BILINGUAL PUBLISHING GROUP

Journal of Botanical Research

Volume 5 | Issue 2 | April 2023 | ISSN 2630-5054（Online）

Volume 5 Issue 2 • April 2023 • ISSN 2630-5054 (Online)

Journal of Botanical Research

Editor-in-Chief

Lianjun Sun

BILINGUAL PUBLISHING GROUP

Volume 5 | Issue 2 | April 2023 | Page1-75
Journal of Botanical Research

Contents

Articles

Review

Journal of Botanical Research
https://journals.bilpubgroup.com/index.php/jbr

ARTICLE

Effects of Water Stress on Growth and Chlorophyll Contents of *Ocimum gratissimum* L. (Basil) [Lamiaceae]

Surukite O. Oluwole, Simeon Y. Asokere, Mautin L. Ogun [*] ***, Tolulope S. Ewekeye, Anthony W. Ojewumi***

Department of Botany, Lagos State University, Ojo, Lagos, 102101, Nigeria

ABSTRACT

Ocimum gratissimum is an essential plant because of its wide food and medicinal usage. Despite its relevance, its morpho-physiological compositions are influenced by several abiotic stresses. Hence, this study examined the effects of water stress on the growth and chlorophyll contents of *O. gratissimum*. Seedlings of *O. gratissimum* were grown in twenty-four pots, two per pot and were arranged using a complete randomized design with four groups: Very Wet *O. gratissimum* (VWO), Moderately Water Stress *O. gratissimum* (MWSO), Strongly Water Stress *O. gratissimum* (SWSO) and Adequately Watered *O. gratissimum* (AWO) as control. Fifty centiliters of water was applied in AWO once daily, VWO twice daily, MSWO once in three days and SWSO once a week. Growth parameters: Stem height, number of leaves, leaf area, stem girth and petiole length were determined one week after treatment for six weeks. Chlorophyll contents were determined at two weeks intervals after treatment for eight weeks. Descriptive statistics such as mean ± standard deviation and one-way Analysis of Variance ($p < 0.05$) were done using SAS software. Results obtained showed the highest mean stem height (27.50 ± 0.29 cm), number of leaves (37.00 ± 9.0), leaf area (735.7 ± 4.12 cm^2), stem girth (0.40 ± 0.00 cm) and petiole length (7.20 ± 0.40 cm) in VWO. Similar results were obtained for chlorophyll (56.70 ± 0.65 mg^{-1}). It could be concluded that regular watering of *O. gratissimum* could promote growth and increase chlorophyll contents of the plant.

Keywords: Water deficit; Pigmentation; Medicinal plant; *Ocimum gratissimum*; Growth

*CORRESPONDING AUTHOR:
Mautin L. Ogun, Department of Botany, Lagos State University, Ojo, Lagos, 102101, Nigeria; Email: mautinogun@lasu.edu.ng; mautinogun@gmail.com

ARTICLE INFO
Received: 24 February 2023 | Revised: 17 March 2023 | Accepted: 21 March 2023 | Published Online: 31 March 2023
DOI: https://doi.org/10.30564/jbr.v5i2.5494

CITATION
Oluwole, S.O., Asokere, S.Y., Ogun, M.L., et al., 2023. Effects of Water Stress on Growth and Chlorophyll Contents of *Ocimum gratissimum* L. (Basil) [Lamiaceae]. Journal of Botanical Research. 5(2): 1-11. DOI: https://doi.org/10.30564/jbr.v5i2.5494

1. Introduction

Water is essential for the survival of all known forms of life. Obviously, vegetation is not an outlier. As the primary component of all living things, water plays a crucial role in a wide variety of biochemical processes, from the production of glucose during photosynthesis to the transport of nutrients and minerals [1,2]. Numerous responses from flora and fauna have been documented in response to climatic change-induced shifts in rainfall patterns and the unpredictable flooding and drought conditions they bring [3]. Water shortages or floods are common causes of plant stress. Reduced stomatal conductance, leaf area, number of leaves, and fresh weight are all results of water stress [4]. Hartmann et al. [5] reported that water stress due to drought is the most significant abiotic factor limiting plant growth and development. Hsiao and Xu [6] documented that a plant's growth is easily slowed down by water stress, and the root system is given more attention than the leaves. To conserve moisture, the leaves of plants in arid regions tend to be few and small.

Pigmentation in plants can be directly related to their stress physiology, as concentrations of carotenoid increase, there is an associated decrease in concentrations of chlorophyll under flooding conditions and the senescence process [7]. A decrease in the photosynthetic capacity of mesophyll cells during continued flooding leads to a further reduction of photosynthesis [8]. Ekanayake et al. [9] reported that moderate water stress slows chlorophyll formation while severe dehydration can be detrimental to the process of chlorophyll formation.

Ocimum gratissimum is an herbaceous plant that is a member of the Lamiaceae family [10]. The leaves, which can reach 10 × 5 cm in size, are ovate to ovate-lanceolate in shape, sub-acuminate to acuminate at the apex, cuneate and decuneate at the base, with a coarsely crenate, serrate margin, pubescent and dotted on both sides, and up to 1.9 m in height [11]. The plant's native range includes India and West Africa and other tropical regions. In Nigeria, it is found in Savannah and coastal areas, and it is known by its several vernacular names. It is called "Efrinrin-nla" for the Yorubas, "Ahuji" by the Abakaliki Igbos, "Nchuanwu" by other Igbos, "Daidoya" by the Hausas [12,13] and Sanmadido by Ogu (Egun) people of Lagos and Ogun States. Thus, this study aimed at assessing the effects of water stress on the growth and chlorophyll contents *Ocimum gratissimum*.

2. Materials and methods

2.1 Collection of materials

Experiments were conducted in a screen house located at the Botanical Garden of the Department of Botany, Faculty of Science, Lagos State University, Ojo, Lagos, Nigeria for a period of 3 months. Forty-eight (48) seedlings of *O. gratissimum* L. about a month old were obtained from the vegetable farm at the Post Service of Ojo Military Cantonment, along LASU-Igando road, Lagos. Loamy soil was obtained from ETF Research Laboratory Complex, Faculty of Science, LASU, Ojo, Lagos.

2.2 Soil preparation

Loamy soil of 8 kg was measured using a weighing balance into equally perforated plastic pots of 22 cm in depth and 16.5 cm in diameter. A total of twenty-four (24) pots were prepared and watered lightly to ease the transplanting of the seedlings the following day.

2.3 Seedling transplant and establishment

The forty-eight (48) seedlings obtained were transplanted, two per pot at 1 cm depth. The seedlings were allowed to establish themselves by providing them with 50 cL of tap water twice daily for four weeks.

2.4 Treatment inducement

The established seedlings of *O. gratissimum* were divided into four (4) groups namely, Very Wet *O. gratissimum* (VWO), Adequately Watered *O. gratissimum* (AWO) (Control), Moderately Water Stressed *O. gratissimum* (MWSO) and Strongly Water Stressed *O. gratissimum* (SWSO) arranged in completely randomized design. Each of the treatments has six replicates. The

VWO was supplied with 50 cL of tap water two (2) times daily. The AWO was supplied with 50 cL of tap water once daily. This was taken as the control experiment. The MWSO were supplied with 50 cL of tap water once in 3 days while SWSO were given 50 cL of tap water once a week.

2.5 Morphological data collection

The collection of morphological data started a week after the inducement of treatments. The morphological character measured were stem height (SH), number of leaves (NL), leaf area (LA), petiole length (PL) and stem girth (SG). Stem height and petiole length were measured and recorded in centimeters using the meter rule. Number of leaves were counted and recorded. Leaf area was gotten by multiplying leaf length by leaf breadth in square centimeters (cm^2) and was calculated using the formula of Okubena-Dipeolu et al. [14].

$$\text{Leaf area } (cm^2) = 0.853 + (\text{leaf blade length} \times \text{leaf blade breadth}) \times 8.7440$$

The stem girth was measured in centimeters using Vernier Caliper.

The morphological characters were collected weekly for six (6) consecutive weeks.

2.6 Chlorophyll contents determination

The chlorophyll contents of the leaf were determined using Dunn et al. [15] and Sumanta et al. [16] methods with slight modifications. Freshly excised 0.5 g leaves of *O. gratissimum* L. was collected from the upper, middle, and lower parts of the plant and weighed. The sample from the three (3) parts for each treatment was chopped and transferred into 20 mL of 98% Di-methyl sulfoxide (DMSO).

The mixture was stored in the refrigerator (10 °C) for about eight (8) weeks after the last chlorophyll extraction for one-time analysis. The absorbance of the extracts was then read in a visible spectrophotometer (Model V5000) at 665 and 649 wavelengths. The measurement was replicated thrice using leaves from 3 different parts of different plants for each treatment. The chlorophyll contents ($mg \cdot L^{-1}$) were calculated using the following equations according to Ekanayake et al. [9] and Sumanta et al. [16].

$$\text{Chlorophyll a (Chl.a)} = 12.47 * A_{665} - 3.62 * A_{649}$$

$$\text{Chlorophyll b (Chl.b)} = 25.06 * A_{649} - 6.5 * A_{665}$$

$$\text{Total Chlorophyll (Chl.)} = 20.2 * A_{649} + 8.02 * A_{665}$$

where A is Absorbance.

Extraction of leaf chlorophyll contents for each of the four treatments was carried out once in two (2) weeks for eight (8) weeks.

2.7 Statistical analysis

Data obtained were analyzed using Statistical Analysis System. One-way Analysis of Variance (ANOVA) was conducted to determine significant differences between the parameters. Means were separated using Duncan's Multiple Range Test (DMRT) at $p < 0.05$.

3. Results

3.1 Effects of water stress on growth characters

Stem height

The result on the effects of water stress on stem height of *O. gratissimum* showed significant differences at $p < 0.05$ among Control Plants (Adequately Watered *O. gratissimum*) (AWO), Very Wet *O. gratissimum* (VWO), Moderately Water Stressed *O. gratissimum* (MWSO) and Strongly Water Stressed *O. gratissimum* (SWSO) from the first week after treatment to the end of the experiment (**Figure 1**). The result however revealed that VWO showed significantly greater stem heights ($p < 0.05$) throughout the period of the experiment except for 1st and 2nd WAT while SWSO showed significantly least stem heights $p < 0.05$ throughout the period of the experiment (**Figure 1**).

Number of Leaves

The result on the effects of water stress on the number of leaves of *O. gratissimum* showed a significant difference at $p < 0.05$ among AWO, VWO, MWSO and SWSO from the 1st week after treatment to the end of the experiment (**Figure 2**). The result however revealed that VWO showed a significantly higher number of leaves ($p < 0.05$) from the 3rd week after treatment to the end of the experiment. While SWSO showed a significantly least number of leaves from the first week after treatment to the end of the experiment (**Figure 2**).

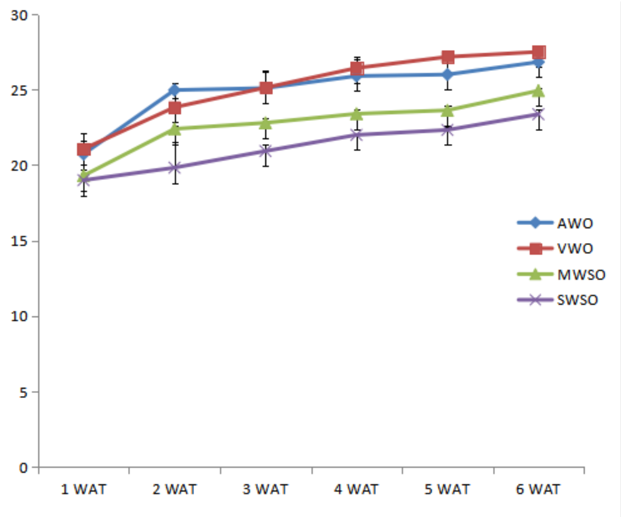

Figure 1. Effects of water stress on stem height of *O. gratissimum.*

AWO: Adequately Watered *O. gratissimum* (Control), VWO: Very Wet *O. gratissimum*, MSWO: Moderately Water Stressed *O. gratissimum*, SWSO: Strongly Water Stressed *O. gratissimum,* WAT: Week(s) After Treatment.

