summary, for Cultivar 2, the Control 1 condition appeared to favor reproductive proliferation and vertical/foliar growth, leading to more peduncles, pods, leaves, and longer stems. In contrast, the Control 2 condition optimized structural robustness and horizontal growth, resulting in significantly greater stem diameter and a higher degree of branching. This suggests that the two control environments induced a differential allocation of resources in Cultivar 2, impacting whether the plant prioritized forming more reproductive structures and vertical height (Control 1) or developing a thicker stem and more lateral growth (Control 2).

Table 3.3: Summary of Cultivar 1 Morphological and Yield Parameters

Replicate	Avg. No. of Leaves per Pot	Avg. No. of Penduncle per Pot	Avg. Length of Penduncle per Pot (cm)	Avg. No. of Pods per Pot	Avg. Length of Pods per Pot (cm)	Avg. No. of Seeds per Pod	Avg. Stem Diameter per Pot	Avg. Stem Length per Pot	Avg. No. of Branches per Pot	Avg. Internode Length per Pot (cm)
Control 1	67.22±2.91	6.47±1.91	29.91±2.90	14.25±4.23	14.83±0.26	14.59±0.21	2.38±0.22	130.14±15.98	5.40±0.95	7.86±2.56
Control 2	63.56±6.57	4.14±0.72	27.63±2.83	11.66±2.64	15.26±0.75	14.55±0.17	2.53±0.27	119.27±13.64	7.80±1.15	8.60±2.31

Key:*=mean±standard deviation of five replicates of both controls

A comprehensive comparison of the two control conditions reveals a clear differentiation in how resources were allocated between yield quality and structural length. Control 1 significantly favored the quality of the reproductive structures, achieving a higher average pod length (12.35 cm vs. 11.27 cm) and a greater average number of seeds per pod (11.64 vs. 10.29). Additionally, Control 1 resulted in a slightly higher total pod count per pot (8.55 vs. 7.90). However, this higher yield quality in Control 1 was accompanied by poorer leaf health, as indicated by a noticeably higher average number of damaged leaves (14.71 vs. 11.75 in Control 2).

In contrast, Control 2 promoted overall structural and linear growth. Plants in Control 2 developed substantially longer average stems (142.37 cm vs. 128.57 cm in Control 1) and significantly longer average peduncles (29.84 cm vs. 25.71 cm). This condition also resulted in a marginally higher average peduncle count per pot (5.59 vs. 5.37). This emphasis on vertical and peduncle elongation in Control 2 came at the expense of branching, which was greater in Control 1 (7.67 vs. 6.15 in Control 2).

In essence, the two controls presented a trade-off: Control 1 fostered plants with superior yield quality (longer pods, more seeds per pod) and a greater degree of branching, but also led to more leaf damage. Control 2, however, pushed for maximum linear growth, resulting in longer stems and peduncles, along with slightly better overall leaf health. While the total leaf count was similar, the differences in stem length, peduncle length, and branching suggest Control 2 allocated more energy toward height and support structures, whereas Control 1 prioritized lateral development and the quality of the final seed product.

Table 3.4: Summary of Cultivar 2 Morphological and Yield Parameters (Mean ± Standard Deviation)

Replicate	Avg. No. of Leaves	Avg. Damaged Leaves	Avg. No. of Penduncles	Avg. Length of Penduncles (cm)	Avg. No. of Pods	Avg. Length of Pods (cm)	Avg. No. of Seeds per Pod	Avg. Stem Diameter	Avg. Stem Length	Avg. No. of Branches
Control 1	61.77±15.33*	14.71±4.28	5.37±1.56	25.71±5.29	8.55±2.53	12.35±0.88	11.64±1.34	2.42±0.24	128.57±22.66	7.67±1.43
Control 2	60.27±9.42	11.75±4.65	5.59±0.84	29.84±5.50	7.90±1.91	11.27±1.04	10.29±1.08	2.35±0.18	142.37±9.23	6.15±1.02

