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Research Article

Response of Cowpea (*Vigna unguiculata* L. Walp.) Varieties to *Striga gesnerioides* (Willd.) Vatke Infestation

[1] Alhassan Bawa, [1] Ismael Yakubu and [2] Yussif Seidu

[1]Department of Sustainable Agriculture, Faculty of Agriculture and Natural Resources, Tamale Technical University, Tamale, Ghana
[2]Department of Agricultural Engineering, Faculty of Engineering, Tamale Technical University, Tamale, Ghana

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Corresponding Author:
Alhassan Bawa
Department of Sustainable Agriculture, Faculty of Agriculture and Natural Resources, Tamale Technical University, Tamale, Ghana
Email: abnaive@gmail.com

Abstract: Production of cowpea within the sub-Saharan Africa, and Ghana in particular, is bedeviled with many challenges, including *Striga* infestation, resulting in abysmal low grain and biomass yields. Thus, the study was conducted to evaluate *Striga's* impact on cowpea growth and yield. During the 2023 agricultural season, the study was carried out in Northern Ghana. A control (non-infested) experiment and a *Striga*-infested experiment were carried out concurrently. Each of the two trials had three replications and was set up using a randomized complete block design. The Gen Stat statistics software edition 12 was used to conduct statistical analyses, such as correlation analysis and Analysis of Variance (ANOVA), and means were separated using Least Significant Differences (LSD) at a 5% probability. The findings showed that cowpea cultivars and *Striga* infestation interacted significantly ($P<0.05$). The results also showed that there was a significant ($P<0.05$) difference among the three varieties in terms of growth parameters like plant height, number of leaves, leaf area, and number of branches; under *Striga*-infested conditions, Padi-tuya produced the tallest plants, the most leaves and branches, and the broadest leaves. *Striga* infestation also had a significant ($P<0.05$) impact on the yield and yield components, including grain yield, 100-seed weight, number of pods per plant, number of seeds per pod, and dry biomass production. Of the three cowpea varieties, Padi-tuya produced significantly higher grain yield components. Ultimately, when *Striga* was present, Padi-tuya yielded significantly ($P<0.05$) more plant height, leaf area, branches, dry biomass production, pods per plant, seeds per pod, 100-seeds weight, and total grain yield than the other two cultivars. It is therefore recommended that in *Striga gesnerioides* - infested agricultural lands, Padi-tuya should be cultivated for increased biomass and grain yield production.

Keywords: Varieties, Cowpea, Striga Infestation, Growth Parameters, Northern Ghana

Introduction

In the US, cowpea was a significant source of animal feed for cows. The fact that the crop was used to feed cows is how it got its name. An annual herbaceous legume, the cowpea (*Vigna unguiculata* L. Walp.) thrives in sandy soil with little precipitation. As a result, it is a significant crop in semi-arid areas of Asia and Africa. Because the plant's root nodules can fix nitrogen from the atmosphere, very little or no nutrient input is necessary. For smallholder farmers with limited resources, the cowpea is a crop that is both nutritious and suitable for intercropping with other crops. Africa is where the cowpea crop was cultivated. It is among the earliest crops grown in Africa. A second domestication event probably occurred in Asia, from where the crop was spread into Europe and the Americas (Gómez, 2004*)*. The crop is used as a fodder for feeding farm animals. The crop's use for feeding cattle is likely responsible for its name (Timko *et al.*, 2007).

The production of over 7.4 million tons of dried grains of cowpeas are achieved globally (FAOSTAT, 2020), with Africa producing nearly 7.1 million. Nigeria is the largest producer and consumer, accounting for 48% of Africa's production and 46% worldwide. Africa exports and imports negligible amounts of cowpea (Nkomo, 2021). The cowpea is a major source of dietary cereal and tuber crops. In addition to its nutritional value, the cowpea is an important source of income for farmers and also help to maintain soil fertility for succeeding cereal crops growing in rotation with it.

The cowpea is the most significant legume in Ghana. Cowpeas can be grown in all of Ghana's ecological zones, but they are produced in greater quantities in the savanna regions of the country's north. Due to the crop's important function in providing the majority of farm households and farm animals with protein, cowpea output has increased in most agricultural systems in emerging nations. Cowpea is a major component of tropical farming systems because of its ability to improve unproductive and infertile lands through nitrogen fixation and as cover crop (Sanginga *et al.*, 2000). Cowpea is mainly grown in Ghana during the rainy seasons in the savanna and transitional agro-ecological zones (CRI, 2006). Cowpea production helps to improve the situation of food security among Ghanaian farmers, especially those who are smallholder farmers. The crop also improves the health and quality of Ghanaian soils. The multiple uses of cowpea has made the crop a traditional and significant crop in African cropping systems (Chweya and Eyzaguirre, 1999). There is therefore the need to take urgent steps to improve the crop for improved yield and growth parameters to enhance sustainable production. However cowpea production in northern Ghana is bedeviled with a lot of challenges, which reduces its production. The most destructive problem of cowpea production is *Striga* infestation (Kondi *et al.*, 2018). Infestation of the cowpea crop with parasitic weeds, *Striga gesnerioides* (Willd.) Vatke and *Alectra vogelii* Benth, is one of the main biological constraints that reduces cowpea productivity among smallholder farmers, especially in the semi-arid regions of West and Central Africa (Hibberd *et al.*, 1996; Ehlers and Hall, 1997).