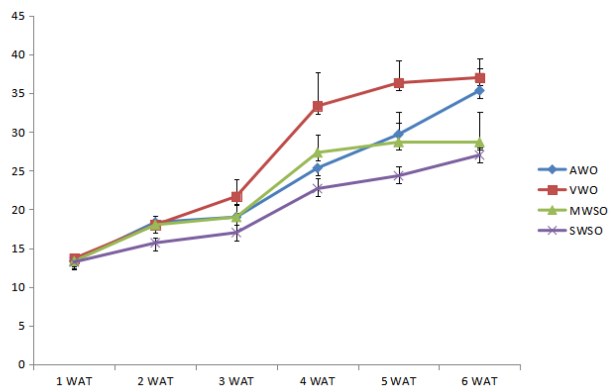

Figure 2. Effects of water stress on number of leaves of *O. gratissimum.*

AWO: Adequately Watered *O. gratissimum* (Control), VWO: Very Wet *O. gratissimum*, MSWO: Moderately Water Stressed *O. gratissimum*, SWSO: Strongly Water Stressed *O. gratissimum,* WAT: Week(s) After Treatment.

Leaf area

The result on the effects of water stress on the leaf area of *O. gratissimum* showed a significant difference at $p < 0.05$ among AWO, VWO, MWSO and SWSO respectively throughout the period of the experiment (**Figure 3**). The results however revealed the highest leaf area in VWO from the 1st week after treatment to the 6th week after treatment and the least leaf area is recorded for SWSO from the 1st week to the end of the experimental period. It can also be seen that the highest leaf area is found in very wet plants in the 6th week of the experiment (**Figure 3**).

Stem girth

The result on the effects of water stress on the stem girth of *O. gratissimum* showed significant differences at $p < 0.05$ among AWO, VWO, MWSO and SWSO respectively (**Table 1**). The result however revealed a significant increase in the stem girth of AWO and VWO from the 1st week after treatment to the end of the experiment while a significant decrease in the stem girth of MWSO and SWSO were observed in the 5th and 6th week after treatment respectively (**Table 1**).

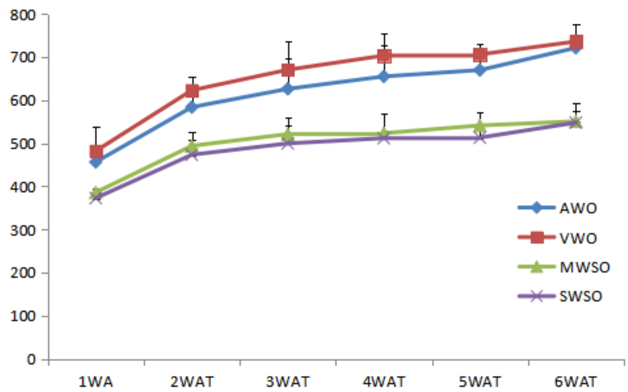

Figure 3. Effects of water stress on leaf area of *O. gratissimum.*

AWO: Adequately Watered *O. gratissimum* (Control), VWO: Very Wet *O. gratissimum*, MSWO: Moderately Water Stressed *O. gratissimum*, SWSO: Strongly Water Stressed *O. gratissimum,* WAT: Week(s) After Treatment.

Petiole length

The result on the effect of water stress on the petiole length of *O. gratissimum* showed significant differences at $p < 0.05$ among AWO, VWO, MWSO and SWSO (**Table 2**). The result however revealed a significant increase in the petiole length of AWO, VWO and MWSO throughout the experimental period while a significant decrease in the petiole length of SWSO from the 5th week after treatment was observed (**Table 2**). The highest petiole length is recorded for VWO in the 6th week after treatment.

3.2 Effects of water stress on chlorophyll contents of *O. gratissimum*

The result on the effects of water stress on chlorophyll contents of *O. gratissimum* showed significant differences at $p < 0.05$ among AWO, VWO, MWSO and SWSO respectively (**Table 3**).

The result revealed a significant increase in the chlorophyll content of AWO while a significant decrease in the chlorophyll content of plants in other treatments (VWO, MWSO and SWSO) from 2nd week after treatment to the 8th week after treatment (**Table 3**). Also, a significant increase in chlorophyll b, and total chlorophyll content was observed throughout the experiment irrespective of the treatment the plants were exposed to. However, the highest total chlorophyll content was observed in VWO in the 8th week after treatment (**Table 3**).

Table 1. Effects of water stress on stem girth of *O. gratissimum*.

Treatment	1WAT (cm)	2WAT (cm)	3WAT (cm)	4WAT (cm)	5WAT (cm)	6WAT (cm)
AWO	0.2 ± 0.00^{a}	0.27 ± 0.03^{b}	0.30 ± 0.06^{b}	0.37 ± 0.02^{a}	0.37 ± 0.03^{b}	0.40 ± 0.03^{a}
VWO	0.23 ± 0.03^{a}	0.30 ± 0.00^{a}	0.33±.0.03a	0.37 ± 0.03^{a}	0.40 ± 0.00^{a}	0.40 ± 0.00^{a}
MWSO	0.2 ± 0.00^{a}	0.27 ± 0.03^{b}	0.30±0.00b	0.32 ± 0.02^{b}	0.30 ± 0.00^{c}	0.30 ± 0.00^{b}
SWSO	0.2 ± 0.00^{a}	0.27 ± 0.03^{b}	0.30 ± 0.00^{b}	0.30 ± 0.03^{c}	0.30 ± 0.00^{c}	0.25 ± 0.03^{c}

Means in the same column that do not have similar superscripts are significantly different at $P < 0.05$.AWO: Adequately Watered *O. gratissimum* (Control), VWO: Very Wet *O. gratissimum,* MSWO: Moderately Water Stressed *O. gratissimum,* SWSO: Strongly Water Stressed *O. gratissimum*, WAT: Week(s) After Treatment.

Table 2. Effects of water stress on the petiole length of *O. gratissimum*.

Treatment	1WAT (cm)	2WAT (cm)	3WAT (cm)	4WAT (cm)	5WAT (cm)	6WAT (cm)
AWO	4.40 ± 0.31^{ab}	5.20 ± 0.4^{a}	5.40 ± 0.31^{b}	6.07 ± 0.30^{b}	6.27 ± 0.23^{b}	7.00 ± 0.35^{ab}
VWO	4.57 ± 0.23^{a}	5.20 ± 0.25^{a}	$6.20\pm.0.4^{a}$	6.93 ± 0.54^{a}	7.0 ± 0.40^{a}	7.20 ± 0.40^{a}
MWSO	4.0 ± 0.12^{cd}	4.23 ± 0.12^{c}	4.83 ± 0.33^{d}	5.03 ± 0.23^{c}	5.30 ± 0.44^{c}	5.47 ± 0.35^{c}
SWSO	4.17 ± 0.17^{bc}	4.80 ± 0.35^{ab}	5.0 ± 0.50^{c}	5.43 ± 0.29^{d}	4.63 ± 0.19^{d}	4.43 ± 0.27^{d}

Means in the same column that do not have similar superscripts are significantly different at $p < 0.05$. AWO: Adequately Watered *O. gratissimum* (Control), VWO: Very Wet *O. gratissimum,* MSWO: Moderately Water Stressed *O. gratissimum,* SWSO: Strongly Water Stressed *O. gratissimum*, WAT: Week(s) After Treatment.

Table 3. Effects of water stress on chlorophyll contents of *O. gratissimum*.

	Chlorophyll a ($mg\cdot L^{-1}$)				**Chlorophyll b ($mg\cdot L^{-1}$)**				**Total chlorophyll ($mg\cdot L^{-1}$)**			
Trmt.	**2WAT**	**4WAT**	**6WAT**	**8WAT**	**2WAT**	**4WAT**	**6WAT**	**8WAT**	**2WAT**	**4WAT**	**6WAT**	**8WAT**
AWO	19.74±0.35[a]	20.08±0.26[b]	20.54±0.17[a]	20.66±0.61[a]	18.17±3.19[a]	19.95±3.68[c]	22.78±2.82[b]	25.14±2.16[cd]	41.42±3.80[a]	43.02±3.74[c]	44.23±2.4c	47.14±2.31[c]
VWO	20.92±0.23[a]	20.55±0.27[a]	19.92±0.56[b]	18.22±0.26[d]	16.54±5.00[b]	24.60±1.09[a]	25.64±2.07[a]	36.77±0.59[a]	39.01±5.37[ab]	46.32±2.29[ab]	48.55±1.92[a]	56.70±0.65[a]
MWSO	20.98±0.17[a]	20.84±0.16[a]	20.65±0.12[a]	19.35±0.38[b]	16.83±0.11[b]	22.99±2.63[bc]	25.79±2.14[a]	26.91±1.68[c]	40.49±0.30[a]	46.31±2.38[ab]	47.22±1.74[ab]	49.90±1.54[ab]
SWSO	20.59±0.42[a]	20.56±0.89[a]	19.45±0.60[b]	18.78±0.17[c]	16.95±2.41[b]	24.03±3.45[b]	26.92±1.51[a]	30.55±0.70[b]	40.12±3.07[a]	47.35±2.77[a]	48.54±0.81[a]	51.29±0.50[b]

Means in the same column that do not have similar superscripts are significantly different at $p < 0.05$. AWO: Adequately Watered *O. gratissimum* (Control), VWO: Very Wet *O. gratissimum,* MSWO: Moderately Water Stressed *O. gratissimum,* SWSO: Strongly Water Stressed *O. gratissimum*, WAT: Week(s) After Treatment.

4. Discussion

4.1 Effects of water stress on growth characters of *O. gratissimum*

Plants' growth and survival are a function of the amount of water readily available for uptake within the reach of the plant's roots. Hence, plants suffer hardship under water stress conditions. While struggling to survive, the majority of them have demonstrated adjustment in their morphological characteristics such as stem height, leaf area, root length and so on [17].

Very Wet *O. gratissimum* (VWO) was found with the highest mean stem height throughout the experimental period except at 2 WAT while Strongly Water Stressed *O. gratissimum* (SWSO) had the least mean stem height from the first week after treatment to the sixth week after treatment (**Figure 1**). This is probably due to the very high-water requirement at the meristematic region of the plant's shoot for cell division which results in growth. Hence reduced stem height of Strongly Water Stressed *O. gratissimum* (SWSO) could be attributed to reduced growth activities caused by severe water stress. The findings of the present study corroborate the reports of those authors [1,3,6,18,19] who submitted significant mean stem height in plants subjected to regular watering. Ayeni et al. [20] found that daily-watered *Abelmoschus esculentus* seedlings had the shortest mature plants, but these results contradict that conclusion. It's possible that the crop was grown in nutrient-depleted soil, which could explain the result. The number of leaves differed significantly ($p < 0.05$) among Adequately Watered Plants *O. gratissimum* (AWO), Very Wet *O. gratissimum* (VWO), Moderately Water Stressed *O. gratissimum* (MWSO) and Strongly Water Stressed *O. gratissimum* (**Figure 2**). The highest number of leaves (37.00 ± 9.0) was obtained in plants watered twice daily compared to other treatments (**Figure 2**). This could infer that *O. gratissimum* tends to produce more leaves during water excess conditions than during water deficit conditions. The significant number of leaves recorded in VWO could be needed to give off excess water into the atmosphere as the plant has no place for storage of excess water. This agrees with the submissions of Adelani [21] and Dauda et al. [22] who reported a significant number of leaves in *Citrus tangelo*, *Abelmoschus esculentus*, *Chocorus olitorus*, *Telferia* spp and *Amaranthus* spp watered daily. Also, various investigators [23-28] have reported the highest number of leaves in plants exposed to regular watering and decreased leaf number under water stress. The significant number of leaves recorded in VWO followed by AWO could also be an indication that *O. gratissimum* requires enough water for proper growth and development and could be attributed to available nitrogen in the soil which was aided by its dissolution potential in soil watered daily and this facilitates its uptake. This agrees with the findings of Olubode et al. [29] who found that as applied moisture content increased, plant nutrient uptake did as well.

A significant leaf area was recorded in VWO. This could be ascribed to the fact that a large leaf area is needed by plants under excess water conditions to aid transpiration and photosynthetic activities. When plants are under extreme water stress, they often reduce their leaf area, stop producing new leaves, or drop their older leaves to conserve water [3]. Results of the present study are in line with the findings of Gonzales et al. [30], Oboho and Igharo [26], Olubode et al. [29], Ogunrotimi and Kayode [28], Adelani [31] who reported that regular watering enhanced leaf area and photosynthesis in plants.

