agronomy

MDPI

Article

Breeding Cowpea for Adaptation to Intercropping for Sustainable Intensification in the Guinea Savannas of Nigeria

Lucky O. Omoigui [1,2,*], Alpha Y. Kamara [1], Abdulwahab S. Shaibu [3], Kamaluddin T. Aliyu [1], Abdullahi I. Tofa [1], Reuben Solomon [1] and Olalekan J. Olasan [4]

1 International Institute of Tropical Agriculture (IITA), Ibadan 200211, Nigeria; l.omoigui@cgiar.org (L.O.O.); a.kamara@cgiar.org (A.Y.K.); k.tijjani@cgiar.org (K.T.A.); a.tofa@cgiar.org (A.I.T.); r.solomon@cgiar.org (R.S.)
2 Department of Plant Breeding and Seed Science, College of Agronomy, University of Agriculture, Makurdi 970101, Nigeria; luckyomoigui@gmail.com
3 Department of Agronomy, Bayero University Kano, Kano 700001, Nigeria; asshuaibu.agr@buk.edu.ng
4 Plant Biotechnology Unit, Department of Botany, Federal University of Agriculture, Makurdi 970101, Nigeria; olasan.olalekan@uam.edu.ng
* Correspondence: l.omoigui@cgiar.org or luckyomoigui@gmail.com

Abstract: Cowpea is a multifaceted crop; however, considerable challenges affect the production of this crop despite its comparatively better adaptation to harsh environments. Most smallholder farmers in West Africa cultivate this crop in intercropping systems where its low plant population does not allow the full expression of the cultivars' yield potential. This is because most varieties currently grown in intercrop have been developed in and for monocropping, although some breeding programs recently have focused on intercrop systems. This study, therefore, aimed to evaluate the performance of some newly developed cowpea breeding lines for adaptation to intercropping systems. Firstly, an on-station field experiment was conducted in 2018. The selected promising lines and a standard check were evaluated in three locations in an intercropping system and on-farm trials. Significant differences were observed among the cowpea genotypes for all the traits measured. Two improved lines, UAM14-122-17-7 and UAM14-123-18-3, had superior grain and fodder yields under sole and intercropping systems and in different agroecological systems, revealing their adaptability. Based on our findings, UAM14-122-17-7 and UAM14-123-18-3 are recommended for a cereal-cowpea mixture because they are adapted to intercropping and produce high-grain yield under intercrop and sole-cropping systems.

Keywords: cowpea; cropping system; on-farm evaluation

Citation: Omoigui, L.O.; Kamara, A.Y.; Shaibu, A.S.; Aliyu, K.T.; Tofa, A.I.; Solomon, R.; Olasan, O.J. Breeding Cowpea for Adaptation to Intercropping for Sustainable Intensification in the Guinea Savannas of Nigeria. *Agronomy* **2023**, *13*, 1451. https://doi.org/10.3390/agronomy13061451

Academic Editor: Rosa Porcel

Received: 28 April 2023
Revised: 20 May 2023
Accepted: 23 May 2023
Published: 24 May 2023

1. Introduction

Cowpea is an important grain legume crop, a major staple food for household nutrition and feed for animals in sub-Saharan Africa, especially in Nigeria. In West Africa, food security is built around a few crops, and cowpea (*Vigna unguiculata* (L.) Walp) is one of them. Cowpea is an important food security crop and a cheap protein source for over 72% of households in West Africa, particularly Nigeria. Cowpea plays an important role in human nutrition, health, food security, and income generation for both smallholder farmers and food vendors in the region [1]. The crop is well adapted to the drier regions of the tropics, where other food legumes do not perform well. Cowpea has a high potential to increase farmers' and traders' incomes, reducing poverty and contributing to food and nutritional security. It also integrates well with different cropping systems and is a source of soil fertility enhancement. Women farmers constitute about 60% to 68% of cowpea production in Nigeria. It is an essential source of income for many farmers, including women, who prepare and sell snacks made from cowpea. It is also an essential component of the intensifying cropping system in the Guinea savannas of Nigeria. Despite the importance of the crop, the overall productivity is very low owing to several biotic and abiotic stresses, particularly getting suitable cultivars that fit in intercropping, which poses a threat to achieving the sustainable high productivity of the crop, especially in the intensifying cropping system [2].

Cowpea is predominantly grown in the drier areas of Nigeria's savannas; however, because of climate change and other environmental vulnerabilities in the dry areas, cowpea production is expanding into the Guinea savannas where the rainfall is sufficient to support the production of the crop. Although the sole cropping of cowpea is profitable, farmers continue to grow cowpea as an intercrop with other cereal crops such as maize, sorghum, and millet. This is because it fits well into the low input, labor-intensive tradition of growing crops in the region. The agricultural production systems in the Guinea savannas are characterized by intensification because of increasing population pressure and the limited potential for expansion of agricultural land [2]. Additionally, disease pressure is of major concern owing to the high humidity that is prevalent in the area. Most smallholder farmers in the Guinea savanna practice cereal–legume intercropping to mitigate the risks of crop failure in monocropping. Many studies have also shown that greater crop yields and the productivity of intercrops relative to sole crops can be achieved because of the complementary use of resources for growth by the intercrop components [3,4]. Therefore, to increase cowpea production and productivity in the region, the development of cowpea varieties that are high-yielding, resistant/tolerant to major foliar diseases and parasitic weeds (*Striga* and *Alectra*), possess farmers' and end-users' preferred characteristics, such as large seed size, seed color, and are adapted to intensifying cropping systems will expand the production of this crop in the Guinea savannas [5].

