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Phytosociological survey of weeds in irrigated maize fields in a Southern Guinea Savanna of Nigeria

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Maize is a food crop for millions of people in sub-Saharan Africa. However, severe weed infestation might cause significant yield loss. This study investigated weed composition, abundance and distribution in maize-based cropping systems in the Southern Guinea Savanna of Nigeria. Fields were surveyed between February and March 2022. The Importance Value Index (IVI) of each weed species was determined using relative frequency, relative density, and relative abundance. A total of 29 weed species from 15 families were identified. Poaceae (34.9 %) was the most prevalent weed family, followed by Cyperaceae (26.9 %) and Portulacaceae (12.8 %). The IVI showed that *Cyperus rotundus* (38.6), *Portulaca oleraceae* (29.4), *Digitaria horizontalis* (25.5), *Brachiaria deflexa* (24.2), *Senna obtusifolia* (17.6), *Ageratum conyzoides* (16.0), *Cynodon dactylon* (12.6), *Phyllanthus niruri* (11.1) and *Eragrostis* sp. (10.6) were the most dominant. Principal Component Analysis (PCA) ordination biplot revealed that *Setaria pumila* was strongly associated with sole maize cultivation, as was *Desmodium scorpiurus* with maize/rice intercropping, *C. dactylon* with maize/pepper, *Euphorbia hirta* with maize/cassava, and *Cleome viscosa* with maize/amaranthus intercropping. Special attention to these weed species is required when making an informed decision on the choice of weed control measures.to reduce yield losses in endemic areas.

KEYWORDS

allelopathy, density, dominance, importance value, principal component, cropping system

Introduction

Sub-Saharan Africa's countries will add more than one billion people by 2050, accounting for more than half of the global population increase (UNDESAPPD (United Nations, Department of Economic and Social Affairs, Population Division), 2019). Unfortunately, the current food production levels are insufficient to feed the predicted population, and addressing this need is a significant problem (Ranganathan et al., 2018). According to a Food and Agriculture Organisation report (FAO et al., 2019), millions of people in sub-Saharan Africa are food insecure. These factors adversely impact healthy living and long-term development. As a result, adopting new high-intensity cropping methods is critical for enhancing agricultural output in this situation (Waha et al., 2020). Maize (*Zea mays* L.) production contributes to food security and income for smallholder farmers in sub-Saharan Africa. It is also an important raw material in the livestock industry for feed formulation. Although it is often grown during the rainy season, it can also be cultivated in a lowland ecosystem during the dry season if dependable irrigation facilities are available. Despite its numerous applications, maize productivity is threatened by weed invasion at various stages of growth (Colbach et al., 2020).

Weeds absorb moisture, nutrients, and sunlight instead of agricultural plants, lowering crop yield and quality (Sabanci and Aydin, 2017). Some weeds also act as alternate hosts for insect pests and pathogens. They are more economically damaging than insects, fungi, or other crop pests (Gharde et al., 2018), causing approximately 40 % of crop output loss. Weeds vary from location to location and season to season, and the level of infestation primarily depends on the species, density and diversity in a crop community (Korav et al., 2018). The morphological architecture of maize plants makes them poor competitors to weeds. Therefore, an infestation of weeds during the prime growth period may result in unacceptable losses (Chauhan, 2020). Weeds are diverse and spread across a vast geographical area. Some species are better suited to highland or lowland environments, while others can thrive in both.

The ability of a weed to dominate specific farmland has significance for its survival and geographical spread. *Oldenlandia corymbosa*, for example, is known to rapidly establish and dominate in a location (Global Invasive Species Database, 2022). The weed produces a large number of seeds, which can be dispersed by farm machinery, wind, and rain. As a result, it becomes increasingly difficult to manage. *Ageratum conyzoides* also produces a large number of seeds and is resistant to a wide range of germination temperatures and light conditions (Yuan and Wen, 2018). Allelopathy is another mechanism of survival and field colonization. For example, some weeds, such as *A. conyzoides* and *Portulaca oleracea*, can release compounds that impair the growth of agricultural plants in their vicinity (Rashidi et al., 2021; Paul et al., 2022).

Weed management is critical for achieving maximum crop production and will play a key role in determining whether we can fulfil future food demands (Korav et al., 2018). Crop production is unattractive to teeming unemployed youths due to the numerous obstacles associated with weed management. Manual weed control is time-consuming, and labour is scarce during the cropping season. Herbicide application provides an immediate response to weed infestations, but it is costly, hazardous to humans and livestock, contaminates soil and groundwater, and escalates production costs. Smallholder farmers in sub-Saharan Africa use various combinations of maize intercropping systems involving cowpea, groundnut, or soyabean for weed control. These combinations can provide some control, but those including sorghum (*Sorghum bicolor* L.), sugarcane (*Saccharum officinarum* L.), rice (*Oryza sativa* L.), pepper (*Capsicum* spp), cassava (*Manihot esculenta* Crantz), and millet (*Pennisetum* spp.) worsen weed infestations.

Weed abundance and distribution are critical determinants of field invasion and crop yield.

Changes in these variables are the result of selective pressures applied by farmers during crop production (Nkoa et al., 2015). Tillage methods, sowing dates, inter and intra-row spacing, herbicide, fertiliser, and cropping system selection are just a few examples. Information on the weed population that causes the most damage to an agricultural crop is crucial for creating long-term weed management strategies. It would also help to increase crop output and harvest quality. Typically, this information is obtained through phytosociological surveys, which include indices such as relative frequency, relative density, relative abundance, and relative importance (Silva et al., 2017). From this perspective, the most impacted component (frequency, density, and abundance) may provide evidence of how environmental agents interact with the weed population (Silva et al., 2017). Therefore, this study investigated weed composition, abundance, and distribution in a lowland environment with maize-based cropping systems.