A significant stem girth was also recorded in VWO. This could infer that the stem guith of *O. gratissimum* is a function of water available for uptake. However, the reduced girth found in water deficit *O. gratissimum* could be because of dehydration of the plant which must have caused reduced photosynthetic activities of the plants [32]. The findings of this study corroborate that of Olajide et al. [33] who reported a significant difference in *Dialium guineense* seedling girth due to the application of different watering regimes. However, a contrasting result was submitted by Gbadamosi [3] who reported that girth of seedlings was not significantly ($p < 0.05$) different under watering regimes and water quantity.

The findings of this study also showed significant petiole length in VWO. The length of the petiole has an influence on the leaf lamina and exposes it to the sun for effective photosynthesis. This could indicate that a long petiole is needed for effective and efficient food production and to act as a storage organ. This study agrees with the reports of Turner [34], Ohashi et al. [35] and Durigon et al. [36] who indicated a significant effect of irrigation deficit in the length of petioles and petiolules. In contrast, petiole length was not significantly influenced by soil water stress but there was a reduction in growth between weeks 3 and 6 because of other weather conditions [37].

4.2 Effects of water stress on chlorophyll contents of *O. gratissimum.*

Because water is essential to all living things and plays a role in crucial biochemical processes like photosynthesis, the productivity of plant species is affected by whether water is available in sufficient quantity and at a biologically tolerable interval [3]. Plants rely on readily available water for a wide range of essential processes, such as cell division, elongation, stem height, leaf expansion, and chlorophyll formation [38].

Results regarding chlorophyll content shown in **Table 3**, indicated a significantly different mean chlorophyll content (56.70 ± 0.65 $mg \cdot L^{-1}$) in VWO followed by SWSO (51.29 ± 0.50 $mg \cdot L^{-1}$). As a result, chlorophyll formation in *O. gratissimum* cannot be said to depend solely on water availability as chlorophyll-b and total chlorophyll content of the plant increased across the treatment all through the experiment period. This result could indicate that electron transport activity and the photosynthesis apparatus of *O. gratissimum* are not damaged by water stress. This study's findings are consistent with those of Dzomeku et al. [37], who found no correlation between soil moisture stress and chlorophyll contents and found that chlorophyll content exhibited undulating characteristics in response to the watering regime. While previous research has shown that water stress reduces wet CO_2 and photosynthesis [35,39-44], the current study finds the opposite to be true for a wheat crop under water stress conditions.

5. Conclusions and recommendation

The results of this study suggested that *O. gratissimum* benefited from an abundance of water, as it expanded and contained more chlorophyll overall. As a result, it might be recommended that this plant be given consistent watering to achieve the best possible growth performance, which in turn typically increases yield and income.

Author Contributions

Oluwole S.O and Asokere, S.Y. conceived the idea, Ogun M.L., Asokere S.Y., Ewekeye T.S. and Ojewumi A.W. designed it, Asokere S.Y., Ogun M.L. and Ojewumi A.W executed it, Oluwole S.O, Asokere S.Y., Ewekeye T.S and Ogun M.L. interpreted the data and Ogun M.L., Ewekeye T.S. and Asokere S.Y. wrote the manuscript.

Conflict of Interest

All authors declare no conflict of interest.

Funding

This research received no external funding.

Acknowledgments

Authors appreciate all members of staff of the Department of Botany, Faculty of Science, Lagos State University, Ojo, Lagos, Nigeria for their support towards the success of this study.

References

[1] Isah, A.D., Bello, A.G., Maishanu, H.M., et al., 2012. Effect of watering regime on the early growth of *Acacia senegal* (LINN) Wild provenances. International Journal of Plants, Animal and Environmental Sciences. 3(2), 52-56.

[2] Fredrick, C., Bamalo, U.M., Chima, U.D., 2018. Effect of watering regimes on the germination

and early seedling growth of *Annona muricata* Linn. Production Agriculture and Technology. 14(1), 66-72.

[3] Gbadamosi, A.E., 2014. Effect of watering regimes and water quantity on the early seedling growth of *Picralima nitida* (Stapf). Sustainable Agriculture Research. 3(2), 23-40.

[4] Vandoorne, B., Mathiew, A.S., Van den Ende, W., et al., 2012. Water stress drastically reduces root growth and inulin yield in *Cichorium intybus* (var. sativum) independently of photosynthesis. Journal of Experimental Botany. 63(12), 4359-4373.
DOI: https://dx.doi.org/10.1093/jxb/ers095

[5] Hartmann, T., College, M., Lumsden, P., 2005. Responses of different varieties of *Lolium perenne* to salivity. Annual Conference of the Society for Experimental Biology. Lancashire.

[6] Hsiao, T.C., Xu, L.K., 2000. Sensitivity of growth of roots versus leaves to water stress: biophysical analysis and relation to water transport. Journal of Experimental Botany. 51(350), 1595-1616.

[7] Penuelas, J., Filellas, I., 1998. Visible and near infra-red reflectant techniques for diagnosing plants physiological status. Trends in Science. 3, 151-156.

[8] Striker, G.G., 2012. Flooding stress on plants: Anatomical, morphological and physiological responses. Botany. 1, 3-28.

[9] Ekanayake, I.J., Oyetunji, O.J., Osonubi, O., et al., 2004. The effects of arbuscular mycorrhizal fungi and water stress on leaf chlorophyll production of cassava (*Manihot esculenta Crantz*). Journal of Food, Agriculture and Environment. 2(2), 190-196.

[10] Iwu, M.M., 1993. Handbook of African medicinal plants, 1st edition. CRC Press Inc.: Boca.

[11] Prabhu, K.S., Lobo, R., Shirwaikar, A.A., et al., 2009. *Ocimum gratissimum*: A Review of its chemical, pharmacological and ethnomedicinal properties. The open Complementary Medicine Journal. 1, 1-15.

[12] Effraim, K.D., Jacks, T.W., Sodipo, O.A., 2003. Histopathological studies on the toxicity of *Ocimum gratissimum* leave extract on some organs of rabbit. African Journal Biomedical Research. 6, 21-25.

[13] Owulade, M.O., Eghianruwa, K.I., Daramola, F.O., 2004. Effects of aqueous extracts of *Hibiscus sabdarffa* calyces and *Ocimum gratissimum* leaves on intestinal transit in rats. African Journal Biomedical Research. 7, 31-33.

[14] Okubena-Dipeolu, E., Olalusi, F., Ayeni, L.S., 2015. Comparative effects of animal manures and mineral fertilizer on agronomic parameters of telfairia occidentalis on luvisol in Lagos, Southwestern Nigeria, research & reviews. Journal of Botanical Sciences. 4(3), 37-41.

[15] Dunn, J.L., Turnbull, J.D., Robinson, S.A., 2004. Comparison of solvent regime to the extraction of photosynthetic pigment from leaves of higher plant. Functional Plant Biology. 31, 195-222.

[16] Sumanta, N., Haque, C.I., Nishika, J., et al., 2014. Spectrophotometric analysis of chlorophylls and carotenoids from commonly grown fern species by using various extracting solvents. Research Journal of Chemical Science. 4(9), 63-69.

[17] Oluwole, S.O., Ogun, M.L., Arowosegbe, S., et al., 2020. Effects of waterlogging on the growth and chlorophyll content of *Ixora coccinea* Lin. (Jungle Flame). International Journal of Plant Research. 10(1), 17-26.
DOI: https://doi.org/10.5923/j.plant.20201001.03

[18] Abdelbasit, H.E., Sadya, M., Ahamad, E., 2012. Variation in drought tolerance and survival among three provenances of *Acacia tortilis* subspecies Raddiana and subspecies Spirocarpa seedlings. Asian Journal of Agricultural Sciences. 4(2), 134-139.

[19] Mohamed, A.E., Khalid, A.I., Talaat, D.A., 2013. Effect of different watering regimes on growth performance of five tropical trees in the nursery. JONARES. 1, 14-18.

[20] Ayeni, M.J., Ale, O.E., Kayode, J., 2015. Effects of irrigation and soil types on the growth

of Okra (*Abelmoschus esculentus* L. Moench). Journal of Plants Science. 3(2), 59-63. DOI: https://doi.org/10.11648/jps.20150302.13

[21] Adelani, D.O., Aduradola, M.A., Osunsina, O., 2020. Effects of watering levels and light intensities on seedling vigour of African star apple (*Chrysophyllum albidum* G. Don). Journal of Research in Forestry, Wildlife & Environment. 12(2), 90-99.

[22] Dauda, T.O., Asiribo, O.E., Akinbode, S.O., et al., 2009. Assessment of the roles of irrigation farming in the millennium development goals. African Journal of Agricultural Research. 4(5), 445-450.

[23] Antunez, I., Retamosa, E.C., Villar, R., 2001. Relative growth rate in phylogenetically related deciduous and evergreen woody species. Oecologia. 128, 172-180.

[24] Asaolu, M.F., Asaolu, S.S., 2002. Proximate and mineral composition of cooked and uncooked *Solanum melongena*. International Journal of Food Sciences and Nutrition. 53, 103-107.

[25] Mukhtar, R.B., Mansur, M.A., Abdullahi, S., et al. , 2016. The growth of *Balanites aegyptiaca* (L.) seedlings under varied watering intervals in the nursery. Agro-Science Journal of Tropical Agriculture, Food, Environment and Extension. 15(3), 30-33.

[26] Oboho, E.G., Igharo, B., 2017. Effect of pre-germination treatments on germination and watering regimes on the early growth of Pycnanthus angolensis (Welw) Warb. Journal of Agriculture and Veterinary Science. 10(3), 62-68.

[27] Ogidan, A.O., Olajire-Ajayi, B.L., Adenuga, D.A., 2018. Assessment of watering regimes on seedlings growth performance of *Kigelia africana* (Lam.) Benth. Proceedings of 6th NSCB Biodiversity Conference. UNIUYO. p. 341-345.

[28] Ogunrotimi, D.G., Kayode, J., 2018. Effect of water regimes on early seedling growth of *Solanum macrocarpon* L.(Solanaceae). Journal of Applied Sciences. 18(2), 79-85.

[29] Olubode, S.O., Hammed, L., Odeyemi, O.M., et al., 2018. Influence of moisture regimes and organic manure on nutrient dynamics and growth of cashew. Acta Horticulturae. 1225(1225), 125-132.

[30] Gonzales, J.A., Gallardo, M., Hilal, M., et al., 2009. Psychological responses of quinoa (*Chenopodium quinoa* Wild) to drought and waterlogging stress: Dry matter partitioning. Botanical Studies. 50, 35-42.

[31] Adelani, D.O., 2019. Effect of watering regime on the growth and nutrient uptake of *Citrus Tangelo* J. W. seedling grown in a mixture of sand and pulverize *Jacaranda Mimosifolia* D. Don leaves. Journal of Research in Forestry, Wildlife and Environment. 11(3), 172-179.

[32] Oluwole, S.O., Ogun, M.L., Balogun, O.A., 2018. The Effects of different watering regimes on the growth of *Talinum trianulare* Jacq. Journal of Research and Review in Science. 5, 14-23.

[33] Olajide, O., Oyedeji, A.A., Tom, G.S., et al., 2014. Seed germination and effect of three watering regimes on the growth of *Dialium guineense* (Wild) seedlings. American Journal of Plant Sciences. 5, 3049-3059.

[34] Turner, L.B., 1991. The effect of water stress on the vegetative growth of white clover (*Trifolium repens* L.): Comparison of long-term water deficit and short-term developing water stress. Journal of Experimental Botany. 42, 311-316.

[35] Ohahsi, Y., Saneoka, H., Kounosuke, F., 2000. Effect of water stress on growth, photosynthesis and photoassimilate translocation in soybean and tropical pasture legume siratro. Soil Science and Plant Nutrition. 46(2), 417-425. DOI: https://doi.org/10.1080|003807682000.10408795

[36] Durigon, A., Evers, J., Metselaar, K., et al., 2019. Water stress permanently alters shoot architecture in common bean plants. Agronomy. 9(3), 1-22.

[37] Dzomeku, B.M., Sarkordie-Addo, J., Darkey, S.K., et al., 2016. Responses of leaf stomata parameter to induced water stress and its relationship with stomatal conductance in false horn plantain. International Journal of Plant and Soil

Science. 12(2), 1-14.