Key:*=mean±standard deviation of five replicates

3.2.4 Cultivar 3: Full Above-Ground Morphological and Yield Characteristics

Table 3.5 presents the mean (μ) and standard deviation (σ) for all measured parameters for Cultivar 3. The comparison of yield components reveals a clear trade-off between quantity and quality driven by the control conditions. Control 2 was highly effective at maximizing pod quantity, producing a higher average number of pods per pot (7.00) with low variability ($\sigma = 0.85$), significantly outperforming Control 1 (4.22). However, Control 1 excelled in pod and seed quality, yielding much longer pods (12.78 cm vs. 8.46 cm) that contained a greater average number of seeds per pod (11.64 vs. 7.48). This suggests Control 2 promoted an aggressive reproductive output at the expense of individual pod development, while Control 1 favored resource allocation to fewer, but superior quality, reproductive structures.

This difference in resource allocation extends to the vegetative and structural traits. Control 2 promoted overall structural complexity and linear growth, leading to higher average values for stem length (140.45 cm), internode length (5.80 cm), and the number of branches (7.00). While Control 2 fostered larger plants and slightly longer peduncles (24.56 cm vs. 22.76 cm), this aggressive growth was associated with poorer leaf health, recording a higher average number of damaged leaves (14.53) compared to Control 1 (9.67). Essentially, Control 2 prioritized creating a larger frame and more numerous, though smaller, yield components, while Control 1 supported a more conservative growth pattern that preserved leaf health and maximized the quality of the final seed product.

Table 3.5: Summary of Morphological and Yield Parameters for cultivar 3(Mean ± Standard Deviation)

Replicate	Avg. No. of Leaves	Avg. Damaged Leaves	Avg. No. of Penduncles	Avg. Length of Penduncles (cm)	Avg. No. of Pods	Avg. Length of Pods (cm)	Avg. No. of Seeds per Pod	Avg. Stem Diameter	Avg. Stem Length	Avg. No. of Branches
Control 1	45.99±12.37*	9.67±2.99	6.00±0.79	22.76±2.70	4.22±1.18	12.78±2.73	11.64±1.34	1.90±0.41	132.69±10.85	5.97±0.55
Control 2	46.66±9.35	14.53±3.46	5.92±0.82	24.56±4.24	7.00±0.85	8.46±1.76	7.48±3.55	1.97±0.31	140.45±10.71	7.00±1.27

Key:*=mean±standard deviation of five replicates of both controls.

3.2.5 COMPARATIVE ANALYSIS OF THE CULTIVARS AND KEY FINDINGS

Comparing the reproductive performance across the three cultivars reveals clear distinctions in their yield potential. Cultivar 1 demonstrated the superior capacity for yield quality, recording the highest average number of pods and seeds per pod, suggesting an effective conversion of resources into reproductive output. Cultivar 2 occupied a middle ground, exhibiting intermediate values across most yield parameters, indicating a balanced, moderate level of reproductive efficiency. In contrast, Cultivar 3 showed the weakest performance in terms of yield, recording the lowest values in pod count and seeds per pod, and was characterized by high variability in some of its yield measurements, signaling an overall suppressed or inconsistent reproductive capability.

Table 3.6: Comparison of cultivars yield Components

Key Finding	Cultivar 1 (Highest Yield)	Cultivar 2 (Intermediate Yield)	Cultivar 3 (Lowest Yield)
Avg. No. of Pods	Highest in Control 1 (14.25±4.23).	Intermediate, with the lowest count in Control 2 (7.90±1.91).	Lowest overall, particularly in Control 1 ((4.22±1.18). Interestingly, Control 2 had a better pod count (7.00±0.85).
Avg. No. of Seeds per Pod	Highest overall and very stable across both controls (approx. 14.57).	Intermediate, but with a noticeable drop in Control 2 (10.29±1.08) compared to Control 1 (11.64±1.34).	Lowest in Control 2 (7.48±3.55). Note the extremely high standard deviation, indicating high variability in this treatment.
Avg. Length of Pods (cm)	Longest in Control 2 (15.26±0.75).	Intermediate (approx. 12.35 cm).	Shortest overall, especially in Control 2 (8.46±1.76 cm).