Several advantages are accruable when crops are intercropped [5]. These include the production of a greater yield on a given piece of land by making more efficient use of the available growth resources, improving soil fertility through biological nitrogen fixation with the use of legumes, and increasing soil conservation with a greater ground cover than sole cropping, as well as providing better lodging resistance for crops that are susceptible to lodging when grown as sole crops. Others include the reduction in pest incidence and provision of insurance against crop failure or unstable market prices for a given commodity. This provides greater financial stability than sole cropping, which makes the system particularly suitable for smallholder farmers and allows for lower input use through reduced fertilizer and pesticide requirements. However, intercropping cowpea with maize has the major weakness of a very low cowpea yield [6]. Cowpea farmers in the dry savanna areas of sub-Saharan Africa obtain low yields, estimated at about 350 kg ha^{-1} [6,7]. A major reason for the low productivity of cowpea in intercropping systems is shading from taller cereal plants [6]. The cowpea varieties selected for intercropping should have some morphological and physiological characteristics such as indeterminate growth habit, more branching, and tolerance to shading. The performance of cowpea intercropped with cereals is dependent on the growth habit of the cowpea crop. Indeterminate cowpea varieties with spreading growth habits normally performed better than the erect cowpea varieties because they are tolerant to shade [8]. Therefore, cowpea varieties that can produce good yields as sole crops and intercropped with maize will increase the productivity of the crop in the Guinea savannas where cowpea–maize intercropping is practiced.

Several studies have shown that the adoption of improved varieties for large-scale production plays a vital role in increasing productivity and net returns [9,10]. Therefore, the development of cowpea varieties that are high-yielding with a combined resistance to pests and diseases, with grain quality traits that meet the detailed set of attributes demanded by farmers and consumers, will boost cowpea production. This will also increase the acceptance rate of improved cowpea varieties and contribute to the enhancement of the cowpea value chain because market demand for grain encourages the farmers to grow the improved cowpea seed, which in turn promotes its adoption. In Nigeria, the low adoption rate of improved cowpea can partly be attributed to the development and release of cowpea varieties that do not align with consumer and market preferences, especially for seed quality traits such as seed color, texture, taste, and size [7]. Given the importance attached to cowpea in WCA, increasing its productivity when grown in different cropping systems combined with developing farmers' and end-users' preferred characteristics should be considered essential breeding objectives in Nigeria. Thus, the development of cowpea varieties that are high-yielding, adapted to intercropping, and possess market-preferred traits will boost the production and adoption of improved cowpea varieties in the Guinea savannas of Nigeria, especially with the changing climate conditions. Thus, the present study was conducted to (i) evaluate the agronomic performance and productivity of some new cowpea breeding lines under multiple cropping systems and (ii) identify suitable candidate lines with high-yield performance in the intercropping system that is predominant in the Guinea savannas of Nigerian.

2. Materials and Methods

2.1. Brief Description of the Breeding Lines

Three cowpea cultivars differing in seed size, maturity, day length, reactions to Striga and major diseases, taste, and growth habit were used for this study. A brief description of the parental materials used for the crosses follows.

BOSADP Brown is a photoperiod-sensitive local landrace popularly grown in northeast Nigeria because of its large seed size; it has a brown seed coat color and is suitable for intercropping. However, this cultivar is highly susceptible to *Striga gesnerioides* and bacterial blight. It is late maturing (90–95 days) with a prostrate growth habit. The large-sized seeds weigh about 30 g/100 seeds (Omoigui personal communication 2019).

YAMISRA is a photoperiod-sensitive local landrace popularly grown in northeast Nigeria, has a large seed size with a white seed coat color, is suitable for intercropping, and is resistant to bacterial blight. However, this cultivar is also susceptible to *Striga gesnerioides*. It is late maturing (80–90 days) with a prostrate growth habit. The large-sized seeds weigh about 28 g/100 seeds.

IT99K-573-1-1 is an IITA-improved variety. It was derived from an F5 selection from the cross IT93K-596-9-12 × IT86D-880. IT93K-596-9-12 involves IT90K-59 and IT86D-715 as parents, and IT86D-880 involves (IT82E-60 × TVu3000) × IT82D-716 as parents. IT90K-59 is a line derived from the backcross IT84S-2246-4/B301//IT84S-2246-4. IT86D-715 is derived from the double cross TVx 6332/TVx 3236//(Kamboinse local/TVx 946-2E). Kamboinse local is a landrace from Burkina Faso, and TVx 946-2E is derived from the cross IFH 503/IFH 44-5, both from Nigeria. TVx 3236 is derived from the cross TVu1509 × Ife Brown. TVx 6332 involves (TVx1193-9F × TVu2027) × TVu625 as parents. Thus, IT98K-573-1-1 has a wide genetic background. It is a semi-erect medium maturing variety with a medium seed size of about 19 g/100 seeds.

The three parental lines were involved in a crossing program in 2016 to generate a three-way cross hybrid (BOSADP × IT99K-573-1-1) × YAMISRA. In the F7, the best-performing lines were selected for preliminary and advanced yield trials. Based on the performance of the advanced yield trials, the promising candidate lines identified were selected for field evaluation and on-farm trials to determine their adaptation to an intercropping system, since the selection of the breeding lines occurred under a sole-cropping system.

2.2. Evaluation of the Derived Cowpea Lines for Grain Yield Performance and Other Important Traits

Twenty-four (24) of the derived lines (tagged UAM series) along with four improved varieties and one local cultivar used as checks (Table 1) were evaluated during the main cropping season of 2017 and 2018 in Makurdi, Benue State. Makurdi lies within 7°41′262″ N and 8°37′66″ E. The soil at the experimental site is sandy loam. The experimental design was a randomized incomplete block design with three replications. Each genotype was grown in a four-row plot, each row 4 m in length, spaced 0.75 m apart, with 0.25 m between plants within the row. Three cowpea seeds were sown per hill and later thinned to two plants per hill two weeks after planting to obtain a final population density of about 106,666 plants ha^{-1}. Similarly, at 2 weeks after planting, a compound fertilizer

(15–15–15 NPK) was applied at the rate of 15 kg ha^{-1}. Weeds were controlled manually throughout the cropping season.

Table 1. Description of the cowpea breeding lines used for the study.