[38] Price, D.T., Black, T.A., Kelliher, F.M., 1986. Effects of sala understory removal on photosynthesis rate and stomatal conductance of Young Douglas-Fir trees. Canadian Journal of Forest Resource. 16, 90-97.

[39] Mosaad, M.G., Ortiz-Ferranru, G., Mahalakhmi, V., 1995. Tiller development and contribution to yield under different moisture regimes in two *Triticum* species. Journal of Agronomy & Crop Science. 36(6), 982-986.

[40] Setter, T.L., Waters, I., Sharma, S.K., et al., 2009. Review of wheat improvement for waterloggging tolerance in Australia and India: The importance of anaerobiosis and element toxicities associated with different soil. Annals of Botany. 103, 221-235.

[41] Lawlor, D.W., 2002. Limitation to photosynthesis in water-stressed leaves: Stomata vs. metabolism and the role of ATP. Annals of Botany. 89, 871-885.

[42] Jaleel, C.A., Manivannan, P., Wahid, A., et al., 2009. Drought Stress in plants: A review on morphological characteristics and pigments composition. International Journal of Agriculture and Biology. 11(1), 100-105.

[43] Farooq, M., Wahid, A., Kobayashi, N.J., et al., 2009. Plant drought stress: Effect, mechanisms and management. Agronomy for Sustainable Development. 29, 185-212.

[44] Riaz, A., Younis, A., Taj, A.R., et al., 2013. Effect of drought stress on growth and flowering of Marigold (*Tagetes erecta* L.). Pakistan Journal of Botany. 45(81), 123-131.

BILINGUAL PUBLISHING GROUP

Journal of Botanical Research

https://journals.bilpubgroup.com/index.php/jbr

ARTICLE

Ethno-medical Profiling of *Myrianthus arboreus* P. Beauv: A Phyto-resource Food of Chimpanzees (*Pan troglodytes* Blumenbach, 1799) in the Ubangi Eco-region of Democratic Republic of the Congo

Pascal Bobuya[1], Koto-Te-Nyiwa Ngbolua[2], Antoine Mumba[3], Masengo Ashande [4], Lemmy Lassa[2], Willy Lusasi[2], Monizi Mawunu [5], Damien Tshibangu[6], Pius Mpiana[6], Virima Mudogo[6]*

[1] *High School of Agricultural studies of Bokonzi, P.O. Box 67, Gemena, Democratic Republic of the Congo*

[2] *Department of Biology, Faculty of Science, University of Kinshasa, P.O. Box 190, Kinshasa XI, Democratic Republic of the Congo*

[3] *Department of Phytotechny, Faculty of Agricultural Sciences, National Pedagogical University, P.O. Box 8815, Kinshasa-Ngalieme, Democratic Republic of the Congo*

[4] *Department of Environment, Faculty of Science, University of Gbado-Lite, P.O. Box 111, Gbado-Lite, Democratic Republic of the Congo*

[5] *Department of Agronomy & Botanical Garden, University of Kimpa Vita, P.O. Box 77 Uige, Republic of Angola*

[6] *Department of Chemistry, Faculty of Science, University of Kinshasa, P.O. Box 190, Kinshasa XI, Democratic Republic of the Congo*

ABSTRACT

The aim of this study was to evaluate the ethnomedical knowledge of the population of South Ubangi on *Myrianthus arboreus*, a plant consumed by chimpanzees, with the assumption that this bio-resource is also used by the population in African Traditional Medicine to treat common diseases. The results revealed that *M. arboreus* treats 23 diseases in the province of South Ubangi in Democratic Republic of the Congo. Of these diseases, six (anaemia, bronchitis, tooth decay, gastritis, hypertension, and spleen) are the most cited. Anaemia and spleen are treated by all socio-cultural groups. The leaf is the most used organ (48%) followed by sap, roots, stems, bark, flowers, and seeds. Expression (61.5%) is the most used method of preparation followed by decoction, maceration, and mastication. Oral (94.5%) is the most used method of administration followed by body bath, massage, anal and auricular route. *M. arboreus* is a vulnerable species (Iv ≥ 2.5) in the study area. The diseases treated are influenced by the level of education and the profession of the respondents ($p < 0.05$). While the mode of preparation of recipes is influenced by the family situation, also the composition of recipes is influenced by gender, age and occupation ($p < 0.05$). The search for new sources of bio-inspired drugs through zoopharmacognosy may thus allow the development of effective phytomedicines for the health care of humans or non-human primates *ex situ*. Thus the need for advanced phytochemical and pharmacological studies and the domestication of *M. arboreus* for its multiple food and pharmacological uses is necessary.

Keywords: Great apes; Zoopharmacognosy; Traditional medicine; Myrianthus arboreus; Domestication

*CORRESPONDING AUTHOR:
Koto-Te-Nyiwa Ngbolua, Department of Biology, Faculty of Science, University of Kinshasa, P.O. Box 190, Kinshasa XI, Democratic Republic of the Congo; Email: jpngbolua@unikin.ac.cd

ARTICLE INFO
Received: 22 February 2023 | Revised: 21 March 2023 | Accepted: 24 March 2023 | Published Online: 31 March 2023
DOI: https://doi.org/10.30564/jbr.v5i2.5491

CITATION
Bobuya, P., Ngbolua, K.T.N., Mumba, A., et al., 2023. Ethno-medical Profiling of *Myrianthus arboreus* P. Beauv: A Phyto-resource Food of Chimpanzees (*Pan troglodytes* Blumenbach, 1799) in the Ubangi Eco-region of Democratic Republic of the Congo. Journal of Botanical Research. 5(2): 12-28. DOI: https://doi.org/10.30564/jbr.v5i2.5491

1. Introduction

Infectious diseases pose a real threat to the survival of humans and non-human primates (NHPs). They can affect the behavior and ability of animals to reproduce in their natural habitat [1]. Due to their phylogenetic proximity, these primates are characterized by their susceptibility to a large number of infectious pathogens (viruses, bacteria, protozoa, helminths, etc.). It has been shown that humans and NHPs have developed similar immune systems during ontogenic evolution and are susceptible to similar infectious diseases [2,3]. Indeed, the major histocompatibility complex class I genes required for the recognition of antigens responsible for parasitic infections are functionally similar in the genera Homo and Pan [4,5]. However, some diseases (e.g. malaria, etc.) common to both humans and HNPs can be fatal in humans, whereas they are less severe and have little or no effect on NHPs [6,7]. These NHPs use various plants for food (primary metabolites) or for self-care (secondary metabolites with pharmacological properties) [8,9]. Such self-medicating behavior also called "zoopharmacognosy" would play a key role in maintaining host-pathogen balance in NHPs and thus in coevolution through the prophylactic activity of plant food resources (nutritherapy). These plant genetic resources are also used by humans because of their therapeutic effects. Thus, zoopharmacognosy constitutes a means for understanding the phenomenon of host-parasite coevolution that can help humans to cope with emerging and re-emerging diseases. Indeed, in order to cope with infectious parasites in the natural environment, the animal kingdom has developed an anti-parasitic behaviour consisting of the use of secondary metabolites of plant origin as chemical defenses for its protection. This plant-animal association is a special case of symbiotism, which has inspired humans since prehistoric times as a source of traditional medicines. Indeed, in the forest regions of tropical Africa (notably the Congo Basin), humans cohabit with NHPs and all use a number of the plants to combat parasitic infections [1]. Such strategy maintains the balance between the host and pathogen and facilitates coevolution. Self-medication behavior in wild animals is an approach that allows the local population to identify new sources of medicines for the traditional treatment of diseases in the forest environment.

Considering the high degree of phylogenetic proximity that exists between chimpanzees and humans, the present study was initiated to assess the ethnomedical knowledge of the population of South Ubangi on *Myrianthus arboreus*, a plant consumed by chimpanzees, on the assumption that this food phytogenetic resource is also used by the population in African Traditional Medicine to treat common diseases. The aims of this study are to determine the sociodemographic parameters of the respondents, to identify the diseases treated by this plant, the organs used, its availability in the area, and the factors that influence the use of this plant genetic resource in South Ubangi.

2. Materials and methods

2.1 Study area

The present study was carried out in the province of South Ubangi in the Democratic Republic of Congo. This province is located in the Ubangi ecoregion, which is considered a sub-region of the northeastern Congolese forests. It is one of the 200 global priority terrestrial ecoregions also known as the "G200" [10]. **Figure 1** shows the geographical location of this province.

2.2 Plant material and its choice

In this study, the plant material was *Myrianthus arboreus*, a food resource for chimpanzees.

2.3 Methods

Survey period and sampling

A pre-survey was first conducted in April 2022 (with 50 respondents) followed by the actual survey from 23 May to July 2022. The pre-survey showed that 85% of the respondents had good ethnobotanical knowledge of *M. arboreus*. Thus, considering a margin of error of 5%, the sample size was estimated at 196 individuals and then rounded up to 200. The sample size is calculated by the Dagnelie formula [11] as follows:

$$n = \frac{p(1-p)z^2}{\varepsilon^2}$$

where z is the normal random variable and corresponds to 1.96 when alpha (α) is equal to 5%; ε is the allowed margin of error (5%) and p is the proportion of people with knowledge about the ethnobotanical value of *M. arboreus* (p=0.85). The stratified probability sampling method (also called proportional stratified random sampling) was adopted. Thus, the study area was divided into five strata and for each stratum, 40 people belonging to the same ethnic group were interviewed [11,12-14].

Data collection

The present study was conducted among five socio-cultural groups (Bomboma, Lobala, Mbanza, Ngbandi, and Ngombe) in the province of South Ubangi. The interview was conducted in Lingala. Survey forms designed by the "Laboratoire d'Ethnobiologie & Phytochimie Médicale" (Department of Biology, Faculty of Science & Technology, University of Kinshasa) were used as a basis for the interviews. The questions included information on socio-demographic characteristics (sex, age, socio-cultural group, and profession); ethnobotanical data (organs used, methods of preparation, diseases treated, etc.), and the availability of the species in the area.

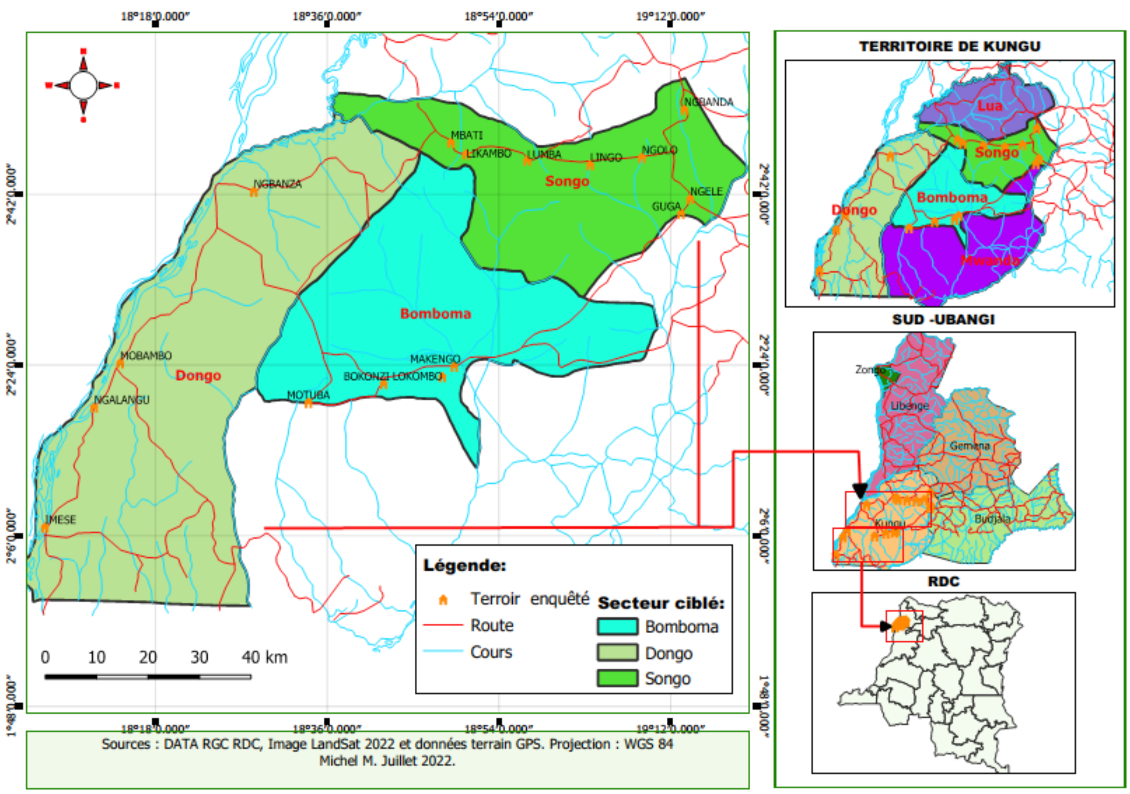

Figure 1. Geographical location of the South Ubangi province (study area).