Materials and methods

Description of the study area

The study was conducted in the four Local Government Areas (LGAs) of Niger State, Southern Guinea Savanna agro-ecological zone of Nigeria. The selected LGAs were Bosso, Gbako, Katcha, and Lapai (Figure 1). The State lies between

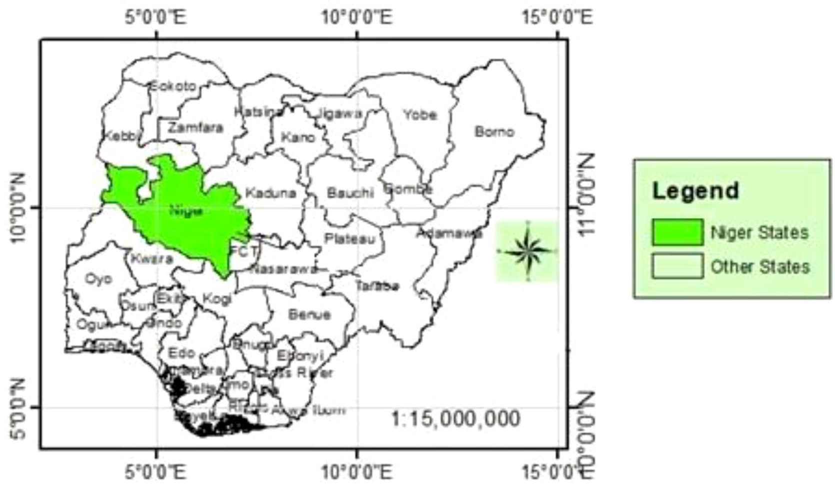

FIGURE 1
Map of Nigeria showing Niger State surveyed for weeds associated with different maize-based cropping systems.

08°–11°30' N and 03°–07°40' E. The dry and rainy seasons are distinct, with annual rainfall ranging from 1,100 mm in the North to 1,600 mm in the South. The highest temperatures are frequently reported between March and June, while the lowest occur between December and January. In the northern zone of the State, the rainy season lasts for 120 days, whereas, in the southern part, it is approximately 150 days. The soils are Alfisols, with a high water-holding capacity derived from basement complex rocks.

Field survey and weed sampling

Surveys were conducted on 18 maize-based farms in the selected LGAs between February and March 2022. Two of the farms were located in Bosso LGA (Anguwan-Shaba _01 and Anguwan-Shaba _02), seven in Gbako LGA (Sabon-Gida_01–Sabon-Gida_07), seven in Katcha LGA (Katcha_01– Katcha_07) and two in Lapai LGA (Lapai GGSS-Day_01 and Lapai GGSS-Day_02). Structured questionnaires were administered to 90 maize farmers (respondents) to obtain information on the cropping history (farm size, maize-based cropping systems, weed control methods and farmers' knowledge of allelopathic weeds). The coordinates of each field were taken using a Global Positioning System (GPS- 4300; Ethrex Garmin, Taiwan) (John et al., 2020). Weeds were sampled when the maize plants were between the vegetative and grain-filling stages. Twenty 0.25 m^2 quadrats were randomly placed along the transect in the "W" guided pattern mapped out in each field for weed species collection (Sintayehu, 2019). The weed species in each quadrat were counted and identified using a standard weed manual (Akobundu et al., 2016).

Data analysis

The following phytosociological parameters were calculated for each species: frequency, relative frequency, density, relative density, abundance, relative abundance, and Importance Value Index (IVI) (Lopes et al., 2021).

$$\textit{Frequency}\ (\%) = \frac{\text{Number of quadrats in which a species was encountered}}{\text{Total of number of quadrats studied}} \times 100$$

$$\textit{Relative Frequency}\ (\%) = \frac{\text{Frequency of a species}}{\text{Total frequency of all species}} \times 100$$

$$\textit{Density}\ (\%) = \frac{\text{Total number of individuals of a species}}{\text{Total area sampled}} \times 100$$

$$\textit{Relative Density}\ (\%) = \frac{\text{Density of a species}}{\text{Total density of all species}} \times 100$$

$$\textit{Abundance} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats in which the species was encountered}}$$

$$\textit{Relative Abundance}\ (\%) = \frac{\text{Abundance of a species}}{\text{Total abundance of all species}} \times 100$$

$$\begin{aligned}&Importance\ Value\ Index\\&\quad = Relative\ Frequency + Relative\ Density\\&\qquad + Relative\ Abundance\end{aligned}$$

The data on the number of weed species from the 18 locations were subjected to Principal Component Analysis (PCA) to determine the relationships among the weed species and between the weed species and maize cropping systems (sole maize, maize/amaranthus, maize/cassava, maize/pepper, and maize/rice). The PCA was based on a correlation matrix of the weed species (variables) (Restuccia et al., 2020). Data were analysed using Statistical Analysis System software version 9.2 (SAS Institute Inc., Cary, NC).