Cowpea Line	Source of Breeding Line	Seed Color	Seed Size	Growth Habit
UAM15-1217-4	FUAM	Brown	Large	Semi-erect
UAM15-2157-4	FUAM	Brown	Large	Semi-erect
UAM15-1217-5	FUAM	Brown	Large	Semi-erect
UAM15-1218-8	FUAM	Brown	Large	Semi-erect
UAM15-L10-3	FUAM	Brown	Large	Semi-erect
UAM15-1271-3	FUAM	Brown	Large	Semi-erect
UAM15-118-5	FUAM	Brown	Large	Semi-erect
UAM15-1217-3	FUAM	Brown	Large	Semi-erect
UAM15-4915-5	FUAM	Brown	Large	Semi-erect
UAM14127-20	FUAM	Brown	Large	Semi-erect
UAM15-1371-7	FUAM	Brown	Large	Semi-erect
UAM15-L8-3	FUAM	Brown	Large	Semi-erect
UAM14-122-17-7	FUAM	Brown	Large	Semi-erect
UAM14-126-L33	FUAM	White	Medium	Semi-erect
UAM14-123-18-3	FUAM	Brown	Large	Semi-erect
UAM14-130-20-4	FUAM	Brown	Large	Semi-erect
UAM14-126-L2	FUAM	White	Medium	Erect
UAM14-126-L32	FUAM	White	Medium	Erect
UAM14-126-L35	FUAM	White	Medium	Erect
UAM14-126-L6	FUAM	White	Medium	Erect
UAM14-126-L30	FUAM	White	Medium	Erect
SAMPEA18	IITA	White	Medium	Erect
UAM14-126-L37	FUAM	White	Medium	Erect
FUAMPEA2	FUAM	Brown	Medium	Semi-erect
UAM14-126-L1	FUAM	White	Medium	Erect
UAM14-126-L34	FUAM	White	Medium	Erect
SAMPEA14	IITA	White	Medium	Erect
SAMPEA17	IITA	White	Medium	Erect
SAMPEA19	IITA	White	Medium	Erect
BornoBrown	Local cultivar	Brown	Medium	Indeterminate

FUAM = Federal University of Agriculture Makurdi, IITA = International Institute of Tropical Agriculture.

Data were collected from the two middle rows. Days to maturity were determined when senesced plants had reached harvest maturity and pods had turned brown. Grain yield was determined by harvesting the two middle rows (6 m^2) in each plot and drying the pods in the open air, after which the pods were threshed, weighed, and moisture content was measured using a Farmex MT-16 grain moisture tester. The grain yield was then adjusted to 13% moisture. Fodder weight after harvesting was determined by weighing fresh fodder samples (minimum of 300 g fresh weight) randomly collected from each plot, oven-dried at 60 °C for 48 h to constant weight, and weighed. The moisture percentage was used to adjust the dry weight to determine the fodder weight per plot and converted to kg/ha. One-hundred-seed weight (seed size) was determined and adjusted to 12% moisture content. Based on the performance of the cowpea lines, seven promising breeding lines and two standard checks were selected for further evaluation to determine their suitability for intercropping with maize in 2019 in two locations: Zaria in the northern Guinea savanna (NGS) and Makurdi in the southern Guinea savanna (SGS).

2.3. Evaluation of the Improved Cowpea Lines under Intercropping

The experimental design used was a split-plot with three replications. Two cropping patterns, cowpea relayed into maize (EVDT99) at 6 weeks after the first crop and sole cropping, were assigned to the main plots and cowpea variety as sub-plot. Seven cowpea lines including the commercial checks with contrasting growth habits were introduced into the maize crop 6 weeks after the maize was planted. The seven cowpea lines were also sole-planted at the time of introduction into the maize crop.

2.4. Planting and Cultural Practices

Before the first crop was established, the field was disc-harrowed and ridged. Three maize seeds were planted on ridges spaced 0.75 m apart at an intra-row spacing of 0.50 m and later thinned to 2 plants per hill to give a population of 53,333 plants ha^{-1}. At planting, fertilizer in the form of NPK 15:15:15 (N 15%: P_2O_5 15%: K_2O 15%) was applied at the rate of 15 kg each of NPK ha^{-1} to all plots. Nitrogen fertilizer was top-dressed in the form of urea at the rate of 30 kg N ha^{-1} at 5 WAP of maize. Cowpea was planted 6 weeks after maize. Two stands of cowpea seeds were planted between two hills of maize, which was equivalent to 0.25 m between the two hills of cowpea. The cowpeas were later thinned to 2 plants per hill to give a population of 106,666 plants per ha. Sole-cropped cowpea was planted on ridges 0.75 m apart with an intra-row spacing of 0.25 m, and three seeds were planted per hill and later thinned to two to give a cowpea population similar to that of maize. Insect pests of cowpea were controlled by spraying cowpea plants with Best Action (30 g L^{-1} cypermethrin + 250 g L^{-1} dimethoate; manufacturer: Modern Insecticides Ltd., Hyderabad, India) at the rate of 1 L ha^{-1} during floral bud formation, flowering, and podding stages.

Data were collected on days to 50% flowering, number of pods per plant, seeds per pod, biomass weight, grain yield, and 100-seed weight of cowpea. At harvest, central rows were harvested when the first flush of pods were matured and dry. Grain yield was based on all plants that were harvested from the two central rows of each plot and was reported on a 100% dry matter basis.

2.5. Field Layout

The experiment consisted of two cropping system patterns (Figure 1), including a sole-cropping pattern (with cowpea sown at 10.7 plants m^{-2}) and an intercropping pattern (with maize sown at 5.3 plants m^{-2} and cowpea sown at 10.7 plants m^{-2}). The cowpea lines (subplots). The cropping pattern is shown in Figure 1.

2.6. Assessment of Productivity

The partial land equivalent ration (LER) [11] was calculated using the equation as follows: Partial LER ($PLER_c$) for cowpea

$$PLER_c = Y_{cm} \text{ in intercropping} / Y_c \text{ in sole cropping}$$

where Y_{cm} is the yield of "cowpea under intercropping with maize" and Y_c is the yield of "cowpea" grown under sole cropping.