Striga gesnerioides, a member of the Scrophulariaceae family, is a devastating obligate root hemiparasite that primarily parasitizes dicotyledonous species, including tobacco, sweet potato, cowpea and other legumes (Botanga and Timko, 2005). At present, the Sudano-Sahelian belt of Africa is more affected by *S. gesnerioides* but the parasite is fast spreading beyond this limit (Carsky *et al.*, 2003). Crop yield losses due to *S. gesnerioides* may be up to 70% depending on the extent of damage and level of infestation (Aggarwal and Ouedraogo, 1989; Alonge *et al.*, 2005). On susceptible cultivars, yield losses can reach 100% when *S. gesnerioides* population was over 10/plant (Kamara *et al.*, 2008). Omoigui *et al.* (2009) added that yield losses caused by this witchweed in dry savanna of sub-Saharan Africa are estimated in millions of tons annually and the prevalence of *Striga* soils is steadily increasing.

Improved cultural practices are one of the many control techniques that have been established (such as hand-picking of emerged shoots before flowering), the use of chemical control, and conventional biological control methods. However, all these *Striga* control strategies could be expensive, ineffective, and labor-intensive for farmers (Daramola *et al.*, 2020). As a result, breeding using many sources of resistance (Berner *et al.*, 1995) to develop varieties that can tolerate *Striga* infection is the best method. Using host plant resistance genotypes is an effective strategy that is less expensive than other approaches and may provide a long-term solution to *Striga's* disruption. Finding *Striga*-tolerant cowpea varieties was the aim of the study, which evaluated cowpea varieties for growth and yield metrics in both *Striga*-infested and non-infested environments.

Materials and Methods

Experimental Site

The experiment was carried out in the Tamale Technical University's Faculty of Agriculture and Natural Resources experiment field in Tamale, Ghana's northern region. Rainfall fluctuated throughout the research period. The Savannah agro-ecological zone of Ghana, which includes the northern region, is distinguished by a single agricultural season and a unimodal tropical monsoon. Beginning in December and ending in March, the harmattan period limits this one farming season. According to Dieni *et al.* (2019), the study area is located between latitudes 9^{o} 16^{1} and 9^{o} 34^{1} North and longitudes 0^{o} 36^{1} and 0^{o} 57^{1} West. In the research area, annual rainfall typically peaks between July and August and ranges from 600 to 1100 mm. Average temperature ranges from 28 ^{O}C to 38 ^{O}C at day and 18 ^{O}C to 25 ^{O}C at night while average humidity ranges from 64 % to 81 % from June to August during the rainy season (SARI, 2008). Table 1 provides detailed information on the rainfall, relative humidity and temperature distribution in the study area during the experimental period.

Table 1: Total rainfall, temperature and relative humidity distribution during the 2022 and 2023 cropping seasons

Month	Total Rainfall (ml)		Temperature (^{O}C)		Relative humidity (%)	
	2022	2023	2022	2023	2022	2023
May	45.6	38.4	35.5	35.5	70	76
June	166.0	68.9	33.2	34.3	70	69
July	122.9	146.4	30.9	30.7	81	75
August	240.0	180.5	30.4	29.8	83	80
September	195.6	227.5	30.5	27.5	84	83
October	153.1	124.3	32.7	32.5	79	80
November	0	7.6	35.6	35.7	68	57
December	0	0	35.8	34.2	44	44
Total	923.2	793.6	264.6	260.2	579	564
Mean	115.4	99.2	33.0	32.5	72.3	70.5

The research area's soil type is sandy loam. The experimental area's vegetation consists of short, drought-resistant trees mixed with grassland. Ghana's soils are formed from parent material that has been severely weathered. The savannah and transition zones have especially low percentages of nitrogen and organic materials. The Savannah agro-ecological zones of Ghana are characterized by alluvial and eroded shallow soils (Oppong-Anane, 2006); the majority of these soils are naturally infertile (Table 2).

Table 2: Average soil fertility status of seven administrative regions of Ghana Source

Region	Soil p^{H}	OM (%)	Total N (%)	Available P (mg/kg soil)	Available Ca (mg/kg soil)
Greater Accra	5.40-8.20	0.10-1.70	0.05-0.90	0.80-144.00	14.00-147.00
Western	3.80-7.10	1.00-5.70	1.00-7.50	0.40-11.30	28.00-420.00
Ashanti	4.30-7.80	1.50-3.00	0.10-0.30	0.10-12.00	50.00-100.00
Brong Ahafo	3.50-6.70	0.30-1.70	No data	0.10-64.30	16.00-140.00
Northern	4.50-6.70	0.60-2.00	0.02-0.05	2.50-10.00	45.00-90.00
Upper West	6.00-6.80	0.50-1.30	0.01-0.07	2.00-7.40	52.00-152.00
Upper East	5.10-6.80	1.10-2.50	0.06-0.14	1.80-14.80	44.00-152.00