Results

Cropping history

Regardless of location, the farms were less than 1 ha in size (Figure 2). Seventy per cent of farmers in Bosso LGA intercropped maize with rice, while the remaining 30 % intercropped with cassava (Figure 3). Gbako LGA had slightly different results: 60 % of farmers intercropped maize with rice, followed by 25.7 % who used pepper, and the remaining 14.3 % intercropped maize with amaranthus. In Katcha, 60 % of farmers intercropped maize with rice, 25.7 % cultivated maize alone, and 14.3 % intercropped with pepper. Ninety per cent of farmers in Lapai LGA intercropped maize with rice, and the remaining 10 % intercropped with amaranthus (Figure 3). In Bosso LGA, 70 % of the farmers used herbicide in combination with hand weeding, and the remaining 30 % used hand weeding alone (Figure 4). In Gbako LGA, 71.4 % of respondents used hand weeding combined with herbicide for weed control, and 28.6 % used hand weeding alone. In Katcha LGA, 65.7 % of farmers used both hand weeding and herbicide, while 34.3 % used only hand weeding. In Lapai LGA, 60 % of farmers mixed hand weeding with herbicide application, and 40 % depended primarily on hand weeding. Based on the oral interview, farmers stopped applying herbicides when they no longer worked. In such cases, herbicide combinations were utilised. None of the farmers knew allelopathic weeds in Bosso, whereas 14.3 %, 11.4 %, and 10 % were aware in Gbako, Katcha, and Lapai LGA, respectively (Figure 5).

Weed species composition

Across the investigated sites, a total of 2, 041 individuals of 29 weed species belonging to 15 families were identified (Table 1). *Cyperus rotundus* L. accounted for 26.9 % of the total individuals, followed by *Portulaca oleracea* L. (12.8 %), *Digitaria horizontalis* Willd (12.1 %), and *Brachiaria deflexa* (Schumach.) C. E. Hubb with 11.9 %. Poaceae (34.9 %) were the most abundant, followed by Cyperaceae (26.9 %), Portulacaceae (12.8 %), Asteraceae (9.6 %), and Euphorbiaceae (6.2 %). The families Rubiaceae, Acanthaceae, and Malvaceae accounted for 2.3 %, 2.1 %, and 1.6 % of all weeds, respectively. However, the Fabaceae and Solanaceae families were both present in identical proportions (1.2 %). The remaining families had abysmally

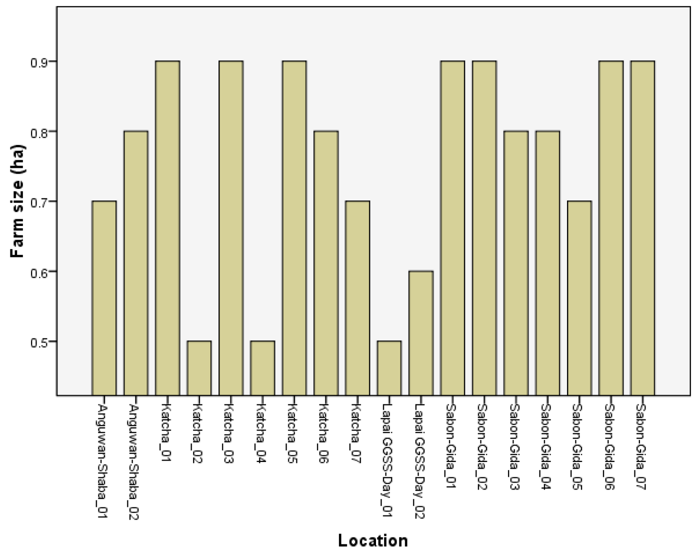

FIGURE 2
Farm size in different locations surveyed for maize-based cropping systems in Southern Guinea Savanna of Nigeria.

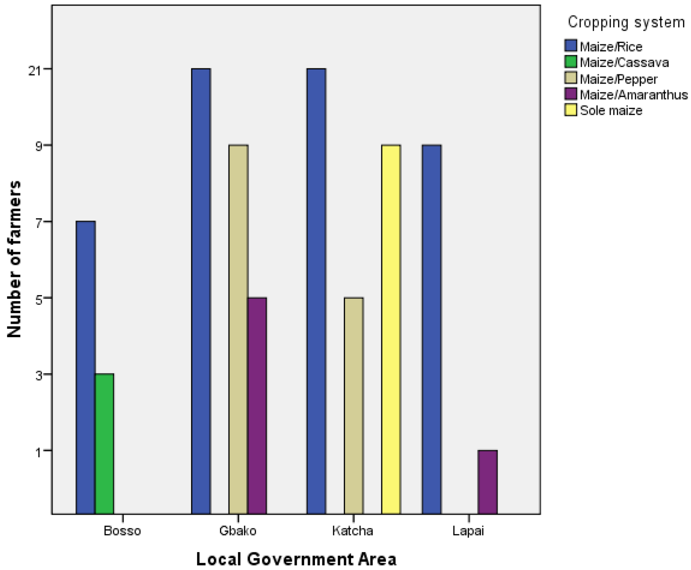

FIGURE 3
Frequency distribution of the farmers involved in maize-based cropping systems in Southern Guinea Savanna of Nigeria.

few members, namely Convolvulaceae (0.4 %), Capparidaceae (0.3 %), Commelinaceae (0.3 %), Leguminosae (0.2 %), and Loganiaceae (0.2 %). Broadleaf weeds accounted for 38.2 % of all weed species in terms of morphology (Table 1). With a relative frequency of 16.3 %, 12.9 %, and 11.7 %, respectively, *P. oleracea*, *D. horizontalis*, and *B. deflexa* ranked the highest among the weed species associated with maize fields. *Cyperus rotundus* (26.9 %), *P. oleracea* (12.8 %), *D. horizontalis* (12.1 %), and *B. deflexa* (11.9 %) were the most frequent and diversely populated weed species based on relative density. *Senna obtusifolia* (L.) Irwin & Bar had the highest relative abundance (16.2 %), followed by *Dactyloctenum aegyptium* (L.) P. Beauv, *Ipomoea triloba*, and *Setaria pumila* (Poir) Roem & Schult, all

