Ife Journal of Agriculture, 2025, Volume 37, Number 1

NODULATION EFFICIENCY AND YIELD COMPONENTS IN COWPEA (*Vigna unguiculata* L. Walp.) VARIETIES CULTIVATED IN SOUTHWESTERN NIGERIA

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ABSTRACT

There is limited information on the genetic variability and relationship between nodulation traits and yield components in cowpea. This study aimed to examine the genetic variability, nexus between nodulation parameters and key yield components; identify important traits for selection in developing high-yielding cowpea varieties with efficient nodulation, and varieties that combine both high grain yield and high relative nodulation efficiency (RNE). Fifty cowpea varieties were evaluated using a randomised complete block design in three replications. The experiment was conducted at the Obafemi Awolowo University Teaching and Research Farm, Ile-Ife, Nigeria. Data were collected on agronomic traits, grain yield, and nodulation parameters. Pearson's correlation was used to assess relationships among these traits. Fisher's least significant difference (LSD) was used to compare means at $P \leq 0.05$. Results showed significant variability among germplasm and correlations between some nodulation parameters and yield traits. Root dry weight was positively correlated with pod length and grain yield. Root fresh weight also showed a significant correlation with grain yield. Shoot dry weight correlated positively with the number of peduncles. It was inferred that there existed wide variability among the germplasm, a strong association between grain yield and RNE; and root and shoot biomass, nodule dry weight and pod length are major traits to be considered for selection in developing high-yielding cowpea with high RNE. Ife Brown, IT10K-817-7, and Oloyin were found to combine high grain yield with high RNE.

Keywords: ***Cowpea, nitrogen fixation, nodulation, nodulation efficiency, yield components.***

INTRODUCTION

Cowpea (*Vigna unguiculata* L. Walp) is an important grain legume and fodder pulse cultivated around the world, which serves as food for man and as fodder for livestock (Singh and Singh 2018; Mfeka *et al*., 2019). It is cultivated in most regions due to its ability to survive in marginal soils and withstand alkaline soils (Elowad and Hall, 1987; Mfeka *et al*., 2019). The ability of cowpea to survive in low-fertility soils and withstand alkaline soils underlines its successful cultivation across many regions (Ndema *et al*., 2010). It is a staple crop in most African countries (Mamiro *et al*., 2011). According to Gomez (2014), Africa is the leading continent in cowpea production, accounting for approximately 68% of global production, followed by Brazil at 17%, Asia at 3%, the USA at 2%, with the remaining 10% produced by the rest of the world. Nigeria in particular, accounts for most of the 68% of cowpea grains produced annually which is estimated to be approximately 2.14 million metric tonnes (Aina, 2022), and consumes more than 3.0 million metric tonnes. Cowpea production in Africa alone accounts for land area of 10 million hectares; and the crop is native to Africa (Khalid *et al*., 2012). Its vegetative parts and seeds constitute a major nutritional contribution to the human diet. The seed contains 25% protein and 64% carbohydrates with 27–34% protein in the leaves (Belane and Dakora, 2012). Cowpea adapts better to drought, high temperature and other biotic stresses compared with other crops (Martins *et al*., 2020), though, drought and high temperature affect the growth and development of many cowpea cultivars (Dadson *et al*., 2005). The demand for external nitrogen input and hence, costs of purchasing commercial nitrogen fertilizers could be minimized drastically through the cultivation of high nitrogen-fixing cowpea varieties which could help to maintain the nitrogen status of soil (Abayomi and Abidoye, 2009). The biological nitrogen fixation of leguminous crops is an effective, cheap and sustainable biological method to enhance soil fertility, thereby increasing crop yield (Bloem *et al*., 2009).

Cowpea can produce relatively high seed and forage yields even in low-fertility soils due to its ability to meet its own nitrogen needs through biological nitrogen fixation. The nitrogen fixed by its root nodules primarily supports the cowpea plant itself during growth, although residual nitrogen may contribute to soil fertility and benefit following crops when plant residues are returned to the soil. Moreover, high rates of nitrogen and excessive moisture are detrimental and can result in excessive vegetative growth, delayed maturity and pod shattering (Ali *et al*., 2004). Nitrogen fixation in legumes is preceded by nodulation. Root nodules are formed from symbiotic relationship between the roots of cowpea and nitrogen-fixing bacteria known as rhizobia (Peech *et al.,* 1953; Wang *et al*., 2018), and their effectiveness can determine the extent of N_2 fixation. Cowpea can fix close to 240 kg N ha^{-1}, and contribute between 50-80 kg of the N fixed ha^{-1} in form of organic residues, thus improves the soil fertility for the subsequent crop in rotation (Quin, 1997; Abayomi and Abidoye, 2009).

Yield components such as pod length, days to physiological maturity, seed number, pod developmental period, number of pods and number of peduncles determine cowpea productivity. Quite a number of studies have been conducted on the interrelationship among agronomic traits of cowpea and have been reported using correlation and regression analyses (Oladejo *et al*., 2011; Cerıtoglu and Erman, 2020). However, there is dearth of information on the relationship between nodulation parameters and yield components of cowpea in southwestern Nigeria. In the Amazonian tropical condition, nodulation parameters, such as nodule number and nodule dry weight, with shoot dry weight and root biomass, have been found to significantly correlate with key yield components (Pinto *et al.,* 2021). Adequate understanding of genetic variability and relationships will help in developing cowpea varieties with improved nitrogen fixation and higher yields. This information is pertinent to selection of cowpea for enhanced yield and nodulation efficiency in breeding programmes. The objectives of this study were therefore to determine the genetic variability, relationship between nodulation parameters and selected yield components among different cowpea varieties grown on an Ultisol soil; identify important traits for selection in breeding high yielding cowpea varieties with efficient nodulation; and varieties that combine high grain yield with high relative nodulation efficiency.