Source: Wood (2013)

Field Preparation, Experimental Materials, and Planting

Before planting, the field was ploughed and harrowed. For the investigation, *Striga gesnerioides* and three varieties of cowpea seeds were employed. The Savanna Agricultural Research Institute (SARI) of the Council for Scientific and Industrial Research (CSIR), located in Nyankpala, Ghana, provided the three cowpea cultivars and *Striga gesnerioides* seeds. Three types of cowpea and *Striga gesnerioides* seeds were sown. The cowpea types were Wan-kai, Padi-tuya, and Kirk-house. Both *Striga* and cowpea seeds were sown at stake on the prepared plots in the experiment, with a sowing depth of 1-2 inches. After being thoroughly combined with fine sand and sieved through a 250 µm sieve, *Striga* seeds were placed in the planting holes. Approximately 2,500 germinable *Striga* seeds were applied to each cowpea hole using the sand-*Striga* combination, which had a 1: 99 by count ratio, in accordance with IITA's (1991) protocol. A coke bottle cap or lead was used to collect the *Striga* seed-sand combination, which was then poured into holes that held two cowpea seeds. The mixture was 1% germinable *Striga* seed-sand mixture was based on a preset 70% purity and 65% germination of the *Striga* seed according to the protocol of (IITA, 1991). The control plots were plots that were not infested with *Striga*.

Experiment Design

A randomized complete block design was used to lay the field by lining and pegging. Two experiments were conducted simultaneously, in which one experiment was used as control (non-infested) and one experiment was infested with *Striga*. Both the *Striga* infested and non-infested experiments were replicated three times. There were 2 m alleys between blocks/replications. Each plot was made of a 2m-row with ten plants in each row. The plot size in both experiments were 1.2 m^2. Intra row spacing was 20 cm and inter row spacing was 60 cm. There were three plots in each replication. Therefore, each of the *Striga*-infested and non-infested experiments contained nine (9) plots; bringing the total number of plots of the entire study to eighteen (18).

Cultural Practices

A hoe was manually used in controlling weeds at three (3) weeks after planting, and was repeated at the fifth (5th) week. Weeding was not done again in the subsequent weeks, in order to avoid destroying the *Striga* plants. Insecticide, K. Optimal was applied every two weeks at the rate, 25 ml of 7.5 liters of water using 15-liter knapsack for both plots to control field pest. There was no fertilizer applied.

Data Collection and Analysis

Data were recorded on growth parameters such plant height, number of leaves, number of branches, leaf area, and days to 50% flowering. The *Striga*-infested and non-infested studies were evaluated every two weeks. Using a tape measure, the height of each plant in each plot was measured from the base to the youngest epical leaf in order to calculate the plant height. The number of leaves per plant was determined by counting the number of leaves on each plant in each plot. Additionally, each plot's branch count per plant was counted and recorded. First, the length and width of the leaves were measured in order to calculate the leaf area. As suggested by Lindsay *et al.* (1983), the leaf area was ultimately determined by multiplying the product of the leaf length and leaf width by a constant (2). The number of days it took for 50 % of the plants in each plot to flower was used to calculate the days to 50 % flowering.

Grain yield per plot, total grain yield per hectare, nodule weight, dry biomass accumulation, number of pods per plant, pod length, number of seeds per pod, width and length of seeds, 100-seed weight, and other yield component data were also measured. Each plot's three (3) plants were uprooted, and the plants' nodules were all removed. A digital scale was then used to determine the nodule weight. Five (5) plants were removed from each plot in order to estimate the dry biomass. The plants were dried in an oven set to 80°C for 72 hours. A beam balance was then used to weigh the dry biomass. The dry biomass weight per plot was then calculated from the resultant weight. The other plots were subsequently subjected to the same process.

By selecting five (5) random plants per plot, counting the number of pods on each plant, and calculating the average number of pods, the number of pods per plant was ascertained. The pod length was measured using the measuring tape by taking pod length of five (5) random pods on a plot and taking the average pod length. Ten (10) pods were selected from each plot, and the number of seeds in each pod was counted. The average number of seeds was then calculated and recorded as the number of seeds per pod. By sampling five (5) seeds and measuring their length and width, the grain/seed length and width were determined using a vernier calliper. After that, the average seed length and width were calculated and recorded as seed length and seed width. A digital scale was used to weigh 100 grains or seeds that were sampled from each plot in order to determine the 100-seed weight. To calculate the grain yield in each plot, the grain yield per plot was measured. This was done by weighing the grains/seeds in each plot by using a beam balance. The total grain yield was determined by summing up all the individual plot yields for each variety, and the resultant total plot yields were later extrapolated to kg/ha basis. This was then recorded as total grain yield in kilograms per hectare.

The Gent Stat statistical software, version 12, was used to examine the data for the *Striga*-infested and non-infested studies independently. The means were then separated using the Least Significant Difference (LSD) at the 5% level of probability after the Analysis of Variance (ANOVA) was calculated. The link between the growth and yield metrics in the *Striga*-infested and non-infested (control) studies was also ascertained by correlation analysis.