Above Ground Morphological Parameters

Cultivar 1 recorded the highest average leaf count with intermediate stem length and diameter. Cultivar 2 had the longest stems and internode lengths. Cultivar 3 recorded the thinnest stems, the lowest leaf count, and the shortest internode lengths.

Table 3.7: Comparison of the cultivars Above ground morphological Parameters

Key Finding	Cultivar 1	Cultivar 2	Cultivar 3
Avg. Stem Length (cm)	Intermediate (approx. 119 to 130 cm). Lower in Control 2.	Longest overall, especially in Control 2 (142.37±9.23 cm).	Longest in Control 2 (140.45±10.71 cm), slightly less than Cultivar 2.
Avg. Stem Diameter (cm)	Intermediate. Slightly thicker stems in Control 2 (2.53±0.27 cm).	Intermediate (2.35 to 2.42 cm).	Thinnest overall, especially in Control 1 (1.90±0.41 cm).
Avg. No. of Leaves	Highest average leaf count (approx. 63.56 to 67.22).	Intermediate (approx. 60 to 61 leaves).	Lowest average leaf count (approx. 46).
Avg. Internode Length (cm)	Intermediate (approx. 7.86 to 8.60 cm).	Longest overall in Control 2 (9.08±1.94 cm).	Shortest overall in Control 1 (4.56±1.23 cm).

STATISTICAL ANALYSIS

Using ANOVA Table 3.8 shows the results of a One-Way Analysis of Variance (ANOVA) comparing the average values of the given parameters across the three different cowpea Cultivars (Cultivar 1, Cultivar 2, and Cultivar 3). There was no statistically significant difference ($P>0.05$) found among the cultivars for Avg Damaged Leaves, Avg No of Peduncles, Avg Stem Length, and Avg No of Branches. The table below provides the mean (μ) and standard deviation (σ) for each parameter by cultivar. These values show the direction of the differences for the significant parameters.

Table 3.8: Results of Statistical Analysis (One-Way ANOVA)

Parameter	F-statistic	P-value	Significance (α=0.05)
Avg No of Leaves	10.7526	0.0004	Significant
Avg Damaged Leaves	0.2231	0.8015	Not Significant
Avg No of Peduncles	0.6479	0.5311	Not Significant
Avg Length of Peduncles (cm)	4.2759	0.0244	Significant
Avg No of Pods	20.1799	0.0000	Significant
Avg Length of Pods (cm)	13.8539	0.0001	Significant
Avg No of Seeds per Pod	15.3146	0.0000	Significant
Avg Stem Diameter	10.8465	0.0003	Significant
Avg Stem Length	1.9306	0.1646	Not Significant
Avg No of Branches	0.2502	0.7805	Not Significant
Avg Internode Length	9.3528	0.0008	Significant

Table 3.9: Summary of Means and Standard Deviations by Cultivar

Cultivar	Avg No of Leaves	Avg Damaged Leaves	Avg No of Peduncles	Avg Length of Peduncles (cm)	Avg No of Pods	Avg Length of Pods (cm)	Avg No of Seeds per Pod	Avg stem diameter	Avg stem length	Avg no of branches	Avg internode length (cm)
Cultivar 1	65.39±5.16	13.02±3.52	5.30±1.83	28.77±2.95	12.95±3.59	15.04±0.58	14.57±0.18	2.45±0.25	124.70±15.14	6.60±1.61	8.23±2.33
Cultivar 2	61.02±12.02	13.23±4.49	5.48±1.18	27.78±5.54	8.22±2.14	11.81±1.07	10.97±1.35	2.39±0.20	135.47±17.86	6.91±1.42	8.43±1.89
Cultivar 3	46.33±10.34	12.10±3.98	5.96±0.76	23.66±3.48	5.61±1.76	10.62±3.14	9.56±3.35	1.93±0.34	136.57±10.96	6.48±1.07	5.18±1.27

Figure 3.1 visualizes the mean and standard deviation for each parameter across the three cowpea cultivars. The error bars represent the standard deviation (σ). For the parameters with a significant difference, you can visually confirm the variation in means: Cultivar 1 consistently shows higher average values for Avg No of Pods, Avg Length of Pods (cm), and Avg No of Seeds per Pod compared to Cultivar 2 and Cultivar 3.