MATERIALS AND METHODS

The study was conducted at the Teaching and Research Farm, Faculty of Agriculture, Obafemi Awolowo University, Ile-Ife (7°28'N, 4°33'E; rainfall -1150 mm; elevation - 224 m asl) located in the humid rainforest ecology of south-western Nigeria during the cropping season (late May to September, 2019) due to the prevalent climate change. Fifty genotypes of cowpea with divergent agronomic and yield characteristics obtained from the Department of Crop Production and Protection, Obafemi Awolowo University (OAU), Ile-Ife and Genetic Resource Centre, International Institute for Tropical Agriculture (IITA), Ibadan were used for this study. The genetic materials used in this study, with their sources and characteristics, are listed (Table 1). The experiment was laid out using a randomised complete block design (RCBD) in three replications. Each was planted to a two-row plot of 2m long with plant spacing of 0.75m between rows and 0.25m within rows with 1m alley. Two seeds were planted per hole while Pendimethalin was sprayed as a pre-emergence selective herbicide, immediately after planting at the rate of 1.5 L ha^{-1}. Cypermethrin at 10% E.C. was applied at the rate of 10 mL L^{-1} of water to control insect pests. Agronomic and yield parameters assessed were days to first flowering (DFF), days to 50% flowering (DF50% F), days to first podding (DFP), days to 50% podding (DF 50% P), days to physiological maturity (DPM), number of pod (NP), number of peduncles per plot (NPD), days to harvest maturity, number of nodules (NND), fresh weight of nodules (NFW), dry weight of nodules (NDW), pod development period (PDP), pod length (PL), shoot fresh weight (SFW), shoot dry weight (SDW), root fresh weight (RFW), root dry weight (RDW), threshing percentage (TRH %), nodulation efficiency (N.E. %) and grain yield (GY). At 38 days after planting (DAP) - late vegetative stage, two randomly selected plants with rooting system were carefully uprooted, with the roots placed in a sieve, bound soils washed off, while the nodules were harvested. The number of nodules harvested was recorded; the fresh and dry weights of nodules were recorded using top loading Mettler Electronic Balance. Relative Nodulation Efficiency (RNE) was calculated to evaluate the nodulation performance of each cowpea genotype. It was derived by expressing the nodule dry weight (NDW) of each genotype as a percentage of the maximum NDW recorded among all genotypes in the study using the formula below:

$$\text{RNE\%} = \left(\frac{\text{NDWgenotype}}{\text{NDWmax}}\right) \times 100$$

Between 60 – 75 days after sowing, pods were harvested from each plot, bulked, threshed, weighed and recorded as the yield per plot.

Table 1: List of cowpea lines, sources and their characters, used in this study at Obafemi Awolowo University, Teaching and Research. Farm, Ile Ife.

S/N	Name	Source	Characters
1	UAM14-155-10-3	UAM, Dutsin-Ma	A medium-duration cowpea variety, adaptability to local conditions, resistance to pests or diseases,
2	ITIID-21-143	IITA, Ibadan	Early maturing variety, drought and pest tolerant, stable across environments.
3	IAR-07-1032-1	ABU, Zaria	Early maturing, suitable for dry savanna, moderate pest resistance.
4	IRS-09-1106-4	ABU, Zaria	High-yielding, *Striga gesnerioides* and drought-resistant, suitable for intercropping.
5	IAR-07-1042-1	ABU, Zaria	Good pod filling, tolerance to pests, and

S/N	Name	Source	Characters
			early planting are suitable
6	IT10K-832-1	IITA, Ibadan	Early maturing, drought-tolerant, compact growth habit.
7	IT08K-193-14	IITA, Ibadan	Resistant to bacterial blight, high pod yield, and adapted to dry zones
8	IT98K-131-1	IITA, Ibadan	*Striga gesnerioides* and drought-resistant, uniform pods, root rot tolerant
9	Oloyin	IAR&T -OAU, Ile-Ife	Sweet brown seeds, moderate yield, preferred in Southwestern Nigeria
10	IT08K-150-24	IITA, Ibadan	Early maturing, high-yielding, adaptable and drought-tolerant
11	IT07K-292-10	IITA, Ibadan	Good root nodulation, suitable for low-input systems
12	IT10K-832-2	IITA, Ibadan	Early maturing cowpea variety, drought-tolerant, compact plant type, suitable for short-season areas
13	IT09K-269-1	IITA, Ibadan	Early maturing variety, good seed yield, drought and pest tolerant, suitable for savanna regions
14	IT11D-16-71	IITA, Ibadan	Drought-tolerant, early maturing variety, moderate resistance to pests, suitable for low-input farming
15	IRS-09-1009-7	ABU, Zaria	High-yielding variety, moderately resistant to *Striga gesnerioides* & drought, suitable for mixed cropping
16	UAM14-154-10-2	UAM, Dutsin-Ma	High yield, resistance to *Striga gesnerioides*, and large brown seeds, suitability for intercropping systems
17	IT07K-274-2-9	IITA, Ibadan	Early maturing cowpea variety, drought-tolerant, high grain yield, and moderately resistant to field pests.
18	IT08K-180-11	IITA, Ibadan	A medium-maturing cowpea variety, moderate yielder, drought-tolerant, and suitable for savanna zones
19	UAM14-145-4-3	UAM, Dutsin-Ma	Medium-duration, adaptability to local savanna conditions, moderate yielder, drought & pest tolerant.
20	IT08K-150-12	IITA, Ibadan	Early-maturing, drought- and *Striga gesnerioides, Alectra vogelii* -resistant

S/N	Name	Source	Characters
			variety, tolerant to leaf spot and bacterial diseases, high pod yield and bold seeds
21	IT07K-243-1-10	IITA, Ibadan	Medium-duration, high resistance to flower bud thrips, adapted to semi-arid zones.
22	IT07K-230-2-9	IITA, Ibadan	Early-maturing, stable grain yield across diverse environments, moderate nodulation capacity
23	IT08K-180-10	IITA, Ibadan	Early-maturing, good seed/grain yield, suitable for humid-fringe conditions.
24	IT07K-291-69	IITA, Ibadan	Early-maturing, high grain and haulm yield—dual-purpose suited for both food and fodder
25	Ife Brown	OAU Ile-Ife / IAR&T	Medium-duration landrace, day-length neutral, brown seeds, fast-cooking, drought-resistant, pest/disease tolerant
26	IT08K-150-27	IITA, Ibadan	Semi-erect, early-medium maturing variety; improves soil microbial activity; suitable for high-density planting
27	IT10K-822-7	IITA, Ibadan	Early-maturing, good seed yield, drought and pest tolerant (notably mosaic virus susceptible).
28	IT10K-822-9	IITA, Ibadan	early-maturing, good yield, drought and pest tolerant.
29	IT10K-863-11	IITA, Ibadan	Early-maturing, lightweight seed, drought-tolerant, moderate yield.
30	IT10K-961-7	IITA, Ibadan	Early-medium maturing, bold seeds, good grain yield, drought-tolerant
31	IT10K-837-1	IITA, Ibadan	Early-maturing, disease-tolerant, moderate seed weight, drought-tolerant.
32	IT10K-817-3	IITA, Ibadan	Early-medium maturing, bold-seeded, good yield, drought-tolerant.
33	ALOKA LOCAL	Nigerian farmer landrace	Landrace variety, drought-tolerant, high fodder/grain yield, hard seed coat.
34	UAM-143-4-1	UAM, Dutsin-Ma	Medium-duration, adaptable, grain and fodder dual-purpose, moderate pest resistance
35	UAM-1055-6	UAM, Dutsin-Ma	Medium-duration, dual-purpose for grain and fodder, moderate drought tolerance.
36	UAM-1056-2	UAM, Dutsin-Ma	Medium-duration, moderate grain and