Gent Stat statistics package edition 12 was also used to combine and evaluate the data from the *Striga*-infested and non-infested studies. The means were then separated using the Least Significant Difference (LSD) at the 5% level of probability after the Analysis of Variance (ANOVA) was calculated. The link between the growth and yield metrics in the Striga-infested and non-infested (control) studies was also ascertained by correlation analysis.

Results and Discussion

Plant Growth and Leaf Development

Plant Height

The *Striga gesnerioides* infection has a considerable impact on plant height. The affected plants showed a significant ($P<0.05$) difference in height (Table 3). Additionally, there were notable significant ($P<0.05$) variations in plant height among the cultivars.

Table 3: Combined analysis of variance for cowpea growth and yield components as affected by the infestation of Striga gesnerioides

Source of variation	df	Plant height (cm)	Leaves per plant	Branches per plant	Leaf area (cm^2)	100-seed weight (g)	Pod length (cm)	Grain yield (kg/Plot)	Pods per plant	Seeds per pod	Biomass yield (kg/plot)
Variety (V)	2	0.001	0.005	0.001	0.043	0.653	0.011	0.001	0.004	1.000	0.002
Treatment (T)	1	0.023	0.037	0.0475	0.009	0.044	1.000	0.069	0.667	0.02	0.539
VxT	5	0.228	0.298	0.177	0.676	0.812	0.767	0.988	0.969	0.901	0.975
Residual	10										
Total	20										
SE		0.593	3.22	0.096	4.98	0.419	0.869	0.035	5.364	0.289	1.049
CV (%)		2.1	4	0.4	6.1	2.4	4.8	4.7	17.8	2.0	3.8

SE = Standard Error; CV = Coefficient of Variation

Table 4: Influence of Striga gesnerioides on plant height, number of leaves, leaf area and number of branches of cowpea during the 2023 cropping season

Variety	Plant height (cm)		Number of leaves		Leaf area (cm^2)		Number of branches	
	Striga-Infested	Non-Infested	*Striga*-Infested	Non-Infested	*Striga*-Infested	Non-Infested	*Striga*-Infested	Non-Infested
Kirk-house	21.75	24.6	37.36	72.0	59.7	73.8	22.4	28.4
Padi-tuya	23.68	26.4	47.11	53.2	75.8	89.8	16.9	29.4
Wan-kai	20.00	23.8	37.11	67.4	85.4	88.9	21.6	16.3
Mean	21.81	24.9	40.53	64.2	73.6	84.2	20.3	24.7
SEM	2.107	4.16	3.259	8.10	8.57	11.88	4.88	3.53
LSD (0.05)	3.549	3.25	3.495	19.48	23.79	15.56	13.01	9.81

SEM = Standard Error of Means; LSD = Least Significant Difference; Measurements were done at 6 weeks after planting

Among the *Striga*-infested cultivars, Padi-tuya produced the tallest plants (23.68 cm), while Wan-kai produced the shortest plants (20.00 cm) (Table 4). It is possible that the parasitic *Striga* might have released some chemical toxins which inhibited the growth and development of host, resulting in the significant variation in plant height among the infested cowpea varieties. Botanga and Timko (2005) also observed that the exchange of chemicals is bidirectional and that the parasite possibly releases some toxins that inhibit the growth and development of the host plants. The tall plants such as Padi-tuya might have produced necrotic lesions on the *Striga* attachment site of their roots, thereby preventing the *Striga* haustoria from getting attached to the host root, resulting in the production of taller plants. This study confirms the findings of Kamara *et al.* (2008) and Carsky *et al.* (2003) who observed that there were differences in the growth of *Striga* on cowpea varieties.

Compared to their counterparts in the non-infected plots, the majority of the genotypes cultivated in the infested plots were shorter. The *Striga*-infested treatments had the lowest mean plant height of 21.81 cm, whereas the non-infested (control) plants had the highest mean plant height of 24.9 cm. Because *Striga* plants compete with the host plants for nutrients, water, light, and space, the observation here suggests that *Striga gesnerioides* may have contributed to the host plants' decreased growth. Wan-kai produced the lowest plant height of 23.8 cm, whereas Padi-tuya produced the highest of 26.4 cm for the control (non-infested plants) (Table 4). However, there were no appreciable variations in plant height across the three types of cowpea.

Leaf Area

Striga infestation significantly reduced leaf production, leaf area and branch development. Among the *Striga*-infested treatments, the variety Wan-kai produced the largest leaf area (85.4 cm^2), whereas Kirk-house produced the smallest leaf area (59.7 cm^2). In addition to serving as a sink, *Striga* also has a significant pathogenic impact on the host, which inhibits the susceptible host's ability to grow and develop. According to Graves *et al.* (1989), the parasitic plant lowers photosynthesis in the host plant, which inhibits growth. The authors also noted that *Striga's* effect on host photosynthesis was responsible for almost 80% of the decline in host growth rate.