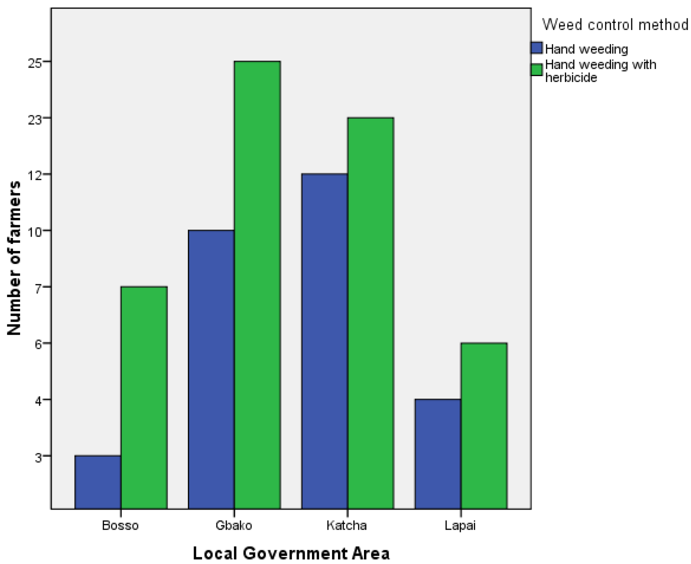

FIGURE 4
Frequency distribution of the farmers adopting different weed control methods under maize-based cropping systems in Southern Guinea Savanna of Nigeria.

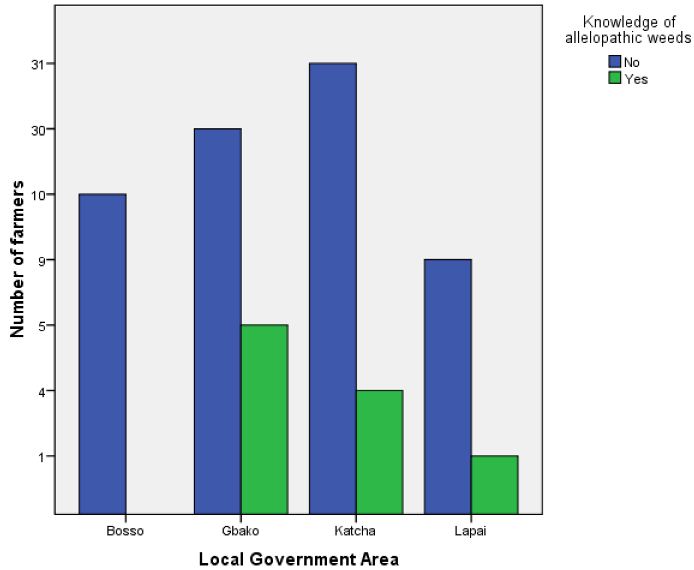

FIGURE 5
Farmers' knowledge of allelopathic weeds under maize-based cropping systems in Southern Guinea Savanna of Nigeria.

with 7.6 %. *Eragrostis* sp., *Spermacoce ocymoides* Burm F., and *Cleome viscosa* L. had a relative abundance of 6.9 %, 6.8 %, and 6.7 %, respectively. Based on IVI, the most common and prevailing weed species in the maize fields was *C. rotundus* with an IVI of 38.6. The other important and troublesome species were *P. oleracea* with an IVI of 29.4, followed by *D. horizontalis* (IVI = 25.5), *B. deflexa* (IVI = 24.2), *S. obtusifolia* (IVI = 17.6), *A. conyzoides* (IVI = 16.0), *Cynodon dactylon* (L.) Pers (IVI = 12.6), *Phyllanthus niruri* (IVI = 11.1), and *Eragrostis* sp. (IVI = 10.6) (Table 1). These weed species belong to the Portulacaceae (broadleaf), Poaceae (grass), Cyperaceae (sedge), Fabaceae (broadleaf), Convolvulaceae (broadleaf), Rubiaceae (broadleaf), and Capparidaceae (broadleaf) (Table 1).

Effect of cropping systems on weed distribution

The abundance and distribution of weeds varied according to the cultivation practices used in the study area (Table 2). The farms under maize/rice intercropping included Anguwan-Shaba_02, Katcha_01, Katcha_05, Katcha_06, Lapai GGSS-Day_01, Sabon-Gida_01, Sabon-Gida_03, Sabon-Gida_05, and Sabon-Gida_06 (Table 2). The difference in the grass and broadleaf abundance was not conspicuous in Anguwan-Shaba_02. Of the 87 individuals, sedges were the most abundant with 37 individuals followed by grasses with 27 individuals and broadleaf species with 23 individuals. In Katcha_01, grass weeds predominated with 100 individuals, whereas 46 individuals of broadleaf species were observed. Of the 104 individuals found in Katcha_05, sedges (58 individuals) were the most prevalent, followed by grasses (32 individuals) and broadleaves (14 individuals). Moreover, in Katcha_06, grass weeds constituted 36 individuals with a comparable number of broadleaf species (31 individuals), but only one individual of sedges was found (Table 2). Weed abundance varied substantially in Lapai GGSS-Day_01, where sedges predominated (33 individuals) against 13 individuals of broadleaf species and just one individual of grasses. Sabon-Gida_01 constituted 173 individuals, with sedges being the most abundant (158 individuals), followed by broadleaves with 8 individuals and grasses with 7 individuals. Sedge weeds dominated at Sabon-Gida_03 with 54 individuals, followed by broadleaves (19 individuals) and grass weeds (6 individuals). Sabon-Gida_05 had only grass (38 individuals) and broadleaf (28 individuals) weeds. Sabon-Gida_06, on the other hand, contained 98 individuals with 37 grasses, 33 broadleaves, and 28 sedges (Table 2).