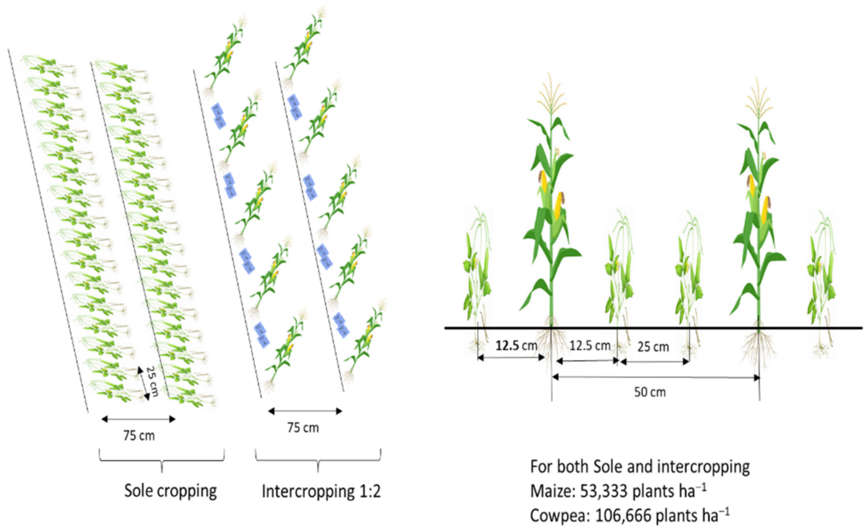

Figure 1. Experimental cropping patterns: cowpea monocropping; cowpea–maize intercropping plots (intercropping) with a seeding pattern 1:2 of maize and cowpea on the same row.

2.7. On-Farm Evaluation

Two promising candidate lines identified from the evaluation with good adaptability to intercropping with good yield, possessing farmer- and market-preferred traits, were recommended for on-farm evaluation under sole cropping with over 50 farmers participating in the evaluation in three locations (Makurdi, Ganjuwa, and Mokwa representing SGS and NGS).

2.8. Statistical Analysis

Analysis of variance (ANOVA) was carried out for data collected in each location and a combined ANOVA across locations was performed after Levene's test for homogeneity of variance had confirmed that data from individual environments (E) could be pooled. The ANOVA was conducted using the PROC MIXED procedure of SAS [12]. Differences between treatment means were compared with LSD at a 5% level of probability. An individual ANOVA was conducted for the locations used in determining the suitability of the improved cowpea lines for intercropping.

3. Results

3.1. Performance of Cowpea Genotypes

Significant differences ($p \leq 0.05$) were observed among the cowpea lines for all the measured traits under sole cropping (Table 2). Most of the cowpea lines reached 50% flowering within 43–49 DAS except for Borno brown, which flowered at 57 DAS. The earliest to reach 50% flowering were SAMPEA 19 and UAM14-126-l34. The improved lines varied in their days to 95% maturity (66–72 DAS) and were much earlier than Borno brown (78 DAS). UAM14-127-20 had the highest number of pods per plant (42.9), followed by UAM14-126-L2 (41.3). In the landrace check, the Borno brown used had fewer pods per plant when compared to the improved lines. For the number of peduncles per plant, UAM15-1371-7 had the highest number of peduncles, followed by SAMPEA 17. The 100-seed weight of the improved lines ranged from 19 (UAM14-126-L34)–31.5 g (UAM15-1217-4), while the commercial check varieties had a 100-seed weight of 14.3 (SAMPEA 19)–20.8 g (SAMPEA 18). For grain yield, UAM14-126-L2 had the highest grain yield (2207.00 kg ha^{-1}) followed by UAM14-122-17-7 (1958.00 kg ha^{-1}), UAM14-12-20 (1853.00 kg ha^{-1}), and UAM14-123-18-3 (1825.00 kg ha^{-1}), while Borno brown had the least grain yield of 989.00 kg ha^{-1}. The highest-yielding improved line had a 33% higher grain yield than the best-yielding check variety. The highest fodder yield of 5056 kg ha^{-1} was recorded by UAM14-126-L32 followed by UAM14-126-L35 (3778 kg ha^{-1}) and UAM14-126-L37 (3667 kg ha^{-1}). Some of the lines with a contrasting reaction to Striga under field conditions were genotypes for resistance to Striga.

Table 2. Grain yield (kg ha^{-1}) and other agronomic traits of cowpea genotypes evaluated on-station in Makurdi in 2018.