The control varieties differed significantly ($P<0.05$) in leaf area (Table 3). The variety Padi-tuya produced the largest leaf area (89.8 cm^2) among the non-infested (control) plants, whereas Kirk-house produced the smallest leaf area (73.8 cm^2) (Table 4). Different genetic variations may have contributed to the notable variance in leaf area among the different non-infested plants. The mean leaf area of the *Striga*-infested treatments was 73.6 cm^2, while the non-infested cowpea plants had the highest mean leaf area of 84.2 cm^2. *Striga* infection might have decreased growth promoters, but increased growth inhibitors in the host resulting in the reduction of the leaf area among the infested cowpea varieties. As a result, the infested plants' leaf area was 12.59 % smaller than that of the uninfested plants. A number of authors (Gebremedhin *et al.*, 2000; Gurney *et al.*, 1995; Frost *et al.*, 1997; Taylor *et al.*, 1996) have reported that the leaf number and area were reduced by 10 and 34%, respectively, as a result of *Striga* infestation.

Number of Leaves

For leaf production, there was a significant ($P<0.05$) difference among the *Striga*-infested cultivars (Table 3). According to Table 4, Padi-tuya had the most leaves (47), whereas Kirk-house and Wan-kai had the fewest (37). In terms of leaf production, Padi-tuya differed significantly from the other two varieties. The notable difference in leaf output among the *Striga*-infested cultivars may have resulted from differences in the cowpea plants' synthesis of strigolactones, which initiate *Striga* germination and development. Very little or no production of strigolactones in a particular variety ensures that very few or no *Striga* germination occurs, and therefore the plant is not parasitized by the *Striga*, and this will be the bane for production of more leaves. Therefore, a cowpea variety that produces little or no strigolactones is deemed tolerant to *Striga* infestation. On average, the infested plants produced the fewest leaves (41), whereas the non-infested types produced the most (64). In addition to the inherent genetic heterogeneity of the cowpea varieties and variations in the experimental field's soil fertility, haustorial initiation of *Striga* may also be responsible for the variation in leaf production.

The number of leaves generated by the non-infested (control) plants varied significantly ($P<0.05$). Of the control plants, Kirk-house produced the most leaves (72), while Padi-tuya produced the fewest (53). Variability in the environment and/or soil fertility may have contributed to the difference in leaf production.

Number of Branches

The *Striga*-infested cowpea plants varied significantly ($P<0.05$) in terms of branch formation (Table 3). With 22 branches, Kirk-house had the most, while Padi-tuya had the fewest (17 branches) (Table 4). The notable variance in branch production among *Striga*-infested cowpea plants was most likely caused by differences in necrotic lesion generation across the infected host plants. Averagely, the non-infested varieties produced the highest mean of 25 branches, whilst the infested plants recorded the lowest mean of 20 branches. The variation between the *Striga*-infested and non-infested varieties for branch production was probably due to the *Striga* infestation. The non-infested cowpea plants also varied significantly ($P<0.05$) among themselves in terms of branch production (Table 3), with Padi-tuya producing the highest branches of 29 whilst Wan-kai produced 16 branches. The variability might have been caused by inherent genetic differences among the cowpea plants.

Nodule Development and Biomass Production

Dry Biomass

The dry biomass produced by the cowpea cultivars varied significantly ($P<0.05$) (Table 3). Wan-kai had the lowest dry biomass of 41.2 g, while Kirk-house recorded the maximum dry biomass of 62.7 g for the *Striga*-infested cultivars (Table 5). Variations in the host plants' resistance mechanisms may be the cause of the variation in dry biomass in this investigation. It is possible that the *Striga* haustoria failed to penetrate the root cortex and/or the endodermis of some of the cowpea plants, and as such could not parasitize such plants. This might have resulted in the production of relatively more dried biomass as compared to the parasitized plants. The mean dry biomass weight of the *Striga*-infested plants was generally lower than that of the non-infested crops. The *Striga*-infested genotypes had the lowest mean dry biomass of 52.3 g, while the control (non-infested) cowpea plants had the highest mean dry biomass of 70.0 g (Table 5). The *Striga* infection could have impeded the stomatal conductance of the affected cowpea plants, resulting in reduced photosynthates accumulation, and subsequently reduced dry biomass production. The observation made here is in support of the findings of Adetimirin *et al.* (2000) that *Striga* reduces the height, dry matter and grain yield of maize, and the reductions were dependent on host genotypes.

Table 5: Influence of Striga on dry biomass, nodule number, nodule weight, and number of pods of cowpea during the 2023 cropping season

Variety	Dry biomass (g)		Nodule number		Nodule weight (g)		Number of pods/plant	
	Striga-Infested	Non-Infested	*Striga*-Infested	Non-Infested	*Striga*-Infested	Non-Infested	*Striga*-Infested	Non-Infested
Kirk-house	62.7	64.0	6.7	54.3	0.00	2.00	32.00	32.3
Padi-tuya	53.0	64.0	26.3	15.0	1.00	0.83	32.67	32.3
Wan-kai	41.2	83.0	9.3	25.3	0.83	0.83	25.67	26.0
Mean	52.3	70.0	14.1	31.6	0.61	1.22	30.11	30.2
SEM	10.68	31.5	12.28	22.52	0.680	0.518	1.721	2.55
LSD (0.05)	29.65	87.5	18.09	62.53	0.89	1.439	4.779	7.09