S/N	Name	Source	Characters
			fodder yield, pest and drought tolerant.
37	IT98K-573-1-1	IITA, Ibadan	Determinate, high-yielding, drought & Striga-resistant, well-adapted
38	VITA 7	IITA, Ibadan	High protein content, aphid resistant, moderate drought tolerance, dual-purpose.
39	IT98K-205-8	IITA, Ibadan	Determinate, 60–65-day maturity, large seeds, *Striga gesnerioides* -resistant, adapted to savanna zones
40	TVU 945	IITA, Ibadan	Mild virus chlorosis response, early flowering/seed set (≈63 days), suitable for screening
41	TVU 2723	IITA, Ibadan	Extra-early maturity, cream-colored seeds with black eye, high protein/mineral content
42	TVU 113	IITA, Ibadan	Days to flowering ~44 days; days to pod maturity ~63 days; intermediate growth habit.
43	TVU 3236	IITA, Ibadan	Semi-erect, thrips-resistant pods, good palatability, short cooking time.
44	KOPOT	Local market, Ile Ife	White, coarse coat, big seeded and relatively short cooking time
45	TVU 1509	IITA, Ibadan	High nodulation, thrips-resistant, phosphorus-efficient, used in BNF studies.
46	IT99K-573-1-1	IITA, Ibadan	Determinate, high-yielding, drought & Striga resistant, widely adapted.
47	IT10K-835-10	IITA, Ibadan	Presumed early-maturing, drought-tolerant, moderate seed yield
48	IT10K-817-7	IITA, Ibadan	early-medium maturity, drought-tolerant, moderate yield
49	IT08K-125-24	IITA, Ibadan	early-medium maturity, Savanna-adapted, drought-tolerant.
50	TVU 43	IITA, Ibadan	Early maturity, black-seeded cultivar with dark eye, suited for early-season planting.

Soil analysis

The particle size distribution was determined using the hydrometer method (Bouyoucos, 1962) as modified by Gee and Or (2002). The organic matter content of the soil was determined using the chromic acid digestion method of Walkley and Black (1934) as reviewed by Allison (1965) and reported by Darrell *et al*. (1994). The standard method (Peech *et al*. 1953) was adopted for the determination of soil pH. Total nitrogen was determined using the microKjeldahl digestion and distillation procedure (Bremner and Mulvaney, 1982). The available phosphorus was determined using the Bray-1 method (Bray and Kurtz, 1945). Exchangeable cations were determined using the ammonium acetate (pH 7) method (Soil Survey Staff, 2008).

Soil samples were taken randomly and bulked. The field moisture capacity was determined gravimetrically. An empty 1000 mL measuring cylinder was weighed with a vent tube inside. The cylinder was filled with soil slowly to prevent compaction until the 1000 mL mark was reached, and the cylinder with soil was reweighed. A layer of cotton wool was placed on the soil, and 150 ml of distilled water was added gently. The cylinder was then covered with perforated polythene and left for 72 hours. Samples were taken from the wetting front of the soil into drying cans of known weight. The weight of the can with soil was taken, and the soil was oven-dried at 105 ^{0}C until a constant weight was attained. The weight of the dried soil was then taken, and the percentage field moisture capacity (FMC) was calculated as follows:

$$\% \text{ FMC} = \frac{\text{weight of wet soil (g)} - \text{weight of oven dried soil (g)}}{\text{weight of oven dried soil (g)}} \times 100$$

All data collected were subjected to analysis of variance (ANOVA) using Statistical Analysis System (SAS) version 9.2 (SAS Institute, 2002) to test for significant difference among the treatments and significant means were separated using Fisher's least significant difference ($P \leq 0.01$) and Pearson's correlation analysis was done ($P \leq 0.05$) to assess relationships among traits.

RESULTS AND DISCUSSION

Table 2 presents the soil physical and chemical properties at the experimental site (0-15 cm depth). The soil was sandy loam with a pH of 4.1, which was extremely acidic. Organic carbon content was 11.9 g/kg, total nitrogen 0.12 g/kg, and available phosphorus 10.91 mg/kg. Low fertility status can be deduced from these values. According to Oyebiyi *et al*. (2018), both the high rainfall and the acidic parent material that yielded the soil lead to a deficit in exchangeable cations in the soil. This significant deficiency leads to the leaching of nutrients and the development of acidic soils.

Table 2: Selected soil physical and chemical properties at the experimental site (soil layer 0-15 cm)

Properties	Values
Particle size distribution (gkg^{-1})	
Sand	783
Silt	52
Clay	165
Texture	Sandy loam
Field moisture capacity (%)	15.68
pH (0.01 M $CaCl_2$ solution)	4.07
Organic carbon (gkg^{-1})	11.9
Total N (gkg^{-1})	0.12
Available P (mgkg^{-1})	10.91

Properties	Values
Exchangeable cations ($cmol^+/kg$)	
Potassium (K)	0.06
Calcium (Ca)	0.11
Magnesium (Mg)	0.06
Sodium (Na)	0.01

Specific varieties such as Ife Brown (2655 kg/ha; RNE: 74.29%), IT10K-817-7 (1410 kg/ha; RNE: 72.73%), and Oloyin (2435 kg/ha; RNE: 69.09%) exhibited both high grain yield and high relative nodulation efficiency, making them strong candidates for future breeding programmes, High-yielding cowpea genotypes were observed even under the strongly acidic soil conditions (pH 4.1), suggesting potential acid tolerance or beneficial associations with acid-adapted rhizobia. While previous studies such as Mengel and Kamprath (1978) and Alves et al. (2021) reported negative effects of low pH on nodulation and nitrogen fixation, the study findings indicate that certain genotypes may still perform well under such conditions. However, since grain yield and nodulation efficiency were not significantly correlated in this study, the observed yield performance may be attributed more to genotype adaptability than to nodulation efficiency alone. However, in the present study, several cowpea genotypes exhibited high relative nodulation efficiency (RNE) values between 61.90% and 91.18%, indicating that specific genotypes or rhizobia strains have adaptive mechanisms for acidic environments.

The total nitrogen in the soil was very low (0.12 g/kg), indicating that Biological Nitrogen Fixation (BNF) is vital for maintaining the fertility of the soil (Abayomi and Abidoye, 2009). This is especially important in soils deficient in nitrogen, such as those available in most agricultural regions of West Africa, which are characterized by leguminous crops. The research work of Hellweg *et al.,* (2009) indicates that *Sinorhizobium meliloti* (strain 1021) possess the ability to induce the expression of genes responsible for exopolysaccharide production, which then confers survival advantage and efficacy under acidic conditions. Such a genetic adaptability may account for the high yields observed despite adverse soil pH conditions.