Data processing and analysis

The socio-cultural importance of *Myrianthus arboreus* according to the socio-cultural groups surveyed was assessed using two ethnobotanical parameters namely the Consensus Disease Value (CDV) and the Frequency of Citing (FC) and the Vulnerability Index (Iv) of the plant as previously described [13].

Microsoft Excel version 2010, IBM SPSS Statistics version 20, Origin version 8.5 Pro and Past version 4.0 were used for data processing and analysis. The collected data are first encoded in Microsoft Excel and then analyzed in IBM SPSS Statistics. Univariate analyses are performed on the categorical variables (socio-demographic and ethnobotanical variables) to obtain descriptive statistics (relative frequencies). The Kolmogorov-Smirnorv test is carried out to confirm the normality of the distribution of the quantitative variables. Bivariate analyses are performed to examine the associations or links between the dependent variables (ethnobotanical parameters) and the independent variables (socio-demographic parameters). Associations between categorical variables are assessed using the Pearson Chi-square statistical test. Multivariate analyses (principal component analyses) are carried out in order to identify, from all the components or factorial axes (initial variables); those that can better explain the use of the plant in the management of the diseases listed by grouping them according to their correlation coefficients.

Ethical considerations

The research protocol for this study was approved by the Ethics Committee of the Department of Life Sciences of the University of Kinshasa. The study respected the principles of the Declaration of Helsinki (free consent of respondents, etc.). All rules of confidentiality and ethics as well as the rules of access and benefit sharing (ABS) related to the use of plant genetic resources in the Democratic Republic of the Congo were respected in this study. Respondents were informed that participation in the survey is voluntary and not subject to any coercion. They were informed that the results of this study will be returned to them in the form of open-access articles for dissemination by local leaders.

3. Results

3.1 Sociodemographic data

Figure 2 shows the age distribution of respondents in the study area.

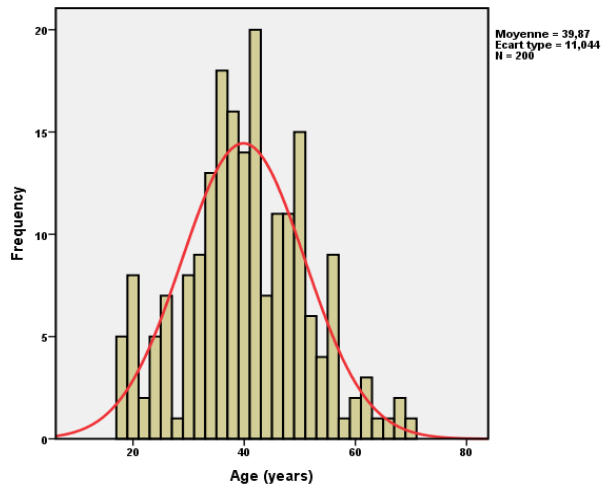

Figure 2. Age distribution of respondents in the study area.

(Legend: Moyenne = mean; Ecart type = standard deviation; N = sample size)

The figure shows that for a sample size of 200, the minimum age was 18 years, the maximum age was 70 years and the mean age was 39.87 ± 11.044 years. Statistical analysis according to Kolmogorov-Smirnov [ddl (200) = 0.069, p = 0.021] or Shapiro-Wilk [ddl (200) = 0.986, p = 0.047] shows that the age distribution of the respondents does not follow a normal distribution ($p < 0.05$) in the population of the surveyed area. Note that among the Lobala, the minimum age was 18 years, the maximum age was 62 years and the mean age was 37.70 ± 10.792 years (n = 40). Among the Ngbandi, the minimum age was 18 years; the maximum age was 61 years and the mean age was 36.07 ± 10.499 years (n = 40). Among the Bomboma, the minimum age was 18 years; the maximum age was 66 years and the mean age was 41.53 ± 10.775 years (n = 40). Among the Ngombe, the minimum age was 19 years; the maximum age was 64 years and the mean age was 41.65 ± 11.012 years (n=40). Among the Mbanza, the minimum age was 19 years, the maximum age was 70 years and the mean age was 42.38 ± 11.236 years (n = 40).

Table 1 shows the frequency of socio-demographic parameters of the respondents.

Table 1 shows that the majority of respondents are aged between 36-50 years, i.e. 52%. This is followed by those aged between 18-35 years, i.e. 33%, and finally those aged over 50 years, who represent 12%. The majority of respondents were men, 64.5%, compared to women, who represented 34.5%.

The majority of respondents have secondary education, i.e. 63.5%. This is followed by those with primary education (18.5%), university graduates (15%), and illiterates (3%). The majority of respondents are farmers, i.e. 38%. They were followed by teachers (35.5%), housewives (22%), the unemployed (2.5%), traditional practitioners (1%), and finally agronomists and traders (0.5%). The majority of respondents were married, i.e. 90%, compared to single people, who represented 10%.

Table 2 shows the distribution of respondents according to age and ethnicity.

Table 2 shows that the majority of respondents were young (18-35 years) among the Lobala, while among the other ethnic groups (Mbanza, Bomboma, Ngbandi, and Ngombe), adults were more numerous (36-50 years).

Table 1. Socio-demographic parameters of respondents.

Socio-demographic parameters		Frequency	Percentage
Age group			
	> 50 years	30	15.0
	18-35 years	66	33.0
	36-50 years	104	52.0
	Total	200	100.0
Gender			
	Female	71	35.5
	Male	129	64.5
	Total	200	100.0
Education level			
	Illiterate	6	3.0
	Primary	37	18.5
	Secondary	127	63.5
	University	30	15.0
	Total	200	100.0
Profession			
	Agronomist	1	0.5
	Unemployed	5	2.5
	Trader	1	0.5
	Cultivator	76	38.0
	Teacher	71	35.5
	Housekeeper	44	22.0
	Tradipractor	2	1.0
	Total	200	100.0
Marital status			
	Single	20	10.0
	Married	180	90.0
	Total	200	100.0

Table 2. Distribution of respondents by age and ethnicity

Age group		Ethnic groups					Total
		Bomboma	Lobala	Mbanza	Ngbandi	Ngombe	
	> 50 years	8	4	7	2	9	30
	18-35 years	9	19	8	17	13	66
	36-50 years	23	17	25	21	18	104
Total		40	40	40	40	40	200

Table 3 shows the distribution of respondents according to age and level of education.

Table 3 shows that regardless of age, the majority of respondents have a secondary education.

Table 3. Distribution of respondents according to age and level of education.

Age group		Education level				Total
		Illiterate	Primary	Secondary	University	
	> 50 years	2	10	12	6	30
	18-35 years	1	13	44	8	66
	36-50 years	3	14	71	16	104
Total		6	37	127	30	200

Table 4 shows the distribution of respondents according to ethnic group and level of education.

Table 4 shows that, regardless of ethnic group, the majority of respondents had a secondary education, except for the Ngombe, where the same number had a university education.

Table 4. Distribution of respondents according to ethnic group and level of education.

Ethnic groups		Education level				Total
		Illiterate	Primary	Secondary	University	
	Bomboma	0	5	27	8	40
	Lobala	1	2	31	6	40
	Mbanza	4	9	27	0	40
	Ngbandi	0	14	26	0	40
	Ngombe	1	7	16	16	40
Total		6	37	127	30	200

Table 5 shows the distribution of respondents according to gender and level of education.

Table 5 shows that, regardless of gender, the majority of respondents had a secondary education. It can also be noted that there were more university graduates among the men than among women, thus raising the need to encourage the enrolment of girls in school and their support up to a higher level.

Table 5. Distribution of respondents by gender and education level.

Gender		Education level				Total
		Illiterate	Primary	Secondary	University	
	Female	3	21	42	5	71
	Male	3	16	85	25	129
Total		6	37	127	30	200

Table 6 shows the distribution of respondents according to gender and level of education.

Table 6 shows that irrespective of gender, there were more married respondents than single respondents.

Table 6. Distribution of respondents by gender and education level.

Sex		**Marital status**		**Total**
		Single	Married	
	Female	12	59	71
	Male	8	121	129
Total		20	180	200

Table 7 shows the distribution of respondents by gender and ethnic group.

Table 7 shows that regardless of ethnic group, the majority of respondents were male, except among the Lobala where women were more numerous.

3.2 Ethnobotanical data

Figure 3 shows the different parts of *Myrianthus arboreus* used.

Figure 3 shows that the most used part is the leaf, 48%. This is followed by the sap (18%), the roots and stems (8.5% each), the bark (6%), and finally the flowers and seeds which represent 5.5% each.

Figure 4 shows the different diseases treated by *Myrianthus arboreus* in traditional medicine.

Figure 4 shows that the most common disease treated is anaemia (33/200), followed by bronchitis (31/200), gastritis (18/200), tooth decay (17/200), spleen (14/200), hypertension (10/200). Other conditions (cough, hemorrhoids, diarrhea, asthma, boils, dehydration, yellow fever, angina, epilepsy, viral hepatitis, headaches, lower abdomen, infections, malaria, foot oedema, measles, visual disturbance, and dermatitis, low back pain, panic attacks, and weight loss) have a low frequency of citation.

Table 7. Distribution of respondents by gender and ethnic group.

Gender		**Ethnic groups**					**Total**
		Bomboma	Lobala	Mbanza	Ngbandi	Ngombe	
	Female	13	24	13	11	10	71
	Male	27	16	27	29	30	129
Total		40	40	40	40	40	200

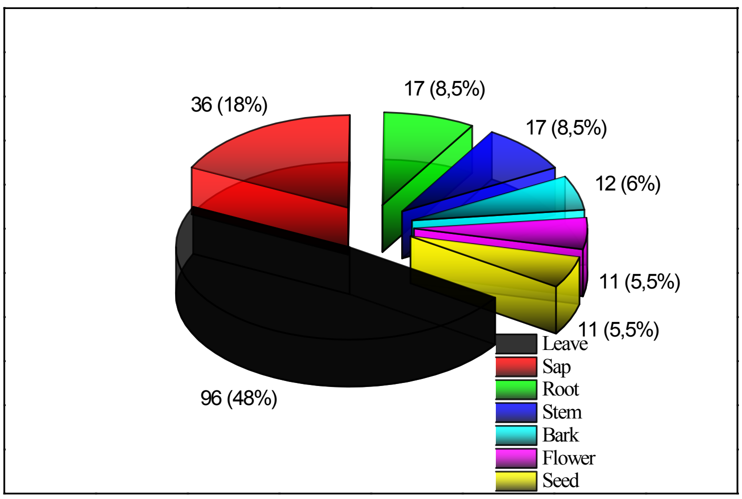

Figure 3. Used parts of *Myrianthus arboreus*.

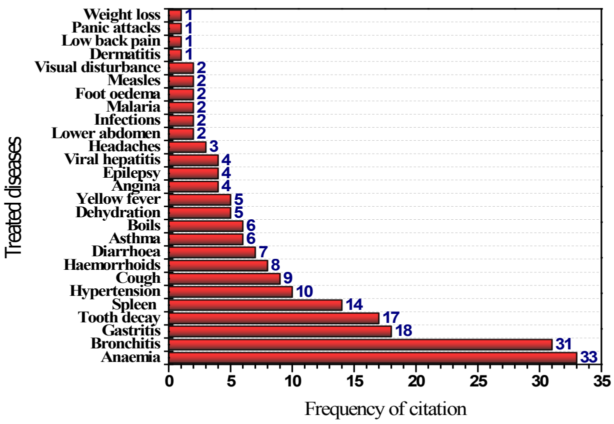

Figure 4. Diseases treated by *Myrianthus arboreus*.

Figure 5 shows the different ways of preparing *Myrianthus arboreus* recipes, while **Figure 6** shows the routes of administration.