SEM = Standard Error of Means; LSD = Least Significant Difference; Measurements were done at 6 weeks after planting

Number of Nodules

According to Table 5, the variety Padi-tuya yielded the most nodules (26) while Kirk-house produced the fewest (7). In terms of nodule production, Padi-tuya and Kirk-house differed significantly. The presence of physical barriers and antibiosis on roots as well as the low production of haustorial initiation factors among the Padi-tuya, probably was the reason why the variety produced relatively more nodules as compared to Kirk-house and Wan-kai. Mohamed *et al.* (2010) made similar observation. Generally, the non-infested varieties produced the highest mean of 32 nodules, whilst plants that are infested had the lowest mean of 14 nodules. *Striga* parasitism may have induced reduction in host photosynthesis among the *Striga*-infested varieties which resulted in the reduction in nodule production.

Among the control (non-infested) plants, Kirk-house recorded the highest number of 54 nodules whiles Padi-tuya produced the lowest of 15 nodules. The three cowpea varieties produced statistically similar number of nodules, probably as a results of similarity in the genetic make-up of those varieties.

Nodule Weight

Nodule weight of cowpea varieties was influenced by *Striga gesnerioides* infection. Among the *Striga*-infested plants, the variety Padi-tuya had the largest nodule weight (1 g), whereas Kirk-house had the lowest nodule weight (0 g) (Table 5). Significant variation among the varieties for nodule weight might be attributed to the diversion of soluble phosphate compound from nodule development to the use of *Striga* plants. Tolerant varieties which produced heavier nodules might have produced low germination stimulant resulting in production of heavier nodules as observed by Mohamed *et al.* (2010). *Striga* parasitism may have also induced reduction in host photosynthesis among the less tolerant varieties which resulted in the reduction in nodule production. Generally, the non-infested plants produce a mean nodule weight of 1.22 g whilst the infested varieties recorded a mean nodule weight of 0.61 g.

Number of Pods Per Plant

Striga infection did not significantly (P>0.05) affect cowpea pod output (Table 3). Of the type of plants afflicted with *Striga*, the variety Padi-tuya produced the most pods (33), whereas Wan-kai produced the fewest (26) (Table 5). Generally, non-infested varieties produced similar numbers of pods, with Padi-tuya and Kirk-house recording the highest number of 32 pods each, whilst Wan-kai recorded the lowest of 26 pods. It is possible that the cowpea varieties were genetically similar resulting in the production of similar number of pods. *Striga* infestation to a larger extent, affect time of flowering, and this influences pod production. Earliness in flowering results in relatively more pod production as compared to delayed flowering.

Grain Yield and Yield Related Components

Grain Yield

Striga infection had a significant (P<0.05) impact on cowpea grain yield (Table 3). Among the *Striga*-infested cultivars, the variety Kirk-house had the highest grain production (0.750 kg/plot), whereas Wan-kai had the lowest (0.540 kg/plot) (Table 6). It's possible that *Striga* parasitism caused the less tolerant cultivars to reduce their host photosynthesis, which in turn decreased grain yield. The diversion of photosynthates produced by cowpea plants from grain development to *Striga* plant development may be the cause of the notable variance in grain production among the cowpea plants. In general, the control plants outperformed the *Striga* afflicted plants by a large margin. The average grain yield of the infested plants was 0.656 kg/plot, compared to 0.858 kg/plot for the control plants. The parasite's inhibition of root nodulation and growth may be the cause of the affected plants' decreased grain output. According to Singh and Emebeche (1990), the level of yield reduction might have been influenced by the time and level of infection.

For grain yield, significant variation also occurred among the non-infested varieties. Kirk-house had the highest grain yield of 0.957 kg/plot whilst Wan-kai produced the lowest grain yield of 0.747 kg/plot among the control (non-infested) plants. Variation in grain yield among the control plants might have been caused by inherent genetic variability among the non-infested plants.

Table 6: Influence of Striga on length of pod, number of seeds per pod, 100-seed weight, and yield of grain of cowpea during the 2023 cropping season

Variety	Pod length (cm)		Number of seeds/pod		100-seed weight (g)		Grain yield (kg/plot)	
	Striga-Infested	Non-Infested	*Striga*-Infested	Non-Infested	*Striga*-Infested	Non-Infested	*Striga*-Infested	Non-Infested
Kirk-house	16.00	16.33	16.00	15.67	14.67	14.67	0.750	0.957
Padi-tuya	18.03	17.70	13.67	14.00	19.67	19.33	0.677	0.870
Wan-kai	20.37	19.37	13.33	13.33	18.00	18.33	0.540	0.747
Mean	18.13	17.80	14.33	14.33	17.44	17.44	0.656	0.858
SEM	0.790	1.620	1.106	0.943	0.430	0.923	0.1300	0.1359
LSD (0.05)	2.194	4.498	2.069	2.618	1.195	2.562	0.1903	0.2004