Phosphorus was available in a very low quantity (10.91 mg/kg), and this is known to affect both nodulation and the process of nitrogen fixation. According to Wang *et al.,* (2018), phosphorus plays a critical role in early nodule development and also aids in the absorption of nitrogen by legumes. Singh and Singh (2018) also emphasized that low levels of phosphorus inhibit rhizobial activity, which may lead to reduced efficiency in nitrogen fixation. Although Peech *et al.* (1953) have reported that the availability of phosphorus increases with an increase in soil pH, findings from this study showed that different varieties of cowpea are capable of nodules and yield well under conditions of limited phosphorus, thus demonstrating their potential as candidates for breeding programmes aimed at acid tolerance and low-input agricultural systems.

Results of analysis of variance (ANOVA) for agronomic and yield components obtained from the evaluation of the 50 cowpea varieties revealed significant genetic variation for days to flowering, pod length, number of peduncles per plant, and grain yield at P ≤ 0.01 level of significance. The enhanced yield potential observed in certain cowpea genotypes may be partly attributed to efficient nitrogen translocation mechanisms, as reported by Ohyama *et al.* (2017) and Ohyama (1984), which facilitate nitrogen remobilization from leaves, stems and pods into developing seeds. Although this study did not directly measure nitrogen partitioning, the observed differences in yield performance under low soil nitrogen conditions suggest possible genotypic variation in nitrogen use efficiency.

The differences within the time taken to flowering and maturity correspond with what has been previously reported. Fatokun *et al.* (2018) pointed out that in cowpea, periods of flowering as well as maturity are quite heritable, meaning that they can serve as very effective criteria for selection when breeding for enhanced early maturity varieties. Oladejo *et al.* (2011) also reported there was significant genotypic correlation between days to flowering and yield, especially where rainfall is erratic since early flowering types will avoid drought. Nonetheless, Singh and Singh (2018) assert that temperature, moisture, and other forms of environmental changes can affect flowering period; therefore, these findings stress the importance of genotype-environment interactions in cowpea breeding

The positive correlation observed in pod length (PL) with yield in this study is in line with earlier work by Aliyu *et al.* (2022), in who reported that pod length was positively related to grain yield and number of seeds in cowpea. Similarly, Kuzbakova *et al.* (2022) reported a strong positive correlation between pod length and seed weight, highlighting that selecting for longer pods may be a practical strategy for improving cowpea yield. Contrarily, Olawuyi *et al.* (2015) noted that pod length is not always a reliable predictor of grain yield, as some short-podded genotypes achieve high yields through higher pod numbers or larger seeds. This suggests that the relationship between pod length and grain yield may be genotype specific and caution should be exercised when using pod length as a selection criterion.

Significant differences were discovered among genotypes for pod length (PL) which correlates with the study by Kuzbakova *et al.* (2022), who pointed out that greater pod length is favourable for seed number per pod and aggregate pod grain yield. This is further supported by Martey *et al.* (2022) who noted that drought tolerant cowpea varieties with longer pods tend to yield more under stress environment. On the contrary, Olawuyi *et al.* (2015) argued that short-podded cowpea varieties can produce high yields due to increased seed weight and better seed filling, implying that pod length is not always a sure predictor of yield.

The number of peduncles (NPD) showed marked genotypic variation, suggesting that the genotypes used in the study are invaluable sources of genetic variability for nodulation and other yield components, and selection for high NPD can be made since NPD is a vital yield determinant in cowpea. The works of Ajeigbe *et al.* (2020) showed that varieties with an increased number of peduncles tend to produce a higher pod count per plant, leading to increased grain yield. Also, as noted by Boukar (2019), the number of peduncles is largely heritable, which confirms that high-peduncle variety selection can improve productivity. Nonetheless, Agbicodo *et al.* (2009) have claimed that peduncle number is determined more by plant phenotype and environmental conditions than genetic factors, which is contrary to the findings of this study with high R^2 values indicating strong genetic influence.

The previously reported wide range of differences in grain yield (GY) among cowpea genotypes (Boukar *et al.,* 2018) has been confirmed by this study. Ayalew and Yoseph (2022) also pointed out that cowpea yield is much more genetically controlled than it is dictated by factors like soil or climatic variations. There is, however, a note of caution from Sarr *et al.* (2020) that suggest certain environmental factors like drought and pest infestation may drastically lower yield potential, even for some of the better genetically endowed varieties. This results clearly suggest that breeding programmes should consider inclusion of stress resistance traits together with traits for high yield to achieve stability in productivity under diverse environment conditions.

Table 3 presents the analysis of variance (ANOVA), which depicts the variation in nodule count (NND) and other traits related to cowpea variety classification. The study revealed strong genotypic differences ($P \leq 0.01$) in NND, NFW, RFW, and SDW. The R^2 value for the number of nodules was 79.79%, indicating that a substantial proportion of the variability in nodule number among the cowpea genotypes is accounted for by the experimental model. The significant genotype effect observed in the ANOVA suggests the presence of genetic variability for nodulation traits, which could be explored through selection programmes. However, given the fact that the efficiency in the cowpeas varies significantly for the genotypes, candidate varieties based solely on nodules will not suffice. Alongside other factors, root and shoot biomass should be taken into account for the greatest nitrogen fixation and grain yield. The coefficient of variation for yield 377.417 also demonstrates that the experiment successfully captured the genetic variation between the different varieties and that the methods employed were consistent.

The high variability seen in nodulation traits is in line with previous work. As noted by Fatokun *et al.* (2018), cowpea genotypes have varying degrees of nodulation efficiency, and some varieties can fix more nitrogen than others. Belane and Dakora (2012) also stated that cowpea genotypes differ, not only in the quantity of nodules, but also in the ability of the nodules to fix nitrogen, clearly indicating the need to assess both nodule number and efficiency. Nevertheless, a number of researchers, including Martins *et al.* (2020), have pointed out the fact that genetic and environmental factors such as soil type, moisture, and the available rhizobia strains are equally important for nodulation. This indicates that the effectiveness of nitrogen fixation is based on the interplay of both the genotype of the plant and other environmental conditions surrounding it.

The hypothesis that bigger root systems improve root fresh weight (RFW) and root dry weight (RDW), along with greater nodule formation capacity, is supported by this study. For instance, genotypes such as TVU 3236 and UAM14-145-4-3, which had high RDW values of 1.75 g and 2.29 g, respectively, also showed relatively high nodule counts and nodulation efficiency (RNE: 75.00% and 73.68%), indicating a potential association between larger root systems and enhanced nitrogen fixation traits. Nevertheless, bigger root systems tend to be advantageous, but as Ohyama *et al.* (2017) pointed out, there is too much root growth, which saps resources from grain production. While there is high fixation of nitrogen, there is also low grain production. This suggests that there has to be a balance between roots and productivity of the plant while breeding for nitrogen-fixing cowpea varieties.