Genotype	DFF	D50F	D95M	Pod per Plant	Peduncle per Plant	Seed per Pod	100 Seed Weight (g)	Grain Yield (kg/ha)	Fodder Yield (kg/ha)
UAM15-1217-4	43.30	48.00	68.30	18.60	14.30	10.60	31.50	1033.00	2556.00
UAM15-2157-4	45.30	49.00	71.30	20.20	14.50	10.20	31.40	1677.00	2278.00
UAM15-1217-5	44.30	47.30	68.70	28.90	18.30	10.90	30.90	1050.00	2444.00
UAM15-1218-8	43.70	47.30	68.30	22.90	15.70	11.20	30.80	1368.00	3000.00
UAM15-L10-3	44.00	47.30	70.70	34.60	22.70	9.20	30.60	1646.00	2111.00
UAM15-1271-3	44.00	48.00	68.00	33.40	14.20	10.90	30.60	1441.00	2278.00
UAM15-118-5	44.70	47.30	69.70	23.90	16.40	10.30	30.50	1280.00	1889.00
UAM15-1217-3	44.30	46.70	70.30	23.90	18.80	9.80	30.40	1370.00	1889.00
UAM15-4915-5	44.00	47.30	71.00	19.50	16.30	9.00	30.10	1187.00	1611.00
UAM14 127-20	44.30	47.00	71.70	42.90	20.70	8.00	29.90	1853.00	1944.00
UAM15-1371-7	44.70	47.70	70.70	32.80	27.80	8.40	29.70	1338.00	2167.00
UAM15-L8-3	44.30	47.30	70.70	21.40	19.50	8.70	28.80	1417.00	2222.00
UAM14-122-17-7	45.70	48.00	71.30	33.90	21.90	11.40	28.00	1958.00	3611.00
UAM14-126-L33	41.30	45.30	69.00	26.10	19.50	10.60	27.60	1785.00	2500.00
UAM14-123-18-3	44.00	47.00	70.00	29.30	25.60	12.70	30.00	1825.00	3167.00
UAM14-130-20-4	42.30	46.00	68.70	28.50	21.30	11.10	25.20	1252.00	1500.00
UAM14-126-L2	38.30	45.00	69.70	41.30	23.10	11.30	23.00	2207.00	2333.00
UAM14-126-L32	44.70	48.00	71.70	28.70	17.10	11.90	22.50	1158.00	5056.00
UAM14-126-L35	40.00	46.30	71.70	33.90	22.30	12.70	21.60	1450.00	3778.00
UAM14-126-L6	42.00	45.30	70.00	25.50	20.10	10.80	21.60	1855.00	3167.00
UAM14-126-L30	41.00	47.00	72.70	25.90	18.80	13.20	21.60	1153.00	2833.00
SAMPEA 18	40.70	43.70	67.70	29.50	21.80	11.90	20.80	1492.00	1722.00
UAM14-126-L37	39.70	44.30	68.00	25.10	19.70	11.10	20.20	1662.00	3667.00
FUAMPEA 2	43.30	46.30	69.30	36.10	24.60	11.30	19.80	1194.00	2000.00
UAM14-126-L1	41.00	46.00	68.30	32.00	21.60	11.30	19.20	1685.00	2500.00
UAM14-126-L34	38.70	44.00	66.30	33.10	23.10	8.70	19.00	1603.00	3556.00
SAMPEA 17	42.30	46.30	68.00	41.10	27.60	11.40	18.60	1662.00	2278.00
SAMPEA 19	40.00	45.30	68.30	33.20	22.50	12.40	14.30	1583.00	3111.00
Borno Brown	47.00	57.70	78.00	15.80	9.70	10.70	20.50	989.00	3083.00
Mean	42.90	47.00	69.90	29.00	20.00	11.00	25.40	1488.70	2629.30
p-value	0.0023	<0.0001	<0.0001	0.0024	0.0032	<0.0001	<0.0001	0.0053	0.0023
SED	1.30	0.85	0.75	7.0	4.55	0.75	1.10	341.80	251.55

DFF = days to first flowering; D50F = days to 50% flowering; D95M = days to 95% maturity. Significant difference was observed at 5% level of probability.

3.2. Performance of Cowpea Breeding Lines under Intercropping

In addition to high yield, cowpea varieties must have specific attributes that provide the characteristics that farmers, consumers, and market demand require in the adoption of improved cowpea varieties. Based on this, five promising breeding lines with an indeterminate growth habit and some commercial varieties were evaluated in two cropping systems to determine their adaptability to intercropping. Although farmers frequently practice relay intercropping of cowpea with cereals, results have shown that this practice significantly reduces the grain yield of some varieties. The performance of the cowpea breeding lines evaluated in the maize–cowpea cropping systems indicated that the cowpea genotype UAM 14-122-17-7 produced the highest grain yield (1283 kg ha^{-1}) in Zaria when intercropped with maize, while under sole cropping the grain yield was 1994.0 kg ha^{-1}. However, the grain yields under both cropping systems were not statistically greater than the highest performing check IT89KD-288 with grain yields of 1162 and 1887.5 kg ha^{-1} under intercrop and sole cropping, respectively (Table 3). A similar trend was observed for UAM14-123-18-3. In Makurdi, UAM14-122-17-7 produced the highest grain yield when intercropped with maize and was comparable to the highest performing check IT89KD-288 (1192.5 kg ha^{-1}), suggesting that UAM114-122-17-7 is better adapted to intercropping than UAM14-123-18-3. All the cowpea genotypes produced the highest grain yield under sole-cropping than in intercropping. However, one of the breeding lines (UAM 14-122-17-7) and the commercial variety (IT89KD-288) popularly grown as intercrops in the Guinea savannas produced higher grain yields that were more than 1000 kg ha^{-1} under intercropping and sole-cropping (Table 3). In addition, grain yields were more reduced for the other cowpea breeding lines than for UAM114-122-17-7, UAM14-123-18-3, and IT89KD-288 when intercropped with maize and sole-cropped except in the Makurdi location, where UAM14-123-18-3 produced a grain yield that was less than 1000 kg ha^{-1}. The 100-seed weight was significant for all the cowpea genotypes evaluated. The different cropping systems did not significantly influence the 100-seed weight (Table 4). UAM14-122-17-7 and UAM14-123-18-3 recorded 100-seed ranges between 26 and 29 g/100-seed weight compared to the standard commercial check varieties, IT89KD-288 (17.7) and IT99K-573-1-1 (19.6) in Zaria. A similar trend was observed in Makurdi. However, a higher 100-seed weight was recorded in Zaria than in Makurdi. IT89KD-288 is an improved variety with white seed color, medium seed size, and an indeterminate growth habit. It is the only improved variety popular with the farmers for intercropping. However, the farmers in the Guinea savannas are increasingly demanding a variety with a large seed size, a brown seed coat color, and adapted to intercropping. Interestingly, UAM-14-122-17-7 possessed the characteristics demanded by the farmers and market in addition to high-grain yield, making the variety a suitable candidate replacement for IT89KD-288.

Table 3. On-station grain yield performance of cowpea genotypes under sole and intercrop systems in two locations in Nigeria in 2019.