The farms supporting only maize cultivation included Katcha_02, Katcha_04, and Katcha_07 (Table 2). Weeds found at Katcha_02 were grasses and broadleaves, with grasses dominating (65 individuals) over the broadleaves (24 individuals). In Katcha_04, grass weeds predominated (92 individuals), followed by broadleaves (10 individuals), and only 1 individual of sedges. There were no sedges in Katcha_07, although there were 24 and 9 individuals of grass and broadleaf species, respectively (Table 2). Maize/pepper cultivation was witnessed in Katcha_03, where only broadleaf (106 individuals) and grass (64 individuals) species were found. In Sabon-Gida_02, broadleaf weeds were the most abundant (22

TABLE 1 Phytosociological parameters of the weed species from the survey of irrigated maize-based cropping systems in Southern Guinea Savanna of Nigeria.

Weed species	Family	Total individuals of weed species	Relative frequency (%)	Relative density (%)	Relative abundance (%)	Importance value index
Ageratum conyzoides L.	Asteraceae	174	5.2	8.5	2.3	16.0
Brachiaria deflexa Schumach.) C. E.Hubb	Poaceae	243	11.7	11.9	0.6	24.2
Brachiaria lata (Schumach.) C. E. Hubb	Poaceae	53	3.7	2.6	1.4	7.7
Cleome viscosa L.	Capparidaceae	7	0.6	0.3	6.7	7.6
Commelina benghalensis L.	Commelinae	6	0.9	0.3	2.5	3.8
Cynodon dactylon (L.) Pers	Poaceae	121	4.3	5.9	2.4	12.6
Cyperus rotundus L.	Cyperaceae	549	9.5	26.9	2.2	38.6
Dactyloctenum aegyptium (L.) P. Beauv.	Poaceae	2	0.3	0.1	7.6	8.0
Desmodium scorpiurus (Sw.) Desv.	Leguminosae	4	0.6	0.2	3.8	4.6
Digitaria horizontalis Willd	Poaceae	246	12.9	12.1	0.5	25.5
Eragrostis sp.	Poaceae	45	1.5	2.2	6.9	10.6
Euphorbia heterophylla L.	Euphorbiaceae	11	2.1	0.5	0.9	3.5
Euphorbia hirta L.	Euphorbiaceae	31	3.1	1.5	1.2	5.8
Ipomoea aquatic Forssk	Convolvulaceae	6	0.6	0.3	5.7	6.6
Ipomoea triloba	Convolvulaceae	2	0.3	0.1	7.6	8.0
Mimosa sp.	Fabaceae	7	1.8	0.3	0.7	2.9
Mitracarpus villosus Sw. DC	Rubiaceae	14	1.2	0.7	3.3	5.2
Nelsonia canescens (Lam.) Spreng	Acanthaceae	40	3.1	2	1.5	6.6
Oldenlandia corymbosa L.	Rubiaceae	17	2.5	0.8	1	4.3
Paspalum scrobiculatum L.	Poaceae	33	2.5	1.6	2	6.0
Phyllanthus niruri L.	Euphorbiaceae	84	6.1	4.1	0.8	11.1
Physalis angulata L.	Solanaceae	24	3.7	1.2	0.6	5.5
Portulaca oleracea L.	Portulacaceae	261	16.3	12.8	0.4	29.4
Senna obtusifolia (L.) Irwin & Bar	Fabaceae	17	0.6	0.8	16.2	17.6
Setaria pumila (Poir) Roem & Schult	Poaceae	2	0.3	0.1	7.6	8.0
Sida acuta Burm f.	Malvaceae	1	0.3	0	3.8	4.2
Spermacoce ocymoides Burm F.	Rubiaceae	16	0.9	0.8	6.8	8.5
Spigelia anthelmia L.	Loganiaceae	4	0.9	0.2	1.7	2.8
Tridax procumbens L.	Asteraceae	21	2.5	1	1.3	4.7

individuals), followed by grasses (15 individuals) and sedge weeds (7 individuals). In Sabon-Gida_04, broadleaves were represented by 56 individuals, followed by grass weeds with 22 individuals and sedges with 17 individuals (Table 2). Maize/amaranthus intercropping in Lapai GGSS-Day_02 resulted in comparable numbers of grass (26 individuals) and broadleaf (28 individuals) weeds but only a limited number of sedges (3 individuals) was found. In Sabon-Gida_07 it resulted in 41 broadleaf and 21 grass individuals but no sedges (Table 2). Maize/cassava intercropping was seen only in Anguwan-Shaba_01, where there was a total of 520 individuals with the maximum number of broadleaf species (268 individuals), followed by sedges (152 individuals) and grass weeds (100 individuals) (Table 2).

The PCA of the weed species from the 18 locations showed that the first three PCs accounted for 86.8 % of the cumulative variance (Table 3). Principal Component 1 (PC 1) explained 43.3 % of the total variance and correlated significantly with *Mimosa* sp., *P. niruri*, *Eragrostis* sp., *A. conyzoides*, *Tridax procumbens* L. *Euphorbia heterophylla* L., *Oldenlandia corymbosa* L., *E. hirta*, *D. horizontalis*, *C. rotundus*, *Physalis angulata* L., and *P. oleracea* (Table 3). Principal Component 2 (PC 2) explained 23.9 % of the variance and correlated positively with*B.deflexa*,*Desmodium scorpiurus*(Sw.) Desv., *I. triloba*, *Mitracarpus villosus* Sw. DC,

TABLE 2 Total individuals of grasses, sedges and broadleaf weeds under different maize-based cropping systems in Southern Guinea Savanna of Nigeria.