The high range of root dry weights (RDW) among genotypes is in line with observations of Quin (1997), who observed that cowpea varieties that support large root systems exhibit higher efficacy in fixing nitrogen and higher resistance to drought stress. Likewise, Maqbool *et al.*, (2022) found that root systems that penetrate deeply into soil exhibit higher adaptability in nutrient-deficient soils, hence higher potential for growth and yield. Nevertheless, Ohyama *et al.* (2017) cautioned that excessive root system formation sometimes compromises shoot and pod elongation, hence the potential to lower overall yield. As such, even though root biomass is crucial to facilitate effective modulation, a balance between root formation and shoots plus pods is crucial to get optimal yield results

Shoot fresh weight (SFW) and shoot dry weight (SDW) also varied significantly among genotypes, reflecting differences in vegetative growth and biomass accumulation. While these traits may be influenced by nitrogen availability, they are not definitive indicators of nitrogen fixation efficiency and should be interpreted alongside nodulation and nitrogen content parameters. Ajeigbe *et al.* (2020) confirmed that more shoot biomass in a particular set of genotypes facilitates more photosynthesis, hence more nodulation and fixation of nitrogen. This is in conformity with the high R^2 values of shoot biomass characters in this study, suggesting high genetic control over such characters. Singh *et al.* (2021), in their turn, cautioned that excessive overgrowth of shoots in some instances leads to wasteful resource allocation, in that more energy is invested in vegetative growth at the expense of reproduction. This means that high shoot biomass selection must be done in conjunction with yield characters to ensure a balance in growth.

Despite significant genetic variance in the number of nodules (NND), in this study, it was found that grain yield was not significantly correlated to the number of nodules *per se.* This aligns with the findings of Singh and Singh (2018), who reported that a higher number of nodules does not necessarily result in greater nitrogen fixation or yield; rather, the efficiency of nodule function is a more reliable indicator of nitrogen fixation effectiveness. Belane and Dakora (2012) also found that there are cowpea genotypes that produce fewer, more efficient nodules fixing more nitrogen per carbon fixed per unit over more plentiful, though less efficient, nodules in high-yielding varieties. In soybeans, however, Alves *et al.* (2021) found that there was a correlation between yield and number of nodules, suggesting that in soybeans, a high number of nodules is a key character for selecting grain yield. The reason for this difference between soybeans and cowpea may be a result of differences in rhizobial specificity and fixation efficacy between legume species.

Table 3: Mean squares from Analysis of variance for phenological traits and yield components of selected cowpea varieties

Source of variation	df	Days to first flowering	Days to 50% flowering	Days to 50% podding	Days to physiological maturity	Days to harvest maturity	Pod length (cm)	Number of peduncles per plant	Grain yield (kgha^{-1})
Replication	2	3.36	12.80	53.86	159.52	117.53	19.93	158.01	853841.48
Genotype	49	153.32**	144.69**	148.16**	158.20**	158.37**	18.34**	221.56**	1264178.78**
Error	98	7.35	9.22	9.82	16.60	16.91	2.16	71.71	217479.43
R^2 (%)		91.55	88.99	88.77	83.67	83.29	81.61	61.43	74.94

Source of variation	Degree of freedom	Number of nodules	Nodules fresh weight	Nodules dry root weight	Shoot fresh weight	Shoot dry weight	Root fresh weight
Replication	2	27.773	0.002	0.0002	1168.793	30.708	0.888
Genotype	49	425.457**	0.183**	0.016**	9908.273**	211.236**	18.267**
Error	98	54.000	0.034	0.002	430.692	29.112	1.433
R^2 (%)		79.789	73.231	76.815	92.039	78.681	86.465

Tables 4a and 4b present mean yield components and nodulation parameters of different cowpea genotypes using the least significant difference (LSD) at a 0.05 significance level. The genotypes were systematically ordered in descending order using their number of nodules (NND) to highlight the differences in their nodulation performance. The observed differences between the genotypes point to a high level of genetic diversity with respect to yield and nodulation traits.

Specific varieties, Ife Brown, IT10K-817-7, and Oloyin, exhibited high yield (insert values) coupled with high nodulation efficiency, making them potential candidates for future breeding programmes. In addition, other genotypes such as TVU 113 and IT08K-180-10 exhibited high relative nodulation efficiencies of 91% and 84%, respectively, in spite of their cultivation in acidic soil conditions. The results point to a natural adaptation of some of the varieties to low-pH soil, hence validating the potential for acid-tolerant cowpea varieties.

The number of nodules (NND) varied between 1.75 and 58.67, pointing to a wide variability in their nodulation potential. Similarly, grain yield (GY) also varied highly, with high-yielding varieties recording over 2,600 kg/ha. Of note is that high-yielding genotypes did not always correspond to high nodule counts, a finding that is in line with the findings of Belane and Dakora (2012) that point to higher relevance of nodulation efficiency over the number of nodes in evaluating the efficacy of nitrogen fixation. In addition, genotypes that exhibited high root and shoot biomass tended to produce better yield, hence validating the hypothesis that accumulation of biomass is key to improving cowpea productivity.

The notable differences in grain yield and Relative Nodulation Efficiency (RNE) observed among genotypes in this study are consistent with findings by Fatokun *et al.* (2018), who reported that genetic variation in cowpea significantly influences both yield and nitrogen fixation potential. Similarly, Boukar *et al.,* (2018) found that a multiple-trait approach to selection that encompasses yield and nodulation efficiency is essential for improving cowpea productivity. Nevertheless, Sarr *et al.* (2020) emphasized that environmental factors, such as soil fertility and drought, can impact yield to a great extent, sometimes even surpassing genetic effects. This means that even though genetic selection is a key factor, breeding programmes must also take account of interactions in the environment to promote yield stability.

Although some high-yielding genotypes in this study exhibited relatively low nodule counts, they still maintained competitive grain yields. This suggests that nodule number alone may not fully explain yield performance, and Schwember *et al.* (2019) emphasize the importance of nodule function or efficiency rather than quantity in contributing to nitrogen fixation.