	Intercrop	Sole	Mean	PLER$_c$	Intercrop	Sole	Mean	PLER$_c$
	Zaria (NGS)				Makurdi (SGS)			
Varieties	Grain Yield (Kg ha^{-1})				Grain Yield (Kg ha^{-1})			
IT89KD-288	1162.0	1887.5	1524.7	0.62	1192.5	1746.1	1469.3	0.68
IT99K-573-1-1	713.2	1999.9	1356.6	0.36	1019.2	1683.6	1351.4	0.61
UAM09-1046-6-1	587.7	1481.1	1034.4	0.40	586.6	1282.0	934.3	0.46
UAM09-1051-1	595.9	1346.1	971.0	0.44	496.6	1218.0	857.3	0.41
UAM14-122-17-7	1283.3	1994.0	1638.7	0.64	1148.5	1728.8	1438.7	0.66
UAM14 -123-18-3	956.4	1989.8	1473.1	0.48	761.4	1752.7	1257.1	0.43
UAM14-126-19-2	816.7	1687.9	1252.3	0.48	1303.8	1562.4	1433.1	0.83
UAM14-127-20-1-1	893.3	1518.6	1206.0	0.59	988.7	1481.8	1235.3	0.67
UAM14-130-20-4	848.0	1739.6	1293.8	0.49	647.8	1474.8	1061.3	0.44
Mean	872.9	1738.3	1305.6	0.5	905.0	1547.8	1226.6	0.58
SED	118.16	123.76	110.12	0.05	145.34	100.28	113.50	0.07
p-value	<0.0001	<0.0001			<0.0001	<0.0001		

PLERc = partial land equivalent ratio for cowpea. Significant difference was observed at 5% level of probability.

Based on the performances of the two new cowpea breeding lines, UAM14-122-17-7 and UAM14-123-18-3, the two breeding lines and the two commercial varieties currently used for intercropping by farmers were recommended for on-farm evaluation under farmer managed conditions in sole-cropping with over 50 farmers participating in the selected communities within three states in 2019 and 2020.

3.3. Assessment of Intercrop Productivity

Willey and Osiru [13] suggested the idea of the LER, and it is described as the proportionate land area required under a pure stand of crop species to yield the same product as obtained under an intercropping at the same management level [14]. The partial LER values of cowpea exceeded 0.5 at both locations for IT89KS-288, UAM14 122-17-7, and

UAM14-127-20-1-1 (Table 3), which suggested that intercropping led to a more productive use of land than sole cropping.

Table 4. On-station seed size performance of cowpea genotypes under sole and intercrop systems in two locations in Nigeria in 2019.

	Intercrop	Sole	Mean	Intercrop	Sole	Mean
	Zaria			Makurdi		
Varieties	100 Seed Weight (g)			100 Seed Weight (g)		
IT89KD-288	17.7	16.5	17.1	16.0	17.6	16.8
IT99K-573-1-1	19.6	17.9	18.7	19.1	15.5	17.3
UAM09-1046-6-1	19.1	16.6	17.9	18.0	15.3	16.6
UAM09 1051-1	18.4	16.5	17.5	17.3	14.9	16.1
UAM14-122-17-7	26.0	27.1	26.6	25.9	24.1	25.0
UAM14-123-18-3	28.9	27.3	28.1	28.2	24.4	26.3
UAM14-126-19-2	19.0	18.7	18.9	26.6	22.9	26.0
UAM14-127-20-1-1	26.2	23.7	25.0	25.7	20.4	23.0
UAM14-130-20-4	26.3	24.5	25.4	23.8	20.9	22.4
Mean	22.4	21.0		22.3	19.5	
SED	2.18	2.31	2.23	2.23	1.92	2.16
p-value	0.0678	0.7569		0.0240	0.0004	

Significant difference was observed at 5% level of probability.

3.4. On-Farm Evaluation

The results of the cowpea genotypes in on-farm trials in the northern Guinea savanna in 2020 and 2021 revealed that UAM14-122-17-7 had the highest grain yield (1868.0 kg ha^{-1}) followed by UAM14-123-18-3 (1820.3 kg ha^{-1}) in on-farm evaluations across the years (Table 5). The cowpea genotype, UAM14-122-17-7, consistently out-yielded the farmers' choice variety by 166%, while UAM14-123-18-3 had a yield advantage of 155% over the farmers' choice variety. The two cowpea breeding lines also recorded the highest grain yields compared to the commercial varieties (IT89KD-288 and UAM09-1051-1). Similarly, in 2021, UAM14-122-17-7 had the highest grain yield (1768.3 kg ha^{-1}) followed by UAM14-123-18-3 (1686.0 kg ha^{-1}) across the years (Table 6).

Table 5. On-farm performance of cowpea genotypes in the northern Guinea savana in 2020.

No. of Communities	No. of Farmers	Variety	Makurdi	Ganjuwa	Mokwa	Combined
			Grain yield kg/ha			
8	10	IT89KD-288	1183.0	1050.0	1245.0	1159.3
	10	UAM14-122-17-2	1956.0	1760.0	1888.0	1868.0
	10	UAM14-123-18-3	1770.0	1906.0	1785.0	1820.3
	10	UAM09-1051-1	1400.0	1200.0	1310.0	1303.3
	10	Farmers check	700.0	690.0	750.0	713.3
		Mean	1401.8	1321.2	1395.6	1372.9
		SED	332.57	338.9	307.6	323.6
		CV (%)	35.37	38.2	32.9	35.1

3.5. Nutritional Composition

The nutritional content of the two candidates' genotypes was analyzed. The nutritional content values in the grain of UAM14 122-17-7 were 22% for protein, 3% for ash, 2.4% for fat, 3.5% for crude fiber, and 64.8% for carbohydrate. The amounts of micronutrients for the genotype were also quite high, at 68.8, 5.7, and 7.2 mg/kg for calcium, zinc, and iron, respectively. The same trend was recorded for UAM14-123-18-3, where the protein content was 24.0%, ash 3.1%, fat 2.3%, crude fiber 3.5%, and carbohydrates 65.9%. High amounts of micronutrients were also found in the grain, with calcium 69.1, zinc 5.8, and iron 6.9 mg/kg (Table 7). The figures recorded here are within the range recorded for cowpea genotypes identified as having high iron and zinc content.