Location	Cropping system	Grasses	Sedges	Broadleaves	Total
Anguwan-Shaba_01	Maize/Cassava	100	152	268	520
Anguwan-Shaba_02	Maize/Rice	27	37	23	87
Katcha_01	Maize/Rice	100	–	46	146
Katcha_02	Sole maize	65	–	24	89
Katcha_03	Maize/Pepper	64	–	106	170
Katcha_04	Sole maize	92	1	10	103
Katcha_05	Maize/Rice	32	58	14	104
Katcha_06	Maize/Rice	36	1	31	68
Katcha_07	Sole maize	24	–	9	33
Lapai GGSS-Day_01	Maize/Rice	1	33	13	47
Lapai GGSS-Day_02	Maize/Amaranthus	26	3	28	57
Sabon-Gida_01	Maize/Rice	7	158	8	173
Sabon-Gida_02	Maize/Pepper	15	7	22	44
Sabon-Gida_03	Maize/Rice	6	54	19	79
Sabon-Gida_04	Maize/Pepper	22	17	56	95
Sabon-Gida_05	Maize/Rice	38	–	28	66
Sabon-Gida_06	Maize/Rice	37	28	33	98
Sabon-Gida_07	Maize/Amaranthus	21	–	41	62
		713	549	779	2041

and *Spigelia anthelmia* L., and negatively with *C. benghalensis*, *B. lata*, *C.viscosa*, and *S. ocymoides*. Furthermore, PC 3 added 19.6 % variance, with *Dactyloctenum aegyptium* (L.) P. Beauv., *Ipomoea aquatica* Forssk, *Sida acuta* Burm f., and *S. obtusifolia* contributing positively (Table 3). The PCA ordination biplot (Figure 6) revealed that *S. pumila* was the only species associated with sole maize cultivation, as were *D. scorpiurus*, *I. triloba*, *S. anthelmia*, *M. villosus*, and *B. deflexa* with maize and rice intercropping, *C. dactylon*, *I. aquatica*, *D. aegyptium*, *S. obtusifolia*, and *S. acuta* with maize and pepper cultivation, *E. hirta* and *P. oleracea* with maize and cassava intercropping, and *C. viscosa*, *C. benghalensis*, and *B. lata* with maize and amaranthus cultivation (Figure 6).

Discussion

Maize cultivation during the dry season in the study locations showed the potential of irrigated agriculture to boost food and nutrition security. The cultivation of maize on less than 1 ha revealed that crop production in the study locations was primarily at the subsistence level. This corroborates the findings of Bjornlund et al. (2020), who reported that agricultural production in sub-Saharan Africa is primarily for domestic consumption. In addition, the low land hectares cultivated with maize could be attributed to the fact that it was grown outside of its natural environment (upland). Although maize does not perform well in a lowland environment, some farmers grow it during the dry season to avoid waterlogging. The widespread maize intercropping systems observed in the study locations were due to farmers' preferences for different types of food. Maize intercropping with rice was the most prevalent because lowland rice cultivars are adapted to hydromorphic farmland. As reported by WBGU (2020), crop diversity has the potential to improve sustainability while also preserving a variety of ecosystem functions. Therefore, intercropping maize with other crops would enhance the number of harvests while reducing the environmental impacts that agricultural production might have (Grote et al., 2021). It is laudable that none of the respondents relied primarily on herbicides for weed control. Excessive herbicide use might contribute to the ineffectiveness of some herbicides and the spread of weeds in Bosso, Gbako, and Katcha LGAs. According to Schütte et al. (2017), indiscriminate herbicide application promotes herbicide resistance and weed persistence. This is worrisome due to the negative impacts of herbicides on farmers, the environment, and biodiversity. The prevalence of farmers engaged in hand weeding is consistent with the findings of Sims et al. (2018). Hand weeding, frequently employed for weed management, may be attributable to a long-standing cultural tradition. It is cheap but tedious, making crop production unappealing to young people. In addition, farmers' responses to allelopathic weed knowledge revealed a general lack of awareness in the study area.

Ecological analysis of the weed data showed that *C. rotundus, P. oleracea, D. horizontalis, B. deflexa, S. obtusifolia, A. conyzoides, C. dactylon, P. niruri* and *Eragrostis* sp. were the

TABLE 3 Eigenvectors of the principal components from the weeds associated with maize-based cropping systems in Southern Guinea Savanna of Nigeria.