Table 4a: Mean values of some yield components and nodulation parameters in cowpea genotypes

Genotype	Days to first flowering	Days to first podding	Days to physiological maturity	Days to harvesting maturity	Number of nodules	Nodules fresh weight	Nodules dry weight	Relative Nodules Efficiency (%)	Shoot fresh weight	Shoot dry weig	Root fresh weight	Root dry weight	Number of peduncles	Pod length	Grain yield (kg/ha
Ife Brown	35.67	40.00	55.67	59.33	51.00	0.70	0.18	74.29	91.17	25.05	5.33	1.65	28.20	12.70	2655.0
IT10K-817-7	46.33	47.33	65.33	69.33	43.60	0.11	0.03	72.73	85.76	20.10	4.24	1.05	18.40	19.20	1410.0
Oloyin	68.00	69.00	87.00	91.00	42.70	0.55	0.17	69.09	33.07	5.63	2.07	0.63	23.40	16.80	2435.0
TVu 113	56.00	57.00	82.33	85.00	42.36	1.26	0.37	70.63	341.70	24.33	9.00	2.00	15.00	18.00	213.3
IT10K-822-9	38.67	39.67	58.67	62.33	39.20	0.09	0.03	66.67	173.70	34.90	8.60	2.32	33.00	18.00	2587.0
IT98K-205-8	40.00	41.00	59.67	63.00	39.00	0.15	0.04	73.33	134.50	43.23	6.50	1.87	30.20	14.10	1379.0
UAM14-145-4-3	40.00	41.00	59.67	62.00	35.62	0.38	0.10	73.68	195.40	46.56	12.50	2.29	25.80	14.10	1198.0
IT09K-269-1	44.33	45.33	60.33	63.33	35.53	0.47	0.14	70.21	162.40	21.26	7.83	2.10	19.30	15.60	1780.0
TVu 3236	43.00	44.00	61.00	63.33	34.71	0.28	0.07	75.00	135.20	16.67	6.29	1.75	63.60	13.40	2601.0
Aloka Local	43.33	44.33	64.67	68.33	30.50	0.27	0.09	66.67	32.21	8.04	1.67	0.68	20.10	11.30	375.0
IT99K-573-1-1	42.00	43.00	65.33	69.00	29.50	0.41	0.12	70.73	186.70	14.17	9.04	1.98	17.10	19.10	2689.0
IT10K-832-2	44.67	45.67	59.33	62.33	28.88	0.21	0.08	61.90	128.50	19.20	7.90	2.26	30.20	18.50	2158.0
UAM-1055-6	38.67	39.67	59.67	61.33	28.33	0.59	0.14	76.27	135.70	21.00	6.95	1.71	20.30	20.90	2590.0
IT08K-150-27	39.33	40.33	60.00	64.67	25.79	0.11	0.04	63.64	90.88	13.78	5.46	1.17	28.10	16.80	1621.0
IT07K-243-1-10	38.00	39.00	58.00	61.33	24.46	0.60	0.22	63.33	159.50	14.81	9.25	2.22	25.10	16.60	2039.0
Kopot	N.A	N.A	N.A	N.A	23.33	0.58	0.15	74.14	159.30	20.00	6.10	1.50	N.A	N.A	N.A
IT11D-16-71	40.67	41.67	58.00	61.67	23.29	0.38	0.06	84.21	116.90	16.39	7.46	2.67	17.10	19.00	2636.0
TVu 2723	35.00	36.00	55.00	58.33	21.97	0.26	0.05	80.77	130.50	21.30	4.03	1.09	20.90	16.90	1442.0
IAR-07-1032-1	38.33	39.33	60.00	63.00	21.00	0.22	0.06	72.73	92.30	10.20	6.00	1.50	38.30	14.60	2137.0
IT07K-230-2-9	37.33	38.33	59.00	61.33	20.00	0.56	0.13	76.79	104.30	21.48	5.50	1.73	30.60	16.20	1791.0
IRS-09-1009-7	35.33	36.33	59.00	62.33	19.00	0.41	0.07	82.93	106.40	16.97	5.53	1.96	19.70	17.80	1160.0
IT08K-180-11	42.00	43.00	61.33	65.67	18.38	0.12	0.04	66.67	87.14	17.09	5.00	1.61	33.20	15.80	2202.0
IT07K-274-2-9	43.33	45.00	60.67	63.67	17.50	0.41	0.11	73.17	138.50	16.21	6.50	1.61	33.40	13.30	1820.0
UAM-1056-2	36.00	37.00	59.00	62.33	17.25	0.44	0.09	79.55	56.67	9.60	3.33	0.83	16.80	16.80	2210.0
UAM-143-4-1	36.67	37.67	58.33	60.33	16.93	0.40	0.14	65.00	53.35	5.78	2.61	0.58	26.80	16.10	1822.0
IT08K-150-12	39.33	40.33	59.33	62.33	16.75	0.11	0.03	72.73	94.21	14.7	5.04	1.43	19.3	15.9	1487.3
LSD (0.01)	4.32	4.45	6.56	6.6	11.91	0.3	0.08	73.33	33.64	18.23	1.94	0.62	13.7	2.89	756.03

Table 4b: Mean values of some yield components and nodulation parameters in cowpea genotypes

Genotype	Days to first flowering	Days to first podding	Days to physiological maturity	Days to harvesting maturity	Number of nodules	Nodules fresh weight	Nodules dry weight	Relative Nodules Efficiency (%)	Shoot fresh weight	Shoot dry weight	Root fresh weight	Root dry weight	Number of peduncles	Pod length	Grain yield (kg/ha
IT10K-822-7	39.7	40.7	59.0	62.3	15.9	0.6	0.1	80.0	221.2	31.6	11.3	2.3	41.3	18.8	2420.0
IT10K-961-7	34.3	35.0	59.0	62.0	15.7	0.2	0.0	80.0	48.8	7.8	3.5	1.1	17.7	16.7	1477.0
IT98K-131-1	53.0	54.0	79.0	82.0	15.0	0.3	0.1	75.0	20.8	2.8	1.7	0.4	22.2	16.9	1730.0
UAM14-155-10-3	43.7	44.7	64.3	69.0	14.5	0.5	0.1	80.4	108.2	14.3	6.4	1.4	32.3	17.1	805.9