Avg No of Leaves is highest for Cultivar 1, and Cultivar 3 has the lowest. Avg Stem Diameter is highest in Cultivar 1 and lowest in Cultivar 3. Avg Length of Penduncles (cm) is highest in Cultivar 1 and lowest in Cultivar 3. Avg Internode Length is highest in Cultivar 2, closely followed by Cultivar 1, and lowest in Cultivar 3.

Observation of Anomalous Growth (Damaged Leaves)

The number of damaged leaves was recorded for each cultivar as an indicator of possible anomalies such as pest or disease stress.

Cultivar 2 under Control 1 recorded the highest mean number of damaged leaves (14.71 ± 4.28), while Cultivar 3 under Control 1 recorded the lowest (9.67 ± 2.99).

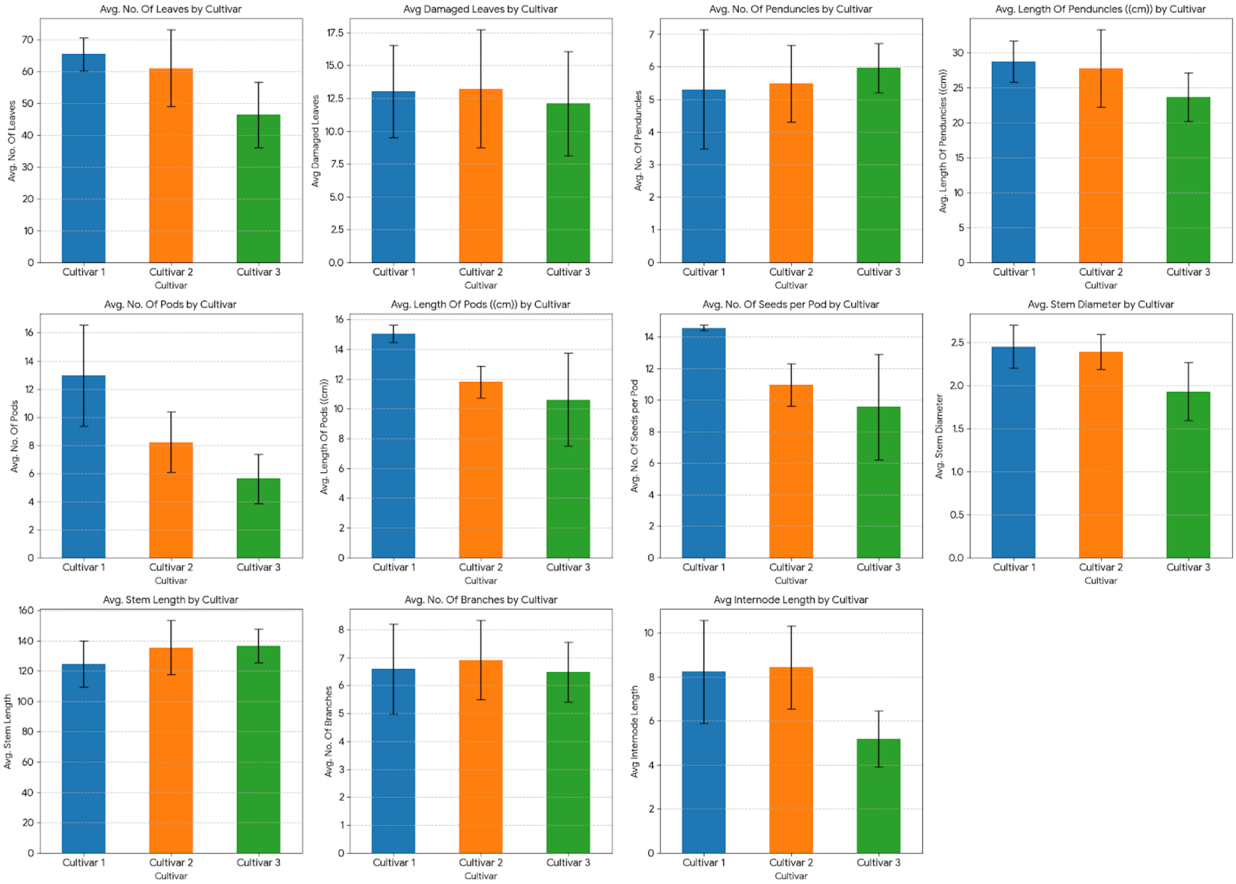

Figure 3.1: The mean and standard deviation for each parameter across the three cowpea cultivars,

3.2.6 Analysis of Below-Ground and Above-Ground Biomass at Harvest Parameters

The below-ground and above-ground biomass at harvest parameters were measured on a single randomly selected pot per cultivar, with all five plants sampled within that pot. This means the values are descriptive subsamples and should be interpreted with the understanding that they represent only one experimental unit per cultivar, unlike the above-ground traits which had n=5 replicates per control.

The parameters analyzed include: average root length, number of branches, number of nodules, root collar diameter, root weight, shoot weight, leaf weight, and the root-to-shoot ratio.

Cultivar 2 recorded the greatest average root length (55.8 cm) and the highest average root weight (5.57g). Cultivar 1 had the second-highest root weight (4.81g). The root collar diameter was largest in Cultivar 2 (2.21 cm). In terms of nodulation, Cultivar 2 had the highest average number of nodules (17.65), while both Cultivar 1 and Cultivar 3 each recorded an average of 15.00 nodules. The average number of root branches was highest in Cultivar 1 (9.00).