Weed species	Eigenvector				
	Prin1	Prin2	Prin3	Prin4	Prin5
Ageratum conyzoides	**0.270**	0.055	0.094	0.062	0.085
Brachiaria deflexa	-0.119	**0.341**	0.048	-0.027	-0.006
Brachiaria lata	-0.044	**-0.309**	-0.120	0.247	-0.037
Cleome viscosa	-0.020	**-0.306**	-0.170	0.220	-0.080
Commelina benghalensis	-0.025	**-0.318**	-0.186	0.158	-0.201
Cynodon dactylon	-0.061	-0.010	-0.065	-0.493	0.153
Cyperus rotundus	**0.251**	0.155	0.033	0.098	-0.101
Dactyloctenum aegyptium	-0.113	-0.019	**0.381**	0.059	-0.060
Desmodium scorpiurus	-0.105	**0.283**	-0.184	0.172	-0.041
Digitaria horizontalis	**0.253**	0.105	0.122	-0.100	0.123
Eragrostis sp.	**0.272**	0.074	0.062	0.043	0.053
Euphorbia heterophylla	**0.258**	0.126	0.067	0.080	0.103
Euphorbia hirta	**0.254**	0.040	-0.081	-0.191	0.113
Ipomoea aquatica	-0.113	-0.019	**0.381**	0.059	-0.027
Ipomoea triloba	-0.105	**0.283**	-0.184	0.172	-0.039
Mimosa sp.	**0.275**	0.052	0.042	0.070	0.005
Mitracarpus villosus	-0.105	**0.283**	-0.184	0.172	0.052
Nelsonia canescens	-0.169	0.260	0.056	0.201	-0.052
Oldenlandia corymbose	**0.258**	0.060	0.143	0.074	-0.017
Paspalum scrobiculatum	-0.210	0.193	0.112	-0.174	0.032
Phyllanthus niruri	**0.273**	0.073	0.058	0.051	0.087
Physalis angulata	**0.232**	0.008	-0.211	0.137	-0.025
Portulaca oleracea	**0.231**	0.067	0.215	0.095	-0.070
Senna obtusifolia	-0.115	-0.013	**0.379**	0.063	-0.067
Setaria pumila	-0.035	-0.033	-0.089	-0.494	0.138
Sida acuta	-0.113	-0.019	**0.381**	0.059	-0.070
Spermacoce ocymoides	-0.113	**-0.266**	0.137	0.252	0.804
Spigelia anthelmia	-0.105	**0.283**	-0.184	0.172	0.407
Tridax procumbens	**0.261**	-0.129	-0.056	-0.047	0.041
Eigenvalue	12.567	6.916	5.694	3.822	0.000
Difference	5.651	1.222	1.872	3.822	–
Proportion of variance explained (%)	43.300	23.900	19.600	13.200	0.000
Cumulative variance explained (%)	43.300	67.200	86.800	100.000	100.000

The bold values are significant at $p \leq 0.05$.

major weeds associated with the irrigated maize fields in this study. This indicates that these weed species are ecologically significant in the surveyed areas. Infestation of these weed species may increase competition with maize for growth resources, resulting in severe yield losses if not effectively controlled. *Cyperus rotundus* is a major concern since it is difficult to control due to its hardy underground stems. Travlos et al. (2018) revealed that weed species with high relative densities and importance values can compete better in an agricultural field than other weed species. The predominance of Poaceae among the identified families showed its importance in the maize ecosystem. The species of this family produce abundant seeds and exhibit aggressive growth and efficient seed dispersal (Silva et al., 2015). These qualities enable its members to occupy ecological niches in environments favourable for plant growth. The highest importance value exhibited by *C. rotundus* refers to its damaging effect on the maize crop. According to Silva et al. (2015), *C. rotundus* thrives well in a humid, shaded or open place and can form an obnoxious weed community, competing with the crop for space and nutrients. The propensity to regenerate *via* seeds, rhizomes, tubers, and basal bulbs also contributed to its

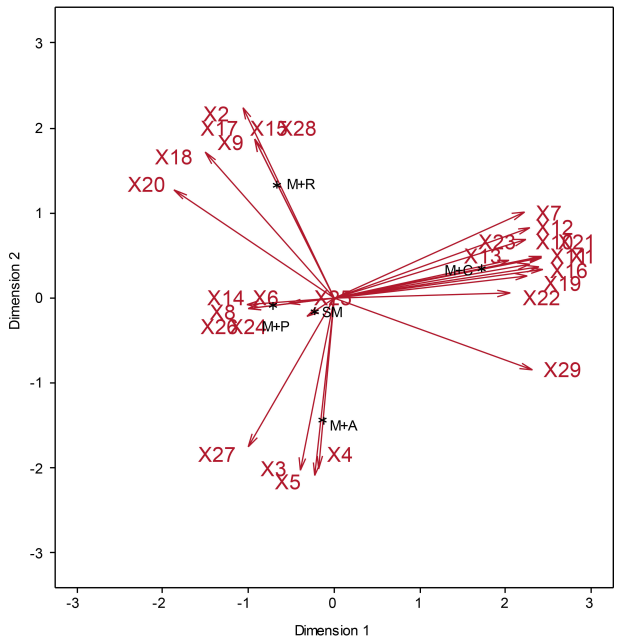

FIGURE 6
Principal component analysis ordination biplot of the weed species associated with maize-based cropping systems in Southern Guinea Savanna of Nigeria. X1, *Ageratum conyzoides*; X2, *Brachiaria deflexa*; X3, *Brachiaria lata*; X4, *Cleome viscosa*; X5, *Commelina benghalensis*; X6, *Cynodon dactylon*; X7, *Cyperus rotundus*; X8, *Dactyloctenum aegyptium*; X9, *Desmodium scorpiurus*; X10, *Digitaria horizontalis*; X11, *Eragrostis* sp.; X12, *Euphorbia heterophylla*; X13, *Euphorbia hirta*; X14, *Ipomoea aquatica*; X15, *Ipomoea triloba*; X16, *Mimosa* sp.; X17, *Mitracarpus villosus*; X18, *Nelsonia canescens*; X19, *Oldenlandia corymbose*; X20, *Paspalum scrobiculatum*; X21, *Phyllanthus niruri*; X22, *Physalis angulate*; X23, *Portulaca oleracea*; X24, *Senna obtusifolia*; X25, *Setaria pumila*; X26, *Sida acuta*; X27, *Spermacoce ocymoides*; X28, *Spigelia anthelmia*; X29, *Tridax procumbens*; M+A, Maize/Amaranthus intercropping; M+C, Maize/Cassava intercropping; M+P, Maize/Pepper intercropping; M+R, Maize/Rice intercropping; SM, Sole Maize.

widespread distribution. Its propagules can remain dormant for extended periods, allowing it to survive periodic flooding or dry seasons. These characteristics give it an edge over other weed species in a specific location (Henry et al., 2021).