SEM = Standard Error of Means; LSD = Least Significant Difference; Measurements were done at 6 weeks after planting

Hundred-Seed Weight

The infested cowpea cultivars showed significant (P<0.05) variation in 100-seed weight (Table 3). Of the *Striga*-infested cultivars, Padi-tuya had the highest 100-seed weight (19.67 g), whereas Kirk-house had the lowest (14.67 g) (Table 6). One possible explanation for the variance in seed weight among cowpea types is that the host plants' varying rates of stomatal conductance lead to less complicated sugar buildup, which is necessary for grain filling. According to Kim *et al.* (2002), tolerant cultivars frequently yield two to two and half times as much as susceptible cultivars, particularly in *Striga*-infested environments, and are not significantly impacted by yield decrease. Among the control (non-infested) plants, Padi-tuya produced the highest 100-seed weight (19.33 g), whereas Kirk-house produced the lowest (14.67 g). The variation in grain weight among the control plants might have been caused by soil variability at the experimental site.

Number of Seeds/Pod

Table 3 shows that the quantity of seeds produced in cowpea pods varied significantly (P<0.05) among infested plants, but not significantly (P>0.05) among non-infested cowpea cultivars. Of the *Striga*-infested plants, Wan-kai had the fewest seeds per pod (13), whereas Kirk-house had the most (16 seeds per pod) (Table 6). With Kirk-house producing the most seeds (16 seeds per pod) and Wan-kai producing the fewest (13 seeds per pod), the non-infested cultivars generally produced statistically comparable amounts of seeds per pod. It is reported that a vascular connection is established when *Striga* infest its host, allowing the weed to imbibe water and nutrients that are essential for its growth and development (Kamara *et al.*, 2008).

Striga Emergence and Intensity

Striga Rating

According to Kim *et al.* (2002), when evaluating crop genotypes for resistance to *Striga* infestation, *Striga* rating was a more suitable method. According to the infested varieties' mean *Striga* plant rating (Table 7), Padi-tuya received a grade of 2, indicating that it can withstand *Striga*. Wan-kai, the variety, received a rating of 4. It is probable that all genotypes with lower *Striga* ratings were more resistant to *Striga* infection than those with higher ratings. The development of necrotic areas at the *Striga* attachment sites on the cowpea roots may be the cause of some genotypes' high tolerance to *Striga*, which prevents the *Striga* haustoria from attaching to the roots of the cowpea plant. This is in consonance with the observation made by Ejeta *et al.* (2000) that the development of necrotic lesions on the root of cowpea causes poor development leading to the death of attached *Striga* on the host. The limited synthesis of host plant root exudate chemicals, which are necessary for *Striga* seed germination, may possibly be the cause of some cowpea genotypes' great tolerance to *Striga*.

Striga Count

Adeosun *et al.* (2001) had described *Striga* emergence and *Striga* count as parameters to assess the tolerance level of crop genotypes. However, Kim *et al.* (2002) reported that it was more appropriate to use *Striga* rating in assessing crop genotypes for tolerance to *Striga* infestation. Due to differences in the plants' resistance to *Striga* infestation, the investigation revealed a considerable range in *Striga* count among *Striga*-infested plants. Padi-tuya recorded 0 and 2 *Striga* plant emergence at eight and ten weeks after planting respectively (Table 7). The varieties Kirk-house and Wan-kai both recorded 1 and 5 *Striga* plant emergence at eight and ten weeks after planting respectively. The implication is that all the cowpea varieties that recorded zero *Striga* emergence would probably be more tolerant to *Striga* than those which recorded higher numbers of *Striga* plants germination. Therefore, Padi-tuya would probably be more tolerant to *Striga gesnerioides* infestation. Lynn and Chang (1990) also observed that the high tolerance to *Striga* of some genotypes may be due to the low production of host plant root exudate compounds that are essential for *Striga* seed germination. The delay of witchweed emergence on resistant genotypes might partly explain why they do not significantly loose their yield under *Striga* infestation (Kamara *et al.*, 2008). According to Alonge *et al.* (2005), even though there are few attached *Striga* on resistant varieties, in most cases, it is likely that the seeds of these parasites contain toxins which leaked into the soil and hindered the root growth. This might lead to insufficient absorption of nitrogen and other nutrients for vegetative growth, which would lower grain output.

Table 7: Variation in Striga count and Striga rating of cowpea varieties during field screening in the 2023 cropping season

Variety	Striga count at 8 WAP	Striga count at 10 WAP	Striga rating at 10 WAP
Kirk-house	1	5	2.33
Padi-tuya	0	2	2.00
Wan-kai	1	5	3.67
Mean	0.67	4.00	2.66
SEM	0.60	0.33	0.60
LSD (0.05)	2	1	1.02

Correlation Analysis for Growth and Yield Parameters

Correlation analysis was computed for all the phenotypic characters and the results show a significant relationship among most of the characters. The number of pods per plant (0.5845**) and number of seeds per pod (0.6452***) were positively and substantially ($P<0.05$) related with the grain yield (Table 8). It is implied that grain yield rises in tandem with increases in the quantity of seeds per pod and pods per plant, and vice versa. The results corroborate with the observation made by Padi (2003) and Ba *et al.* (2004) who reported a positive correlation of grain yield with pods per plant. However, the biomass yield (-0.5183**) of cowpea plants and grain yield showed a negative but significant ($P<0.05$) association.