For above-Ground Biomass at Harvest, Cultivar 3 recorded the highest average shoot weight (28.18g) and the highest average leaf weight (7.67g). Cultivar 2 followed closely in shoot weight with 27.93g. The root-to-shoot ratio was highest in Cultivar 1 (0.2204), followed by Cultivar 3 (0.1707).

Table 3.10: The below ground and above-ground biomass at harvest parameters compared across cultivars.

Cultivar	Average Root Length (cm)	Average No. of Branches	Average No. of Nodules	Average Root Collar Diameter (cm)	Average Root Weight (g)	Average Shoot Weight (g)	Average Leaf Weight (g)	Root to Shoot Ratio (R:S)
Cultivar 1	42.0	9.00	15.00	2.06	4.58	20.78	6.46	0.2204
Cultivar 2	55.8	8.20	17.65	2.21	5.57	27.93	6.56	0.1995
Cultivar 3	41.5	6.25	15.00	2.09	4.81	28.18	7.67	0.1707

Plate 3.1: Show Leaf damage forms.

Plate 3.2: Root sample of cultivar 1

Plate 3.3: Root sample of cultivar 2

Plate 3.4: Root sample of cultivar 3

Plate 3.5: Cultivar 1 at flowering and pod formation stage

Plate 3.6: Cultivar 2 at flowering and pod formation stage

Plant 3.7: Cultivar 3 at flowering and pod formation stage

Plate 3.8: Cultivar 1 at week 3

Plate 3.9: Cultivar 2 at week 3

Plate 3.10: Cultivar 3 at week 3

CHAPTER FOUR

DISCUSSION

The comparative morphological characterization of the three cowpea varieties—BBT Brown (ARTPEA/BBT/72/B), BBT White (ARTPEA/BBT/22/W), and ART White (SAMPEA-13/Ife-98-12)—demonstrated distinct differences in vegetative and reproductive performance under low-management conditions. These differences confirm the wide intraspecific diversity of *Vigna unguiculata*, which has been repeatedly emphasized in literature as one of the crop's key strengths for adaptation and breeding (Afiukwa, 2017; Digrado *et al*., 2024; Akinyemi *et al*., 2025). Morphological variation, especially when observed in early and reproductive stages, provides valuable insight into how genotypes interact with environmental stress factors such as low soil fertility, pest incidence, and limited management inputs—conditions that are typical of Nigerian smallholder systems.