The high importance values in *P. oleracea, D. horizontalis, B. deflexa, S. obtusifolia, A. conyzoides, C. dactylon. P. niruri* and *Eragrostis* sp. suggest that they are highly aggressive weeds in the maize crop cycle and must be eradicated. In the phytosociological weed surveys carried out in some maize fields, Khan et al. (2012) and Khatam et al. (2013) also reported that some of these weeds exhibited high importance values in the weed community. Moreover, the coexistence and abundance of Poaceae and Asteraceae weeds in some fields support the findings of Štefanić et al. (2019) from a survey of arable areas on the Istria Peninsula. Some species such as *A. conyzoides*, *O. corymbosa*, and *P. oleracea* have a short life cycle (annual) that allows them to reproduce quickly, giving them the potential for a very high intrinsic rate of increase (Global Invasive Species Database, 2022). In addition, *A. conyzoides* seeds germinate at varying temperatures to ensure survival and persistence (Paul et al., 2022). Therefore, its remarkable physiological adaptability has also contributed to its prevalence in agricultural farmlands.

Although *O. corymbosa* and *P. oleracea* are annual plants, they can act as short-lived perennials under favourable conditions (India Biodiversity Portal, 2018). In a study, Mercado and Lapitan (2018) reported abundant *A. conyzoides* and *P. oleracea* in maize and rice intercropped fields, similar to what we found in this study. The ability of these weeds to produce and disperse thousands of seeds over a long distance makes them successful in infested farmlands. *Spermacoce ocymoides* and *P. niruri*, like *O. corymbosa* and *P. oleracea*, produce numerous seeds (Mercado and Lapitan, 2018; Tropical Plants Database, 2022). At the onset of the wet season, the seeds germinate and emerge quickly. Furthermore, they are well-suited to hydromorphic soils, and mature plants may withstand floods for several years without harm.

The uneven distribution of grass, sedge and broadleaf weeds throughout the surveyed sites was caused partly by different weed management strategies. Furthermore, broadleaf weeds were more prevalent than grass and sedge species due to their smothering effect on grass and sedge species. The positive association of PCs with weed species demonstrated that increasing the abundance of one of them increases the prevalence of the others. This is consistent with the findings of

Ciaccia et al. (2019) in a study with *C. rotundus* and *P. oleracea*. Although crop combinations aimed at weed management should consider soil fertility sustainability, none of the crops intercropped with maize possessed this attribute. The composition and distribution of identified weed species demonstrated the impact of maize farmers' cropping systems. *Setaria pumila*'s significant association with sole maize cultivation, for example, suggested that weeds in the same family as a crop could be damaging to its development and production performance.

Because it belongs to the same family as the cassava component, the appearance of *E. hirta* in maize and cassava intercropped fields could be attributed to the same reason. Furthermore, the unique interaction of *S. pumila* with sole maize farmlands may be related to seed dispersal ease, long-term longevity, and fast germination and emergence (Dowsett et al., 2018). *Portulaca oleracea*, on the other hand, belongs to a different family (Portulacaceae) yet has been identified as a significant maize weed. This is consistent with the findings of Mendes et al. (2018), who reported it as a prominent maize weed. Furthermore, *P. oleracea* produces allelopathic compounds that inhibit the growth of other plants in its vicinity. In another study, Rashidi et al. (2021) demonstrated that *P. oleracea* reduced the germination of common bean (*Phaseolus vulgaris* L.) and onion seeds (*Allium cepa* L.). *Desmodium scorpiurus*, *I. triloba*, *S. anthelmia*, and *M. villosus*, on the other hand, produce a large number of seeds as a mechanism of dissemination and perpetuation in maize and rice intercropped fields. Consequently, the shading effect of their broad leaves limits the proportion of sunlight required for grass weed growth and development. The same reason likely explains the abundance of broadleaf weeds in maize and amaranthus intercropped, and maize and pepper cultivation systems. *Cynodon. dactylon* reproduces through seeds (Ngondya et al., 2019). It has a root system that can grow deep into the soil under drought conditions. These characteristics most likely contributed to its survival and abundance under the maize and pepper intercropping system. The maize and rice intercropping system resulted in mild grass infestation (*B. deflexa*), most likely due to the preponderance of broadleaf weeds in the invaded fields. This contradicts the findings of Henry et al. (2021), who found that intercropping maize with rice increased the incidence of grass weeds.

Conclusion and recommendations

In conclusion, *C. rotundus, P. oleracea, D. horizontalis, B. deflexa, S. obtusifolia, A. conyzoides, C. dactylon, P. niruri, and Eragrostis* sp. were the most important weed species in the investigated locations. Poaceae was the family with the most members. According to morphology, broadleaf species accounted for 38.2 % of the total species studied. Anguwan-Shaba_01 and Katcha_01 had the most grass weeds (100 individuals), while Sabon-Gida_01 and Anguwan-Shaba_01 had the most sedge (158 individuals) and broadleaf (268 individuals) weeds, respectively. *Setaria pumila* was strongly associated with sole maize cultivation, as was *D. scorpiurus* with maize and rice inter-cropping, *C. dactylon* with maize and pepper cultivation, *E. hirta* with maize and cassava inter-cropping, and *C. viscosa* with maize and amaranthus cultivation. These weed species are trouble-some and have the potential to impair maize productivity. Therefore, site-specific and weed-specific control measures should be prioritized when developing a sustainable weed management plan for maize production. Farmers should desist from excessive herbicide application to avoid deleterious impacts on humans, livestock and the environment.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Author contributions

MS, ED, OO, TF, and JB contributed equally to undertaking this project. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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