Genotype	Days to first flowering	Days to first podding	Days to physiological maturity	Days to harvesting maturity	Number of nodules	Nodules fresh weight	Nodules dry weight	Relative Nodules Efficiency (%)	Shoot fresh weight	Shoot dry weight	Root fresh weight	Root dry weight	Number of peduncles	Pod length	Grain yield (kg/ha
TVu 945	53.7	54.7	74.3	77.3	13.8	0.2	0.0	76.5	85.2	14.2	2.1	0.5	10.0	13.9	734.8
IT10K-837-1	38.0	39.0	59.7	62.7	13.1	0.1	0.0	69.2	81.3	11.9	4.9	1.1	26.0	15.8	1672.0
Vita 7	46.3	47.3	69.0	72.0	12.1	0.1	0.0	69.2	21.0	2.9	0.9	0.2	25.3	15.8	1013.0
IT08K-193-14	44.7	45.7	66.3	68.7	10.4	0.4	0.1	71.4	151.8	20.7	7.3	1.2	23.2	18.1	1927.0
IT08K-125-24	37.3	38.3	59.3	62.7	10.0	0.2	0.1	77.3	73.4	8.7	3.2	0.8	24.8	15.2	1747.0
IT10K-863-11	38.0	39.0	59.3	62.7	9.2	0.5	0.1	76.1	119.9	13.1	7.5	1.9	15.6	16.8	2526.0
TVu 43	43.0	44.0	60.3	63.3	8.9	0.1	0.0	75.0	117.9	12.8	4.8	1.1	24.1	17.7	2377.0
IT07K-292-10	75.3	76.3	93.3	96.7	8.6	0.3	0.1	78.6	65.3	10.1	4.9	1.3	26.8	13.8	156.3
IRS-09-1106-4	35.7	36.7	57.7	61.3	8.3	0.1	0.0	71.4	76.4	12.1	4.8	1.1	33.2	14.9	1974.0
UAM14-154-10-2	42.3	43.3	63.3	66.0	8.0	0.1	0.0	72.7	58.4	7.6	4.0	0.9	17.7	19.2	1481.0
IT11D-21-143	36.7	37.7	57.3	60.7	7.7	0.6	0.1	76.4	89.1	14.7	4.1	1.0	21.4	16.9	2057.0
TVu 1509	38.3	39.3	57.0	60.0	7.4	0.2	0.1	61.9	39.8	9.7	2.2	0.1	25.2	6.2	799.4
IAR- 07-1042-1	36.0	37.0	60.0	63.0	7.0	0.1	0.0	76.9	88.3	19.4	5.7	1.5	24.3	14.5	1378.0
IT10K-817-3	39.0	40.0	58.3	61.0	6.7	0.7	0.2	75.4	70.8	9.5	4.8	0.9	21.7	17.4	2268.0
IT98K-573-1-1	37.7	38.7	59.7	64.0	6.3	1.0	0.3	71.1	78.2	12.7	3.1	1.0	29.2	19.6	2451.0
IT08K-180-10	37.3	38.3	58.7	61.7	6.1	0.3	0.0	91.2	124.2	15.7	4.8	1.1	28.8	18.4	2475.0
IT10K-832-1	41.3	42.3	64.7	68.0	5.9	0.6	0.2	73.7	123.6	18.7	6.1	1.7	19.4	16.1	1574.0
IT10K-835-10	40.3	41.3	58.7	62.0	5.6	0.8	0.3	67.9	74.1	10.6	3.6	0.9	23.6	16.9	2143.0
IT07K-291-69	41.3	42.3	62.0	64.0	5.1	0.3	0.1	77.4	73.5	9.1	4.8	1.0	21.3	16.2	1928.0
IT08K-150-24	38.7	39.7	60.3	62.7	4.5	0.3	0.1	65.4	83.0	29.6	4.5	1.7	22.6	15.9	1685.0
LSD (0.01)	**4.3**	**4.5**	**6.6**	**6.6**	**11.9**	**0.3**	**0.1**	**73.3**	**33.6**	**18.2**	**1.9**	**0.6**	**13.7**	**2.9**	**756.0**

However, it should be noted that nitrogen fixation is just one of several factors influencing yield potential, and a direct correlation between fixation efficiency and yield was not established in this study. This is in line with observations of Singh and Singh (2018), who found that certain cowpea genotypes produce fewer yet more efficient nodules, resulting in higher nitrogen fixation and grain yield. By contrast, Alves *et al.* (2021) observed a correlation between yield and number of nodules in soybeans, suggesting that in some legumes, a higher number of nodules is a key driver of better nitrogen fixation and grain yield. The reason for the difference between soybean and cowpea is possibly attributed to differences in rhizobial specificity, efficacy of nitrogen assimilation, and root system structure.

The strong correlation between root and shoot biomass and grain yield established in this work is in agreement with Mutunga *et al.* (2022) observations which states that varieties that exhibit high biomass accumulation yield more and also display high stress resistance. Likewise, Ajeigbe *et al.* (2020) observed that higher shoot biomass is positively associated with photosynthesis, hence enabling better fixation of nitrogen and grain formation. Nevertheless, Singh *et al.* (2021) cautioned that overgrowth of vegetative mass is likely to interfere with resource allocation, negatively impacting grain yield even in cases of high biomass accumulation. This is a reason why adopting well-balanced selection approaches is crucial to ensuring maximum biomass yield and reproductive potential.

Table 5 presents the descriptive statistics of yield components and nodulation parameters in the 50 cowpea genotypes, highlighting the wide genetic diversity underlying such traits. The mean number of nodes per plant (NND) was established to be 18.95; however, it varied widely, between 1.75 to 58.67, thus indicating a high extent of variability in terms of nodulation potential. Similarly, root dry weight (RDW) varied widely, between 0.15 to 3.43 g, indicating that there existed genotypes that would have more developed root systems, possibly to facilitate better nutrient uptake and fixation of nitrogen. The pod length also varied widely, having a mean of 16.29 cm, whilst its range was between 5.32 cm to 23.11 cm, indicating varying pod structure and hence their respective potential to accommodate grain formation. The grain yield (GY) also varied widely across genotypes, between 156.3 kg/ha to 2,689 kg/ha, hence indicating a high extent of variance in yield potential. The wide range in yield and nodulation traits indicates great potential for genetic improvement of yield in cowpea. In addition, the high standard deviations observed in most of these traits indicate the impact of environmental influences such as soil fertility and soil moisture on their phenotypic expression.

Table 5: Descriptive Statistics for yield components and nodulation parameter

Variable	Mean	Standard Deviation	Minimum	Maximum
Days to 50% flowering	46.80	7.86	37.00	84.00
Days to 50% podding	48.79	8.05	40.00	86.00
days to physiological maturity	62.59	8.55	50.00	97.00
Days to harvesting maturity	65.76	8.58	56.00	102.00

Variable	Mean	Standard Deviation	Minimum	Maximum
number of nodules	18.95	13.26	1.75	58.67
Nodules fresh weight	0.37	0.29	0.01	1.29
Nodules dry weight	0.10	0.08	0.00	0.38
shoot fresh weight	106.20	59.63	14.50	341.70
shoot dry weight	15.91	9.45	2.00	55.40
Root fresh weight	5.42	2.64	0.50	13.00
Root dry weight	1.40	0.66	0.15	3.43
Number of peduncles	25.14	11.05	3.33	81.33
Pod length	16.29	2.78	5.32	23.11
Seed number	12.47	2.48	3.00	19.00

The notable variation in nodule number (NND) between different genotypes is in line with Fatokun *et al*., (2018) observation of a high level of genetic diversity in cowpea nodulation, hence suggesting potential for the selection of genotypes that improve nitrogen fixation. Similarly, Belane and Dakora (2012) observed that some cowpea genotypes produce a smaller number of nodules but of higher efficacy, whereas others produce more of a lower efficacy in fixing nitrogen. Nevertheless, Ndema *et al.,* (2020) highlighted that nodulation efficacy is not just a function of the genetic makeup; soil nitrogen status, efficacy of rhizobia strains, and effects of drought stress also take their parts in it. As such, genetic improvement to raise nodulation efficacy is possible, yet it is equally crucial to control external aspects to maximize fixation of nitrogen.