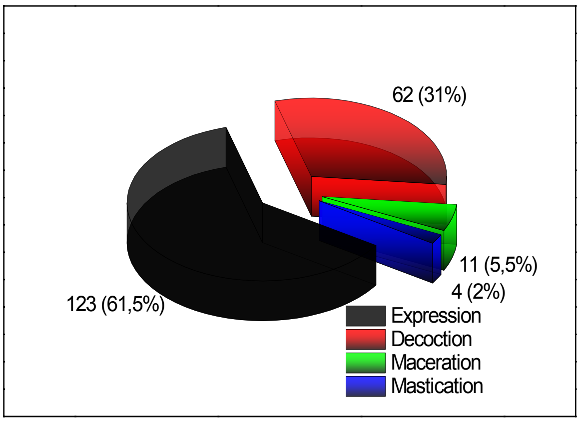

Figure 5. Recipe preparation methods.

Figure 5 shows that the most commonly used method of preparation is an expression, which accounts for 61.5%. This is followed by decoction (31%), maceration (5.5%), and finally mastication (2%).

Figure 6 shows that the most commonly used route of administration is oral (94.5%). This is followed by the body bath, massage and anal route (1.5% each). The ear route accounts for only 1%.

Figure 7 gives the composition of recipes while **Figure 8** gives the availability of the plant in the environment.

Figure 7 shows that the majority of respondents used the plant alone without combining it with another plant (i.e. 96.5%), while 3.5% of the respondents used the plant in combination with other plants.

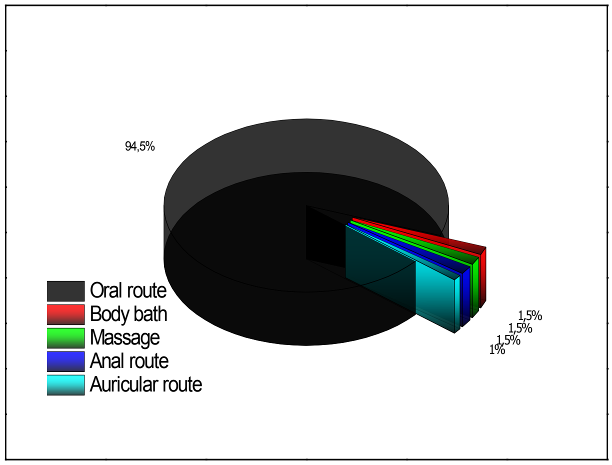

Figure 6. Recipe administration methods.

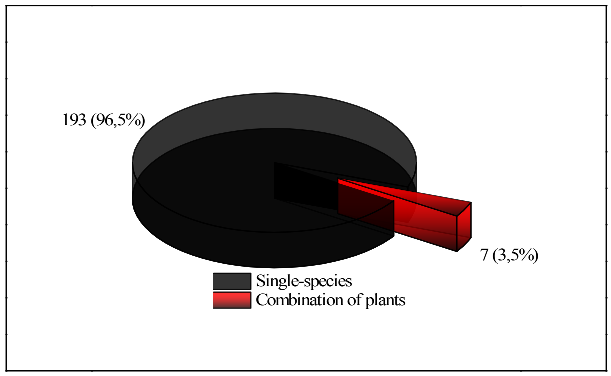

Figure 7. Composition of recipes.

Figure 8 shows that the majority of respondents (78.5%) confirm that the plant has become rare in the area. While 21.5% of the respondents said that the plant was not very abundant in the area.

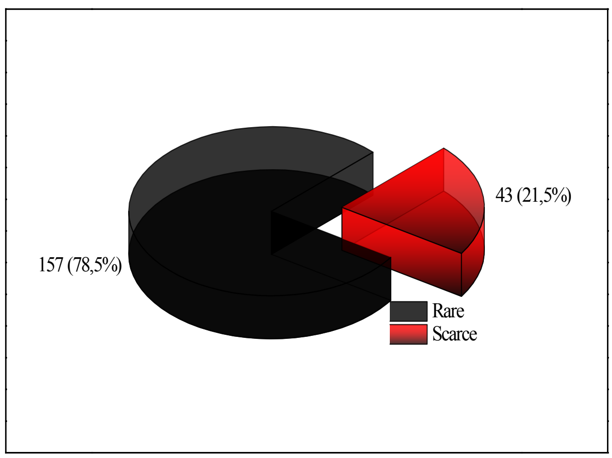

Figure 8. Availability of *Myrianthus arboreus* in the study area.

Table 8 gives the consensus value of the diseases and their frequency of mention.

Analysis of two ethnobotanical indicators, such as the consensus value of diseases and the frequency of citation, shows that six diseases (anaemia, bronchitis, tooth decay, gastritis, hypertension, and spleen) were the most cited (**Figure 4** and **Table 8**), and have received consensus from the respondents. Anaemia and spleen are treated by all socio-cultural groups.

The vulnerability index of *Myrianthus arboreus* is presented in **Table 9**.

Table 9 shows that *Myrianthus arboreus* is highly vulnerable (Iv ≥ 2.5) in the study area. According to Ngbolua [13], the vulnerability of a plant depends on a number of parameters including frequency of use, morphological type, and abundance in the environment, ethno-medical use, and parts used, biotope, mode of diaspora dissemination, stage of development of the plant and mode of collection. This index shows that if no strategy is adopted in the short term, there is a risk of extinction of this plant species, which is useful both for humans (medicine) and for great apes (food resources). It is therefore urgent to domesticate it with a view to creating a productive ecosystem (source of raw materials for the manufacture of phytomedicines, carbon sink, etc.).

3.3 Statistical analysis

Bi-variate analysis

Statistical analysis indicated that the parameter "disease treated" was influenced by the respondent's level of education and occupation ($p < 0.05$). The mode of recipe preparation was, however, influenced by the family situation, while the parameter CR (recipe composition) was influenced by gender, age, and occupation ($p < 0.05$) (**Table 10**).

The binary logistic regression modeling did not make it possible to identify the determinants or factors associated with the population's perception of the availability (1) or non-availability (0) of the plant in the environment. Indeed, the regression coefficients for each of the variables (age, gender, level of education, and family situation) are not significant ($p > 0.05$).

Multivariate analysis

a. Relationship between diseases and ethnicities

i Hierarchical bottom-up classification between ethnicities and diseases treated

The dendrogram of similarity of five ethnic groups established according to twenty-seven diseases treated with plants by the different populations that make up these ethnic groups highlights two large ethnic groups (**Figure 9**) that are significantly different ($R^2 = 0.9$). The Mbanza ethnic group, located at a Euclidean distance of 18.5, forms the first group, while the second, subdivided into three subgroups, is made up of the Ngbandi, Ngombe, Bomboma, and Lobala ethnic groups, located at a Euclidean distance of 16. It is clear that the Ngbandi population has the same ethnobotanical knowledge as the Ngombe population but is also close to the Bomboma population, which is also close to the Lobala population.

ii Correlation between diseases treated and ethnicity

The correlation matrix between twenty and seven diseases treated and five ethnic groups in the province of South Ubangi (**Figure 10**) reveals five hierarchical classes of diseases: Class 1 (An); Class 2 (Ang, As, Lb, Co, De, Der, Di, Ep, Fo, Fu, Ha, He, Hb, In, La, Ma, Me, Pa, Sp, Vh, Vd, Wl, Yf); Class 3 (Br); Class 4 (Ga) and Class 5 (Td).

b. Relationship between diseases and used plant parts

i Bottom-up hierarchical classification between plant parts used and diseases treated

Two large groups of plant parts used in the treatment of diseases that are very significantly different ($R^2 = 0.98$) are highlighted by the dendrogram resulting from the Hierarchical Clustering between diseases treated and plant parts (**Figure 11**). The leaves of the plants used alone form the first group at a Euclidean distance of 22 from the origin. Flowers, seeds, roots, stems, bark and sap form the second group at a Euclidean distance of 18 from the origin and are subdivided into several subgroups. Flowers, seeds, roots, stems and bark show similarities to sap in the treatment of different diseases.

ii Correlation between diseases treated and plant parts used.

Table 8. Consensus value of diseases and frequency of citation.

Diseases treated	**Ethnic groups**					**CVD**	**Frequency of Citation**
	Bomboma	Lobala	Mbanza	Ngbandi	Ngombe		
Anemia	11	5	2	8	7	0.14	0.17
Angina	0	0	4	0	0	0.02	0.02
Asthma	5	0	0	0	1	0.02	0.03
Lower abdomen	0	0	0	0	2	0.01	0.01
Bronchitis	7	2	0	13	9	0.13	0.16
Tooth decay	0	6	11	0	0	0.07	0.09
Dermatitis	1	0	0	0	0	0.00	0.01
Dehydration	1	0	0	3	1	0.02	0.03
Diarrhea	4	0	2	1	0	0.03	0.04
Epilepsy	0	0	3	0	1	0.02	0.02
Yellow fever	2	2	0	0	1	0.02	0.03
Furuncle	0	0	1	3	2	0.02	0.03
Gastritis	2	10	0	1	5	0.07	0.09
Hemorrhoid	0	5	0	2	1	0.03	0.04
Viral hepatitis	2	0	0	0	2	0.02	0.02
Hypertension	0	6	0	0	4	0.04	0.05
Infections	2	0	0	0	0	0.01	0.01
Low back pain	0	0	1	0	0	0.00	0.01
Malaria	0	0	0	0	2	0.01	0.01
Headache	0	0	1	2	0	0.01	0.02
Edema (feet)	0	0	2	0	0	0.01	0.01
Paronychia	0	0	1	0	0	0.00	0.01
Weight loss	0	0	1	0	0	0.00	0.01
Spleen	1	4	5	3	1	0.06	0.07
Measles	0	0	2	0	0	0.01	0.01
Cough	0	0	4	4	1	0.04	0.05
Vision impairment	2	0	0	0	0	0.01	0.01
Total	40	40	40	40	40	1.00	1.00

Legend: Consensus value of diseases (CVD).

Table 9. Vulnerability index of *Myrianthus arboreus*.

Characteristics		Vulnerability level
C1	Frequency of use: High	3
C2	Plant organ: Leaves, Sap	1
C3	Stage of development: Adult	2
C4	Collection: Picking	3
C5	Pharmaceutical form: Expression and Decoction	3
C6	Biotope: Secondary forest	2
C7	Mode of diaspora dissemination: Sarcochory	3
C8	Morphological type: Tree	3
C9	Abundance: Rare	3
Vulnerability Index (IV)		2.56

Legend: Level 1: Low vulnerability, Level 2: Medium vulnerability, Level 3: High vulnerability [13].

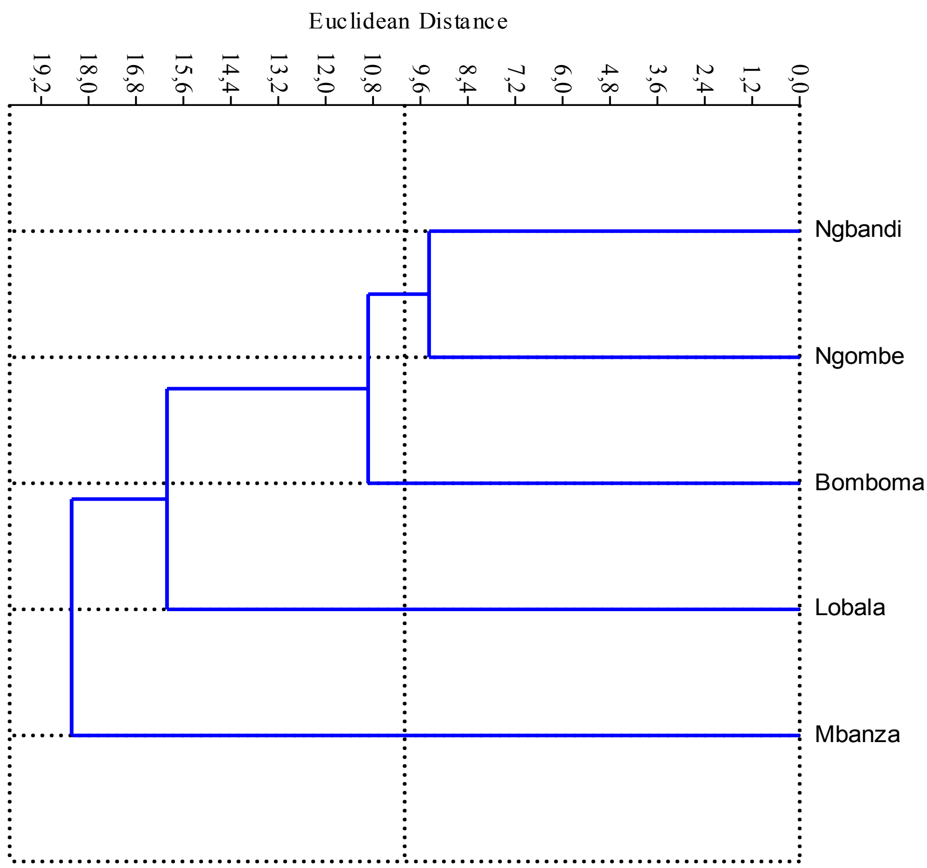

Figure 9. Hierarchical bottom-up classification of five ethnic groups according to diseases treated with plants.