The overall performance trend observed in this study suggests that ART White (SAMPEA-13/Ife-98-12) expressed superior reproductive capacity under limited nutrient availability, while BBT Brown exhibited stronger vegetative vigor. This implies differences in resource allocation patterns among the varieties. The higher pod and seed production observed in ART White indicates a genotype that efficiently partitions assimilates toward reproductive structures—a trait desirable in low-input systems where vegetative overgrowth may not translate into grain yield. This observation is consistent with the findings of IAR&T (2022), which reported that SAMPEA-13 maintains stable yields under moderate stress conditions due to its early maturity and efficient flowering behavior.

In contrast, BBT Brown's longer stems and peduncles point toward stronger vegetative investment and higher canopy development. Such morphological traits are often associated with greater photosynthetic area and weed suppression ability (Osipitan, 2021). However, as noted by Manda et al. (2019), excessive vegetative growth in cowpea can reduce assimilate flow to pods, leading to smaller seed sets. Therefore, while BBT Brown's growth vigor may confer advantages under dense planting or intercropping systems, it may not always maximize grain yield under resource constraints.

BBT White's moderate vegetative growth coupled with its relatively low nodulation indicates potential challenges in nitrogen acquisition or less effective symbiotic association with native rhizobia. This aligns with findings by Dakora and Keya (1997), who highlighted that genetic variation among cowpea genotypes significantly influences nodulation efficiency and nitrogen fixation rates. Low nodulation may also be attributed to site-specific soil microbial composition, as noted by Peoples *et al*. (2009), since different soils harbor distinct rhizobial populations that determine host compatibility.

The significant varietal differences in morphological parameters, particularly leaf number, pod length, and seed number, align with earlier work by Aina (2020) and Oladimeji (2024), who observed that morphological indices explain a large portion of phenotypic variability among Nigerian cowpea varieties. Similarly, Digrado *et al*. (2024) demonstrated that morphological diversity is not only a function of genetic background but also a reflection of environmental plasticity. The high morphological variability observed in this study, even under uniform low-management conditions, suggests that these varieties possess flexible growth responses, an important trait for adaptation to fluctuating rain-fed environments.

The results further corroborate the report of Kouakou *et al*. (2022), who emphasized that early-maturing white-seeded varieties perform well in humid and derived savanna zones where rainfall is erratic. ART White's early flowering and pod set can thus be interpreted as adaptive traits ensuring reproductive success before the onset of terminal drought. This adaptive behavior is comparable to that reported by Poudel *et al*. (2025b), who found that early-flowering lines exhibit greater stability in grain yield across diverse ecological conditions due to their shorter life cycle.

Additionally, the observed difference in stem diameter and internode length supports the findings of Afiukwa (2017), who linked stem robustness to lodging resistance and better pest tolerance. Stronger stems may also provide mechanical support for pod-bearing branches, indirectly influencing reproductive success. Therefore, BBT Brown's thick stems and longer internodes suggest suitability for high-rainfall zones where lodging can reduce pod retention and harvestability.

The observed differences in leaf damage among cultivars may reflect variation in natural pest resistance or stress tolerance. Although no pesticides were applied, visible damage was minimal in ART White, implying potential inherent resistance or morphological escape mechanisms such as thicker leaves or less attractive foliar chemistry. According to Asante *et al*. (2010), variations in leaf texture and pigmentation can affect pest feeding preferences in cowpea, and these traits often correlate with morphological descriptors. Hence, ART White's relatively healthier foliage under natural field conditions provides an additional advantage in low-input farming systems.

From an agronomic standpoint, the results reinforce the importance of morphological evaluation as a cost-effective approach to selecting varieties suited for smallholder environments. In Nigeria, where most farmers rely on manual tools and organic nutrient recycling, varieties with strong early growth, erect habits, and high nodulation are favored because they combine yield stability with resilience (Osipitan, 2021). The strong nodulation and pod development in ART White suggest suitability for intercropping with cereals, enhancing nitrogen balance within the farming system. Similarly, BBT Brown's vigorous canopy may serve as a ground cover to suppress weeds and minimize soil moisture loss, contributing to sustainable intensification goals highlighted by FAO (2012).