The wide range observed in grain yield (156.3–2,689 kg/ha) supports the report by Boukar *et al.,* (2018), which emphasized that genotypic diversity is a key driver of yield potential in cowpea. This variation indicates opportunity for progress through direct selection on grain yield. However, in breeding contexts where trait correlations are weak or gains from single trait selection are limited, Chaudhary *et al.,* (2024) suggest that incorporating multiple traits, including physiological and agronomic characteristics may enhance selection efficiency. Nevertheless, it was observed by Sarr *et al.,* (2020) that environmental aspects such as soil nutrient status and drought stress affect yield performance, sometimes overpowering genetic effects when viewed in isolation. This indicates that breeding programmes need to broaden their objectives beyond genetic potential to also address aspects of stress adaptation in order to promote yield stability.

Results of Pearson's correlation between yield components and nodulation parameters of the 56 cowpea genotypes was presented in Table 6 and it provides key information on the determining factors of grain yield and nitrogen fixation. The results indicate that root dry weight (RDW) was positively correlated with pod length (PL) (r = 0.18) and grain yield (GY) (r = 0.41), while root fresh weight (RFW) also shows a positive correlation with grain yield (r = 0.19). In addition, shoot dry weight (SDW) is positively related to the number of peduncles (r = 0.20) **, indicating that

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accumulation of biomass is key to improving cowpea productivity.

Notably, the number of nodules (NND) is not positively correlated to any of the yield traits, hence upholding that a higher number of nodules in itself is not a guarantee of a grain yield improvement. The hypothesis that biomass-related aspects, such as root weight and shoot weight, play a more determining role in yield compared to having a higher number of nodules is upheld. The high correlation between root dry weight and grain yield indicates that more developed root systems improve productivity by enabling better nutrient and water uptake. The failure of correlation between number of nodules and yield indicates that functionality of nodulation, and not quantity of nodules, is responsible for determining nitrogen fixation efficacy.

The observed positive correlation between root dry weight (RDW) and grain yield (GY) is in support of Quin (1997) observations that more developed root systems in cowpea varieties generally lead to better nitrogen fixation and grain yield owing to better nutrient use efficiency. Similarly, Odeku et al. (2024) highlighted root biomass's crucial role in cowpea yield, especially in low-resource environments, in which efficient uptake of water and nutrients is a prerequisite for maintaining productivity. In contrast, Ohyama *et al.* (2017) cautioned that overdevelopment of roots sometimes diverts resources to reproduction at the expense of grain yield, even though there is a boost in nitrogen fixation. Consequently, though it is beneficial to choose for more developed root systems, there is a need to strike a balance between root and shoot biomass to obtain maximum productivity.

The significant correlation established between shoot dry weight (SDW) and number of peduncles (NPD) (r = 0.20*) supports the claims of Ajeigbe *et al*., (2020), who reported that cowpea varieties that exhibit high shoot biomass often exhibit high flowering and pod-set ratios, hence higher grain yield. Similarly, Croce *et al*., (2024) emphasized that higher shoot vigour enhances photosynthesis, hence improving reproduction processes and grain yield. Singh and Singh, (2018) in a contrasting note, emphasized that excessive vegetative growth in some cases can result in wasteful resource allocation, and negatively influence seed formation, even when high biomass is produced. This highlights the importance of achieving an optimal balance between vegetative growth and reproductive development in breeding programmes aimed at enhancing cowpea yield potential.

The failure to obtain a significant correlation between grain yield and number of nodules (NND) is in line with claims of Belane and Dakora (2012), who expressed that counts of nodules are poor indicators of nitrogen fixation efficacy or yield potential. They claimed that some cowpea genotypes yield fewer but more efficient nodules, hence improving nitrogen fixation and, in turn, grain yields. In a contrasting example, Alves *et al*. (2021) reported a correlation between yield and number of nodules in soybeans, implying that in some legume species, high counts of nodules can positively impact nitrogen fixation and grain yield. The discrepancies observed in soybeans in comparison to cowpea can be attributed to differences in rhizobial strain specificity, mechanisms of nitrogen fixation, or root system structure.

The correlation between relative nodule efficiency (RNE) and shoot dry weight (SDW) in different cowpea genotypes that were examined, highlighting the importance of biomass accumulation in attaining high nitrogen fixation efficacy and grain yield.

Genotypes UAM14-145-4-3, IT98K-205-8, and IT10K-822-9 recorded the maximum shoot dry weights of 46.56 g/plant, 43.23 g/plant, and 34.90 g/plant, respectively. In contrast, the genotypes IT08K-180-10, IT11D-16-71, and IT10K-822-7 displayed high relative nodule efficiencies (RNE) of 91%, 84%, and 75%, respectively, in conjunction with grain yields of 2475, 2636, and 2601 kg/ha. The high yield combined with high relative nodule efficacy reveals that effective nodulation is crucial to facilitate high nitrogen fixation and seed formation. This is in line with Singh and Singh (2018), who observed that highly efficient nodules are better at fixing nitrogen in a usable state for the plant, hence improving pod and seed yields.

The positive correlation between grain yield and relative nodule efficiency in this study is in line with earlier work by Belane and Dakora (2012), who reported that high-efficiency cowpea genotypes produce more biomass and seed yields owing to more efficient nitrogen assimilation. Aliyu *et al.,* (2023) also found that legumes that exhibit efficient nodulation support higher yields in low-nitrogen soils, hence implying that there is a crucial role of efficient fixation of nitrogen in grain yield. In contrast, Alves *et al*., (2021) found a positive correlation between yield and total soybean nodule count, indicating that more nodules would support fixation of nitrogen in particular legume species. The differences in results between soybeans and cowpeas would be a reflection of varying rhizobial interactions, varying strategies of fixation of nitrogen, and adaptations to prevailing environmental conditions.

CONCLUSION

This study highlighted the importance of nodulation efficiency and biomass accumulation, in evaluating cowpea yield, hence determined key traits for breeding programmes and soil management strategies. There existed wide variability among the germplasm, strong association between grain yield and relative nodule efficiency; and also root and shoot biomass, nodule dry weight and pod length are major main traits to be considered for selection in developing dual purpose cowpea genotypes of high yielding and nodulation efficient. Ife Brown, IT10K-817-7, and Oloyin were found to combine both high grain yield and high relative nodulation efficiency. Selection for high relative nodule efficiency combined with high root and shoot biomass has potential to boost nitrogen fixation, promote drought

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