Table 10. Results of the statistical analysis.

Parameters SD	Statistics	PU	MS	MP	VA	CR	Disponibility
Gender	*χ2*	4.485	28.241	4.938	4.050	3.992	0.664
	ddl	6	28	3	5	1	1
	p-value	0.611	0.453	0.176	0.542	0.046	0.415
Age group	*χ2*	9.697	71.731	7.974	11.952	6.696	0.939
	ddl	12	56	6	10	2	2
	p-value	0.6435	0.775	0.24	0.288	0.035	0.625
Education level	*χ2*	21.446	118.444	7.708	11.49	1.939	3.941
	ddl	18	84	9	15	3	3
	p-value	0.2585	0.008	0.564	0.717	0.585	0.268
Profession	*χ2*	25.796	236.829	24.925	9.078	14.873	6.522
	ddl	36	168	18	30	6	6
	p-value	0.896	0	0.127	1	0.021	0.367
Marital status	*χ2*	5.003	40.195	9.366	2.704	0.806	0.161
	ddl	6	28	3	5	1	1
	p-value	0.543	0.064	0.025	0.745	0.369	0.688

Legend: PU (part used); MS (disease treated); MP (method of preparation); VA (route of administration); CR (recipe composition).

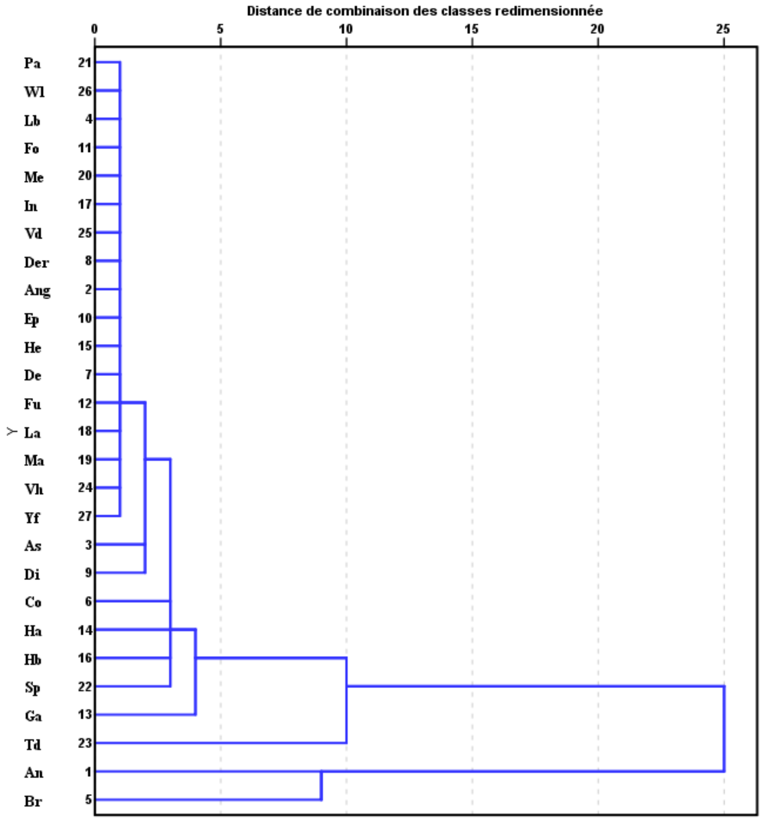

Figure 10. Hierarchical classification diagram displaying relation between twenty-seven diseases treated by five ethnic groups in the South Ubangi province.

Legend: Anaemia (An); Angina (Ang); Asthma (As); Low back pain (Lb); Bronchitis (Br); Cough (Co); Dehydration (De); Dermatitis (Der); Diarrhoea (Di); Epilepsy (Ep); Foot oedema (Fo); Furuncle (Fu); Gastritis (Ga); Haemorrhoids (Ha); Headaches (He); High blood pressure (Hb); Infections (In); Lower abdomen (La); Malaria (Ma); Measles (Me); Paronychia (Pa); Spleen (Sp); Tooth decay (Td); Viral hepatitis (Vh); Visual disturbance (Vd); Weight loss (Wl); Yellow fever (Yf).

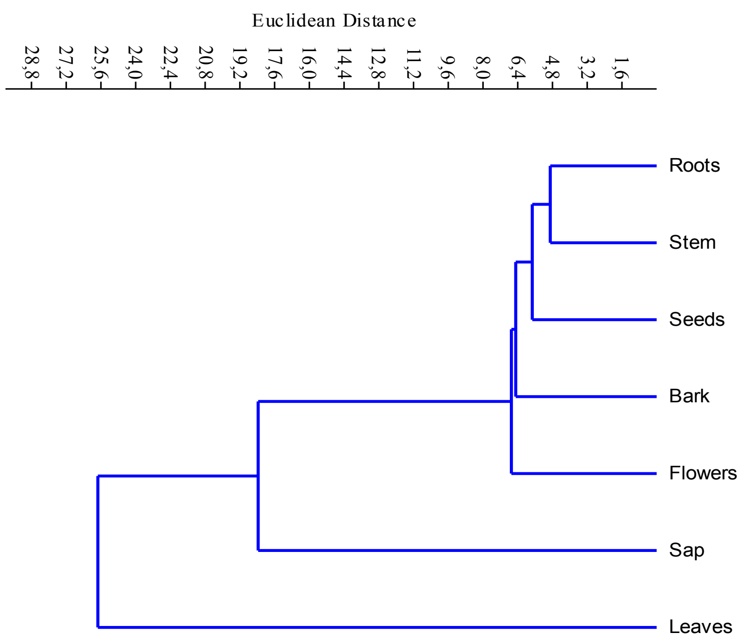

Figure 11. Hierarchical bottom-up classification of diseases treated according to plant parts used.

The different organs of *Myrianthus arboreus* are used to treat five classes of diseases (**Figure 12**): Class 1 (An); Class 2 (Ang, As, Lb, Co, De, Der, Di, Ep, Fo, Fu, Ga, Ha, He, Hb, In, La, Ma, Me, Pa, Vh, Vd, Wl, Yf); Class 3 (Br); Class 4 (Sp) and Class 5 (Td). Class 2 is the most represented with 23 diseases.

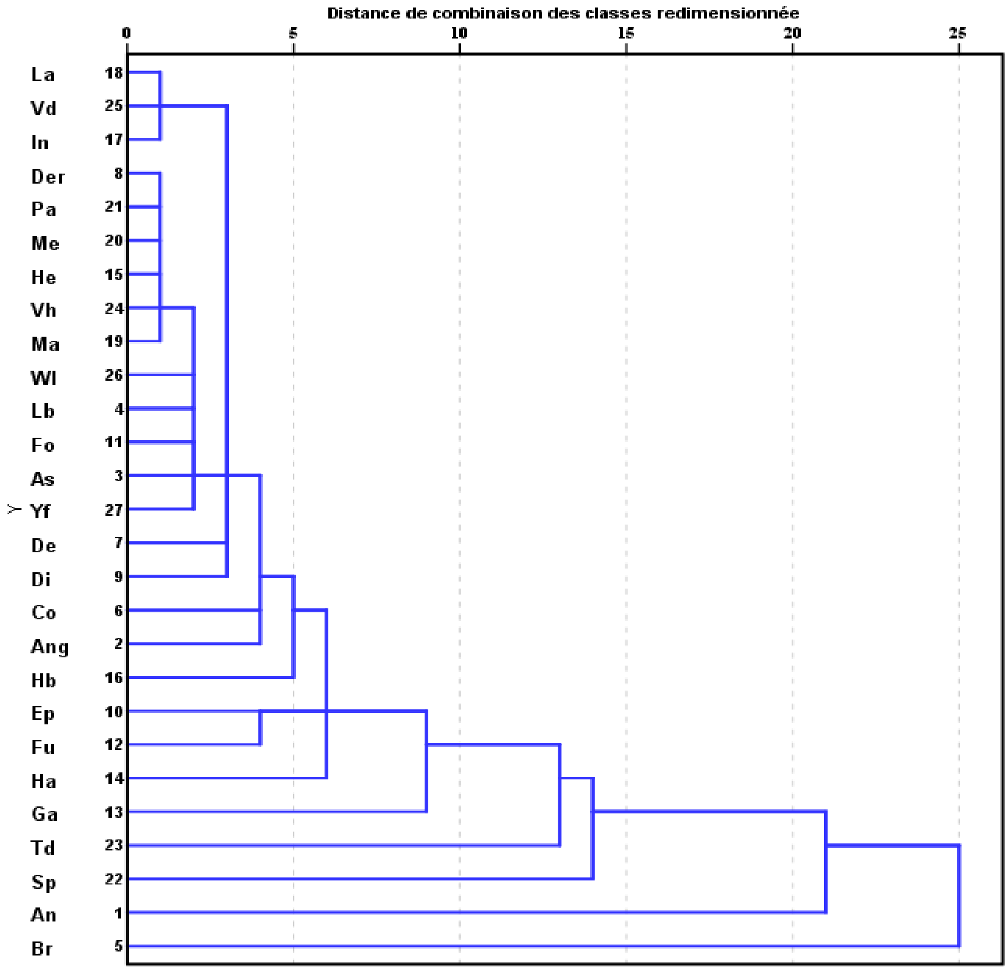

Figure 12. Hierarchical classification diagram displaying relation between twenty-seven diseases treated and plant parts used.

Legend: Anaemia (An); Angina (Ang); Asthma (As); Low back pain (Lb); Bronchitis (Br); Cough (Co); Dehydration (De); Dermatitis (Der); Diarrhoea (Di); Epilepsy (Ep); Foot oedema (Fo); Furuncle (Fu); Gastritis (Ga); Haemorrhoids (Ha); Headaches (He); High blood pressure (Hb); Infections (In); Lower abdomen (La); Malaria (Ma); Measles (Me); Paronychia (Pa); Spleen (Sp); Tooth decay (Td); Viral hepatitis (Vh); Visual disturbance (Vd); Weight loss (Wl); Yellow fever (Yf).