Table 6. On-farm performance of cowpea genotypes in the northern Guinea savanna in 2021.

No. of Communities	No. of Farmers	Variety	Makurdi	Ganjuwa	Mokwa	Combined
			Grain yield kg/ha			
8	10	UAM09-1051-1	1411.0	1255.0	1350.0	1338.7
	10	UAM14-122-17-2	1875	1650	1780	1768.3
	10	UAM14-123-18-3	1690	1608	1760	1686.0
	10	IT89KD 288	1390	1280	1255	1308.3
	20	Farmers check	735	600	708	681.0
		Mean	1420.2	1278.6	1370.6	1356.5
		SED	290.51	282.12	294.72	287.97
		CV (%)	30.49	32.89	32.05	31.65

Table 7. Proximate composition and micronutrient content of the new cowpea genotypes.

	UAM14-122-17-7	UAM14-123-18-3
% Moisture	9.4	9.1
% Ash	3.0	3.1
% Fat	2.4	2.3
% Protein	22.0	24.0
% Crude Fiber	3.5	3.5
% Carbohydrate	64.8	65.9
Calcium (mg/kg)	68.7	69.1
Zinc (mg/kg)	5.7	5.8
Iron (mg/kg)	7.2	6.9
Calcium (mg/kg)	8.3	7.9

4. Discussion

Despite the significant role of cowpea in food and nutrition security, the release of improved cultivars for wide-scale production and breeding still needs improvement, partially attributable to the limited breeding efforts to identify and select suitable genotypes adaptable to variable cropping systems. The phenotypic evaluation of the cowpea genotypes revealed significant differences in grain yield and other agronomic traits. The superiority of the newly improved cowpea lines in grain yield and other essential traits revealed their potential for commercialization and as elite breeding parents in cowpea improvement programs. The yield of the best-improved line was 33% higher than the best-yielding check variety. This showed the superioirty of the improved lines over the existing current commercial varieties.

Because of the rapid human population explosion, the amount of cultivable land at the subsistence household level is gradually decreasing. Most farmers own small plots of land, especially in the savannas of West Africa. Hence, there is a need to increase crop production per unit of cultivated land using various techniques, including multiple cropping [11]. This limitation in land areas has exerted pressure to meet the basic demands of human beings for food, fiber, and oil. The superior performance of the improved cowpea lines under sole and intercropping systems revealed the suitability of these lines under both cropping systems. Intercropping is an effectual and economical production system because, besides increasing the production per unit area and time, it also increases the growers' resource use efficiency and economic stock [13]. It also guards against total crop failure and ensures food security [10]. UAM14-122-17-7 had a superior grain yield under sole and intercropping systems, revealing its potential for cultivation under both cropping systems. The grain yield of the determinate erect cowpea (IT93K-573-1-1) was significantly reduced when intercropped with maize. This suggested that cowpea genotypes with indeterminate growth habit are more suitable for this system because they do not flower at the same time and have more time to recover from the negative effects of shading from the maize. This was confirmed by the high-yield performance of the indeterminate cowpea genotypes (UAM114-122-17-7 and IT89KD-288) when intercropped with maize. Under the intercropping system, the high-grain yield of UAM14-122-17-7 will encourage farmers to adopt this variety as most farmers normally intercrop cowpea with cereals. This indeterminate cultivar also gave a higher yield when planted sole. It also possesses the good seed quality traits desired by farmers and consumers (brown seed coat color with large seed size).

The on-station and on-farm trial results revealed the superiority of the newly developed improved cowpea lines, UAM14-122-17-7 and UAM14-123-18-3, over other improved cowpea genotypes tested. In addition to high-grain yields, UAM14-122-17-7 and UAM14-123-18-3 had excellent quality seed traits that meet farmers' and market demand (brown, large-seeded cowpea varieties). The yield potential of the nine selected cowpea lines in intercropping showed that some lines performed better than others in the different environments (Zaria and Makurdi). The partial LER values exceeded 0.5 at both locations for some lines, suggesting that intercropping led to more productive land use than sole cropping. The intercropped cowpea performed relatively better in the SGS than the NGS, as indicated by more partial LER values above 0.6. This result agreed with an earlier finding by Kermah et al. [15], who reported a greater LER (1.16–1.81) when maize–cowpea intercrops were planted on the same rows in the NGS of Ghana.

The consistent high-yield performance of UAM14-122-17-1 and UAM14-123-18-3 across the two environments demonstrated the effectiveness of the breeding methods used to incorporate favorable alleles for high-grain yield and large seed size. This implies that the gain in selection under sole cropping can be translated to intercropping when selection is made. The high-grain yield and seed quality traits (brown, large seed size) clearly showed that UAM14-122-17-1 and UAM14-123-18-3, which were selected based on the per se performance at UAM in an advanced yield trial in 2018, are adapted to several locations in the savannas of Nigeria. Although UAM14-126-19-2 was the highest-yielding line in intercropping in the Makurdi environment, it was unsuitable in the Zaria environment, the same as IT99K-573-1-1, limiting their superior performance across environments. The consistent ranking of UAM14-122-17-7, IT8KD-288, and UAM14 123-18-3 indicated these cowpea genotypes consistently outperformed the other genotypes across the test environments, confirming their wide adaptability in the savannas of Nigeria. Similarly, in the on-farm testing, UAM14-122-17-7, IT8KD-288, and UAM14-123-18-3 produced significantly higher yields that were consistently superior to any other cowpea lines in all the test environments. The cowpea lines also recorded higher seed sizes, which are attributes desired by farmers and consumers in accepting improved cowpea varieties.

The proximate composition of the two cowpea varieties is within the range recorded for cowpea genotypes identified as having good protein content and high levels of various macronutrients. The information on the nutritional content of the two cowpea varieties will be of interest in the food industry for product development.