Ecologically, cowpea's ability to fix atmospheric nitrogen through nodules reduces dependency on synthetic fertilizers, mitigating both cost and environmental impact (Poudel et al., 2025a). Thus, identifying varieties that maintain high nodulation even under low nutrient availability, as seen in ART White and BBT Brown, is critical for sustainable soil fertility management. Moreover, the varietal differences in canopy structure observed in this study could inform breeding programs targeting climate adaptation, as canopy architecture influences evapotranspiration and temperature regulation in cowpea stands (Kim et al., 2025).

The findings of this research align with the broader trend in cowpea improvement programs emphasizing early maturity, disease resistance, and seed color preference. For example, Boukar *et al*. (2015) and Nwagboso *et al*. (2024) both reported that market and regional preferences strongly influence adoption, white-seeded varieties dominating southern Nigeria and brown-seeded varieties preferred in the north. The inclusion of both seed types in this study therefore reflects practical relevance to farmer choices. Furthermore, the significant morphological contrasts between BBT and ART lines reaffirm the breeding progress achieved by IAR&T and IITA in diversifying Nigeria's cowpea genetic base (IITA, 2022).

Importantly, the study highlights how morphological diversity bridges traditional selection and modern molecular approaches. Oladimeji (2024) and Kumar (2025) emphasized that combining morphological and molecular data improves the accuracy of variety identification and selection. Thus, the morphological distinctions established in this study, such as stem vigor, pod architecture, and nodulation patterns, could serve as baseline descriptors for integrating molecular markers in future cowpea breeding and seed certification efforts.

Although this study provided valuable insights, several limitations must be acknowledged. The experiment was conducted in a single location and planting season, which may not capture the full range of genotype × environment interactions. Environmental factors such as rainfall distribution, soil microbiota, and temperature variations could significantly influence trait expression in other regions. Future multi-location and multi-season trials would therefore be essential to confirm the stability of observed traits.

Additionally, the study focused solely on morphological parameters without integrating physiological or molecular measurements. While morphological traits provide useful indicators of performance, they are often influenced by environmental factors (IBPGR, 1983; Fukuda *et al*., 2010). Hence, combining morphological data with biochemical and genomic analyses would yield a more holistic understanding of varietal performance. Another limitation is the relatively small plot size, which, although suitable for controlled observation, may not fully represent field-scale dynamics experienced by farmers. Nonetheless, the controlled setup ensured uniformity and reliability of data for comparative analysis.

The results have direct implications for breeding programs and extension strategies in Nigeria. ART White's high yield potential under minimal management inputs makes it an ideal candidate for dissemination among smallholder farmers, especially in the southern and middle-belt zones. Its early flowering and pod development traits also fit into double-cropping systems where rapid maturity is advantageous. In contrast, BBT Brown's strong stem and canopy characteristics could be exploited in breeding programs focused on lodging resistance and biomass production, while BBT White may require improvement in nodulation efficiency to maximize its potential.

From a farmer adoption perspective, these morphological distinctions can simplify varietal identification and selection during participatory breeding and demonstration trials. As noted by Isaacs and Diallo (2021), farmers tend to adopt varieties that they can easily distinguish based on visible traits such as plant height, seed color, and pod structure. Therefore, integrating the morphological profiles from this study into extension materials can enhance awareness, adoption, and correct seed use.

CONCLUSION

This study established that improved cowpea varieties differ significantly in morphological and reproductive responses under low-management conditions. ART White (SAMPEA-13/Ife-98-12) exhibited the most favorable combination of yield-related traits, while BBT Brown demonstrated superior stem vigor. The findings highlight the importance of morphological screening as a low-cost, field-relevant tool for identifying adaptable and high-performing cowpea varieties. Future studies should integrate molecular characterization and multi-environment testing to enhance breeding efficiency and ensure sustainable productivity across Nigeria's diverse agro-ecological zones.

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