Additionally, *Striga* count at 10 WAP was negatively but significantly ($P<0.05$) associated with plant height (-0.0955**), number of branches per plant (-0.2884*), and leaf area (-0.0171**), according to the correlation analysis. Additionally, the number of pods per plant (-0.0413*), 100-seed weight (-0.2348***), and grain production per plot (-0.0133**) showed a negative but significant correlation with the *Striga* rating at 10 WAP. This indicates that high rate of *Striga* emergence and *Striga* intensity could be responsible for the low grain and biomass yield among the cowpea varieties. Grain yield did not, however, significantly ($P>0.05$) correlate with plant height (-0.1839 ns), leaf area (-0.4583 ns), number of branches per plant (0.0284 ns), 100-seed weight (-0.1974 ns), or pod length (-0.3188 ns), according to the correlation analysis.

Table 8: Correlation coefficients among phenotypic parameters measured as influenced by Striga gesnerioides

	Plant Height (cm)	Branches per Plant	Leaf Area (cm^2)	Pods per Plant	Seeds per Pod	100 Seed Weight (g)	Pod Length (mm)	Grain Yield per Plot (kg/plot)	Biomass Yield (kg/plot)
Plant Height (cm)									
Branches per Plant	-0.0698 ^{ns}								
Leaves per Plant	-0.0914 ^{ns}	0.9687***							
Leaf Area (cm^2)	0.4636*	-0.0054 ^{ns}							
Nodules Weight (g)	0.0544 ^{ns}	-0.1364 ^{ns}	-0.0551 ^{ns}						
Striga count at 10 WAP	-0.0955 **	-0.2884 *	-0.0171 **						
Pods per Plant	-0.1576 ^{ns}	0.1249 ^{ns}	-0.026 ^{ns}						
Seeds per Pod	-0.1085 ^{ns}	0.0935 ^{ns}	-0.384 ^{ns}	0.2856 ^{ns}					
100 Seed Weight (g)	0.2355 ^{ns}	-0.1617 ^{ns}	0.0242 ^{ns}	-0.1061 ^{ns}	-0.7013***				
Pod Length (mm)	0.1404 ^{ns}	-0.101 ^{ns}	0.2128 ^{ns}	-0.296 ^{ns}	-0.6562***	0.63***			
Grain Yield per Plot (kg/plot)	-0.1839 ^{ns}	0.0284 ^{ns}	-0.4583 ^{ns}	0.5845**	0.6452***	-0.1974 ^{ns}	-0.3188 ^{ns}		
Striga rating at 10 WAP	-0.1685 **	-0.1378 *	-0.0823 **	-0.0413 *	-0.2329 ^{ns}	-0.2348***	0.5849ns	-0.0133 **	
Biomass Yield (kg/plot)	0.5673**	0.179 ^{ns}	0.7928***	-0.354 ^{ns}	-0.2916 ^{ns}	-0.1209 ^{ns}	0.1213 ^{ns}	-0.5183 ^{ns}	
Total Grain Yield (kg/ha)	-0.1839 ^{ns}	0.0284 ^{ns}	-0.4583 ^{ns}	0.5845**	0.6452***	-0.1974 ^{ns}	-0.3188 ^{ns}	1***	-0.5183**
Total Biomass Accumulation (kg/ha)	0.5673 ^{ns}	0.179 ^{ns}	0.7928***	-0.354 ^{ns}	-0.2916 ^{ns}	-0.1209 ^{ns}	0.1213 ^{ns}	-0.5183 ^{ns}	1***

**Significant at p<0.05, **Significant at p<0.01, ***Significant at p<0.001 and ns Non significant at p>0.05; WAP = weeks after planting*

Conclusion

Cowpea growth and yield were significantly affected by *Striga gesnerioides* infestation, with notable reductions observed in plant height, leaf area, number of leaves and branches, biomass, pod production, 100-seed weight, and grain yield. Among the three varieties tested, Padi-tuya consistently outperformed Kirk-house and Wan-kai across these traits, indicating a higher tolerance to Striga stress.

Given the vital role of cowpea as a nutrient-rich crop for food security in Ghana and across Africa, the development and promotion of tolerant cultivars are crucial. The substantial genetic variability within cowpea provides opportunities for improvement, particularly against stresses such as Striga infestation, pests, diseases, drought, and soil salinity. In this context, Padi-tuya demonstrates strong potential as a resilient variety that can support higher biomass and grain productivity in Striga-infested fields, especially within Ghana's Guinea Savannah agro-ecological zone.

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Author’s Contributions

Alhassan Bawa: Research designed, analysis of data, written first draft and proof reading manuscript.

Ismael Yakubu and Yussif Seidu: Data collection, statistical analysis and proof reading drafted manuscript.

Ethics

This article is original and contains unpublished materials. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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