Based on their performance in on-station and on-farm trials, the cowpea lines designated as UAM14-122-17-7 (FUAMPEA 3) and UAM14-123-18-3 (FUAMPEA 4) with brown, large seed sizes were nominated for registration and release in Nigeria. The release of the two cowpea genotypes will ensure the sustainability of cowpea production and productivity, especially in Nigeria's southern and Guinea's savannas, where farming intensification is practiced.

5. Conclusions

This study demonstrated considerable differences in the performances of the new cowpea breeding lines in the maize relay intercrops. The two breeding lines, UAM14-122-17-7 (FUAMPEA 3) and UAM14-123-18-3 (FUAMPEA 4), produced higher grain yields and recorded higher 100-seed weights compared to the commercial varieties under sole and intercrop systems. However, UAM14-122-17-7 showed better adaptability for relay intercrops because of its superior yield performance. Based on the excellent performance of UAM14-122-17-7 (FUAMPEA 3) under sole-cropping and intercropping, coupled with the seed quality traits, this cowpea cultivar can be recommended for Guinea's savanna ecology to boost cowpea production in those areas. However, the physiological basis of the adaptability of the cowpea cultivar to intercropping needs to be investigated.

Author Contributions: Conceptualization, L.O.O. and A.Y.K.; methodology, L.O.O., A.Y.K., A.I.T., R.S. and A.S.S.; software, L.O.O., A.I.T. and A.S.S.; validation, L.O.O.; formal analysis, L.O.O., K.T.A. and A.S.S.; investigation, L.O.O. and O.J.O.; resources, L.O.O. and A.Y.K.; data curation, L.O.O., K.T.A., R.S. and A.S.S.; writing—original draft preparation, L.O.O.; writing—review and editing, A.Y.K., A.S.S. and O.J.O.; visualization, L.O.O.; supervision, L.O.O.; project administration, L.O.O. and A.Y.K.; funding acquisition, L.O.O. All authors have read and agreed to the published version of the manuscript.

Funding: This development of the cultivars was funded by Kirkhouse Trust, UK, grant number 001 and The Bill and Melinda Gates Foundation (BMGF) through the AVISA project, grant number OPP1198373.

Data Availability Statement: Data are contained within the article.

Acknowledgments: The authors would like to thank the IITA agronomy staff for their technical support.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Omoigui, L.O.; Danmaigona, C.C.; Kamara, A.Y.; Ekefan, E.J.; Timko, M.P. Genetic Analysis of Fusarium Wilt Resistance in Cowpea (*Vigna unguiculata* Walp.). *Plant Breed.* **2018**, *137*, 773–781. [CrossRef]
2. Jules, P.; Camilla, T.; Stella, W. Sustainable Intensification in African Agriculture. *Int. J. Agric. Sustain.* **2011**, *9*, 5–24.
3. Willey, R.W. Resource use in intercropping systems. *Agric. Water Manag.* **1990**, *17*, 215–231. [CrossRef]
4. Rao, M.R.; Singh, M. Productivity of risk evaluation in contrasting intercropping systems. *Field Crop Res.* **1990**, *23*, 279–293. [CrossRef]
5. Lithourgidis, A.S.; Dordas, C.A.; Damalas, C.A.; Vlachostergios, D. Annual Intercrops: An Alternative Pathway for Sustainable Agriculture. *Aust. J. Crop Sci.* **2011**, *5*, 396–410.
6. Olufajo, O.O.; Singh, B.B. Advances in Cowpea Cropping Systems. In *Challenges and Opportunities for Enhancing Sustainable Cowpea Production*; International Institute of Tropical Agriculture: Ibadan, Nigeria, 2002; p. 267.
7. Kamara, A.Y.; Omoigui, L.O.; Kamai, N.; Ewansiha, S.U.; Ajeigbe, H.A. *Improving Cultivation of Cowpea in West Africa*; International Crops Research Institute for the Semi-Arid Tropics (ICRISAT): Kano, Nigeria, 2018.
8. Ewansiha, S.U.; Kamara, A.Y.; Onyibe, J.E. Performance of Cowpea Cultivars When Grown as an Intercrop with Maize of Contrasting Maturities. *Arch. Agron. Soil Sci.* **2014**, *60*, 597–608. [CrossRef]
9. Manda, J.; Khonje, M.G.; Alene, A.D.; Gondwe, T. Welfare Impacts of Improved Groundnut Varieties in Eastern Zambia: A Heterogeneous Treatment Effects Approach. *Agrekon* **2017**, *56*, 313–329. [CrossRef]
10. Wossen, T.; Abdoulaye, T.; Alene, A.; Nguimkeu, P.; Feleke, S.; Rabbi, I.Y.; Haile, M.G.; Manyong, V. Estimating the Productivity Impacts of Technology Adoption in the Presence of Misclassification. *Am. J. Agric. Econ.* **2019**, *101*, 1–16. [CrossRef]
11. Abate, M.; Alemayehu, G. Biological Benefits of Intercropping Maize (*Zea Mays L*) with Fenugreek, Field Pea and Haricot Bean under Irrigation in Fogera Plain, South Gonder Zone, Ethiopia. *Agric. For. Fish.* **2018**, *7*, 19.
12. SAS Institute Inc. *SAS JMP®14 Documentation Library*; SAS Institute Inc.: Cary, NC, USA, 2018.
13. Willey, R.W.; Osiru, D.S.O. Studies on mixtures of maize and beans (*Phaseolus vulgaris*) with special reference to plant population. *J. Agric. Sci.* **1972**, *79*, 519–529. [CrossRef]
14. Maitra, S.; Shankar, T.; Banerjee, P. Potential and advantages of maize-legume intercropping system. In *Maize—Production and Use*; Hossain, A., Ed.; Intechopen: London, UK, 2020. [CrossRef]
15. Kermah, M.; Frank, A.C.; Adjel-Nsiah, S.; Kahiabor, B.D.; Abaido, R.C.; Giller, K.E. Maize-grain legume intercropping for enhanced resource use efficiency and crop productivity in the Guinea savanna of northern Ghana. *Field Crop Res.* **2017**, *213*, 38–50. [CrossRef] [PubMed]