4. Discussion

Myrianthus arboreus P. Beauv. (Cecropiaceae) is an indigenous tree found in the secondary forests of the Ubangi ecoregion of the Democratic Republic of Congo. Its root bark is traditionally used to treat diabetes. Organs such as leaves, stem bark and trunk wood of this plant species contain pentacyclic triterpene acid compounds such as myriaboric acid, ursolic acid, euscaphic acid, tormentic acid, myrianthic acid, myrianthinic acid, arjulonic acid and arboreic acid. The leaves also contain peptide alkaloids such as myrianthin A, myrianthin B, and myrianthin C and phytosterols namely stigmasterol, β-sitosterol and β-sitosterol-3-O-β-D-glucopyranoside. Four pentacyclic triterpenes of the Δ12 ursene type containing the trans-feruloyl moiety namely 3β-O-trans-feruloyl-2α, 19α-dihydroxyurs-12-en-28-oic acid, 3β-O-trans-feruloyl-2α-hydroxy-19α-methoxyurs-12-en-28-oic acid, 2α-acetoxy-3β-O-trans-feruloyl-19α-hydroxyurs-12-en-28-oic acid, 2α-acetoxy-3β-O-trans-(3'-methoxy-4'-formyl)cinnamoyl-19α-methoxyurs-12-en-28-oic acid were also isolated from the root bark of M. arboreus. Phenolic compounds such as protocatechuic acid, myrianthiphyllin, orientin, chlorogenic acid, isoorientin and 3,4-dihydroxybenzaldehyde were isolated from this plant species. Three flavonoids, namely epicatechin, epigallocatechin and dulcisflavan, and two ursan-like triterpenoids, namely euscaphic acid and tormic acid, were also isolated from this plant. Pharmacological investigations of the plant extracts revealed anti-diabetic, wound healing, antibacterial, anti-infectious, antioxidant, antiplasmodial, anticancer and antinociceptive activities [15-18]. Severin et al. [19] reported that *Myrianthus arboreus* is a popular volunteer leafy vegetable in West Africa. This vegetable is of interest because its inclusion in the diet helps prevent cardiovascular diseases. Indeed, Amata [20] reported that the young leaves contain proteins and minerals (calcium, magnesium, potassium, phosphorus, sodium, iron, copper and zinc). The dried seeds or balls of M. arboreus are rich in lipids [21]. These seeds contain trace elements (Fe, Mn, Zn), macroelements (Ca, Mg, P, K), proteins, carbohydrates, dietary fibre, and total polyphenols [19]. The plant has antimicrobial, anti-amoebic, wound healing and antioxidant properties [15,22-24]. In Nigeria, leaf extracts are used to treat diarrhea, vomiting and amoebic dysentery [25]. In the Republic of Congo, chopped leaves are consumed raw with salt to treat pregnancy-related complications and heart disorders [26]. In the western part of the Democratic Republic of Congo, *M. arboreus* is used to treat several diseases including tooth decay, paralysis, epilepsy, external haemorrhoid, convulsions and mental disorder [27]. Apart from convulsions and mental disorders, other diseases are also recognised and treated by the same plant in the Southern Ubangi. Thus, when a plant is used in two different settings for the same purpose, its pharmacological activity will be effective. In North Ubangi, this plant is used to treat monkeypox [28,29]. According to Bobuya et al. [30], the Ngbaka of South Ubangi uses the plant to treat 23 diseases (abscesses, sinusitis, dental caries, wounds, gastritis, hemorrhoids, anemia, amoebic dysentery, vomiting, otitis, eye pain, bronchitis, breastfeeding, back pain, headache, macrocephaly, sickle cell anemia, malaria, lower abdomen, heart palpitations, epilepsy, hernia, and menstrual disorders). The nutritional and pharmaco-biological properties of *M. arboreus* make this biological resource a choice plant material for domestication for *ex situ* conservation.

5. Conclusions

The aim of this study was to assess the ethno-medical knowledge of the Southern Ubangi population on *Myrianthus arboreus* (a plant consumed by chimpanzees). The study found that *M. arboreus* cures 27 diseases; six diseases (anaemia, bronchitis, tooth decay, gastritis, hypertension and spleen) are the most cited. Anaemia and spleen are treated by all socio-cultural groups. The leaf is the most used organ followed by the sap, roots, stems, bark, flowers and seeds. Expression is the most used method of preparation, followed by decoction, maceration and mastication. The oral route is the most used route of administration followed by body bath, massage, anal route and auricular route. *M. arboreus* is a vulnerable species in the study area. The disease treated is influenced by the respondent's level of education and occupation. The mode of preparation of recipes is influenced by the family situation, while the composition of recipes is influenced by sex, age and profession. The Ngbandi ethnic group has the same ethnobotanical knowledge as the Ngombe ethnic group but both are close to the Bomboma and Lobala. The search for new sources of bio-inspired medicines through zoopharmacognosy can thus allow the development of alicaments or nutraceuticals to fight against human diseases but also for the health care of HNPs ex situ. Hence, the need to conduct more in-depth chemical and biological studies on *M. arboreus* with a view to its pharmaceutical valorization according to the principle of access and benefit sharing but also its domestication.

Author Contributions

Conceptualization, P.B. and K.N.N.; Methodology, P.B. and K.N.N.; Formal analysis, D.A., J.D.M., M.K., N.K.N., and M.M.; Investigation, M.M; Writing - original draft preparation, P.B., K.N.N. and A.M. Writing - review, and editing, P.B., K.N.N., A.M., C.M., L.L., M.M., D.T., P.T., and V.M. All authors have read, and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare that there is not conflict of interest.

Funding

This research received no external funding.

Acknowledgments

The authors would like to thank the population of South Ubangi Province for their free consent to participate in this study. They also thank the "Laboratory of Ethno-biology and Medical Phyto-chemistry (E-PHYMED)" of the University of Kinshasa for technical assistance.

References

[1] Huffman, M.A., Koshimizu, K., Ohigashi, H., 1996. Ethnobotany and zoopharmacognosy of *Vernonia amygdalina*, a médicinal plant used by humans and chimpanzees. Caligari, P D S, Hind, D J N Compositae Biology and utilization. 31(304), 351-360.

[2] Leendertz, F.H., Pauli, G., Maetz-Rensing, K., et al., 2006. Pathogens as drivers of population declines: The importance of systematic monitoring in great apes and other threatened mammals. Biological Conservation. 131(2), 325-337. DOI: https://doi.org/10.1016/j.biocon.2006.05.002

[3] Woodford, M.H., Butynski, T.M., Karesh, W.B., 2002. Habituating the great apes: The disease risks. Oryx. 36(2), 153-160. DOI: https://doi.org/10.1017/S0030605302000224

[4] De Groot, N.G., Otting, N., Doxiadis, G.G.M., et al., 2002. Evidence for an ancient selective sweep in the MHC class I gene repertoire of chimpanzees. Proceedings of the National Academy of Sciences of the United States of America. 99(18), 11748-11753. DOI: https://doi.org/10.1073/pnas.182420799

[5] Maibach, V., Hans, J.B., Hvilsom, C., et al., 2017. MHC class I diversity in chimpanzees and bonobos. Immunogenetics. 69(10), 661-676. DOI: https://doi.org/10.1007/s00251-017-0990-x

[6] De Groot, N.G., Stevens, J.M.G., Bontrop, R.E., 2018. Does the MHC confer protection against malaria in bonobos? Trends in Immunology. 39(10), 768-771. DOI: https://doi.org/10.1016/j.it.2018.07.004

[7] Kambale, D.D., Masi, S., Lrela, A.K., et al., 2022. Le régime alimentaire des Gorilles de plaine de l'Est, *Gorilla beringei graueri* et la pharmacopée humaine : Alimentation ou automédication? (French) [The diet of Eastern Lowland Gorillas, Gorilla beringei grauri and the human pharmacopoeia: Food or self-medication?]. Journal de Primatologie. 13. DOI: https://doi.org/10.4000/primatologie.13443

[8] Mongeke, M.M., Ngbolua, K.N., Bakola, R.D., et al., 2018. Enquête sur les plantes utilisées en médecine traditionnelle par les Bambenga: Pygmées du secteur de Dongo en République Démocratique du Congo (French) [Survey on plants used in traditional medicine by the Bambenga: Pygmies of the Dongo sector in the Democratic Republic of the Congo]. Revue Marocaine des Sciences Agronomiques et Vétérinaires. 6(4), 469-475.

[9] Ngbolua, K.N., Shetonde, O.M., Mpiana, P.T., et al., 2016. Ethno-pharmacological survey and ecological studies of some plants used in traditional medicine in Kinshasa city (Democratic Republic of the Congo). Tropical Plant Research. 3(2), 413-427.

[10] Ngbolua, K.N., Ndanga, B.A., Gbatea, K.A. et al., 2018. Environmental impact of wood-energy consumption by households in Democratic

Republic of the Congo: A Case Study of Gbadolite City, Nord-Ubangi. International Journal of Energy and Sustainable Development. 3(4), 64-71.

[11] Masengo, C.A., Bongo, N.G., Robijaona, B., et al., 2021. Etude ethnobotanique quantitative et valeur socioculturelle de Lippia multiflora Moldenke (Verbenaceae) à Kinshasa, République démocratique du Congo (French) [Quantitative ethnobotanical study and socio-cultural value of *Lippia multiflora* Moldenke (Verbenaceae) in Kinshasa, Democratic Republic of the Congo]. Revue Marocaine des Sciences Agronomiques et Vétérinaires. 9(1), 93-101.

[12] Ngbolua, K.N., Inkoto, C., Mongo, N., et al., 2019. Étude ethnobotanique et floristique de quelques plantes médicinales commercialisées à Kinshasa, République démocratique du Congo (French) [Ethnobotanical and floristic study of some medicinal plants marketed in Kinshasa, Democratic Republic of the Congo]. Revue Marocaine des Sciences Agronomiques et Vétérinaires. 7(1), 118-128.

[13] Ngbolua, K.N., 2020. Ethnobotanique quantitative: Approches méthodologiques pour l'évaluation et la valorisation des connaissances endogènes dans les régions tropicales (French) [Quantitative Ethnobotany: Methodological approaches for the evaluation and valorization of endogenous knowledge in tropical regions]. Éditions universitaires européennes: Latvia.

[14] Masengo, C.A., Inkoto, C.L., Munsebi, J.M., et al., 2021. Connaissance et utilisation de *Quassia africana* (Simaroubaceae) par les Mongo, Yaka et Yombe de Kinshasa en République démocratique du Congo (French) [Knowledge and uses of *Quassia africana* (Simaroubaceae) by the Mongo, Yaka and Yombe peoples of Kinshasa in the Democratic Republic of the Congo]. Revue Marocaine des Sciences Agronomiques et Vétérinaires. 9(4), 761-769.

[15] Kasangana, P.B., Haddad, P.S., Hoda, M.E., et al., 2018. Bioactive pentacyclic triterpenes from the root bark extract of *Myrianthus arboreus*, a species used traditionally to treat type-2 diabetes. Journal of Natural Products. 81, 2169-2176.
DOI: https://doi.org/10.1021/acs.jnatprod.8b00079

[16] Kasangana, P.B., Eid, H.M., Nachar, A., et al., 2019. Further isolation and identification of anti-diabetic principles from root bark of *Myrianthus arboreus* P. Beauv.: the ethyl acetate fraction contains bioactive phenolic compounds that improve liver cell glucose homeostasis. Journal of Ethnopharmacology. 245, 112-167.
DOI: https://doi.org/10.1016/j.jep.2019.112167

[17] Kingsley, B.H., Akosua, R.D., Kingsley, I.A., et al., 2020. Flavanols and triterpenoids from *Myrianthus arboreus* ameliorate hyperglycaemia in streptozotocin-induced diabetic rats possibly *via* glucose uptake enhancement and α-amylase inhibition. Biomedicine & Pharmacotherapy. 132, 110847.
DOI: https://doi.org/10.1016/j.biopha.2020.110847

[18] Katemo, M., Mpiana, P.T., Mbala, B.M., et al., 2012. Ethnopharmacological survey of plants used against diabetes in Kisangani city (DR Congo). Journal of Ethnopharmacology. 144(1), 39-43.
DOI: https://doi.org/10.1016/j.jep.2012.08.022

[19] Severin, Y.K., Marcel, K.K., Janat, A.M.B., et al., 2018. Variabilité chimique et nutritive des graines de *Myrianthus arboreus* P. Beauv. (Cecropiaceae) de quatre régions de la Côte d'Ivoire (French) [Chemical and nutritive variability of *Myrianthus arboreus* P. Beauv. seeds (Cecropiaceae) from four regions of Ivory Cost]. Journal de la Société ouest-africaine de chimie. 045, 27-30.

[20] Amata, I.A., 2010. Valeur nutritionnelle des feuilles de *Myrianthus arboreus* : Une plante à brouter (French) [Nutritional value of *Myrianthus arboreus* leaves: A plant browse]. International Journal of Agricultural Research. 5, 576-581.

[21] Katou, Y.S., 2015. Caractérisation chimique et

physico-chimique de la matière grasse extraite des graines de *Myrianthus arboreus* (Cecropiaceae) de Côte d'Ivoire (French) [Chemical and physico-chemical characterization of the fat extracted from *Myrianthus arboreus* (Cecropiaceae) seeds from Côte d'Ivoire]. [Master's thesis]. Abidjan: Université Nangui Abrogoua. p. 58.

[22] Biapa, P., Agbor, G.A., Oben, J.E. et al., 2008. Phytochemical studies and antioxidant properties of four medicinal plants used in Cameroon. African Journal of Traditional, Complementary and Alternative Medicines. 4(4), 495-500.

[23] Omotayo, F.O., Borokini, T.I., 2012. Comparative phytochemical and ethnomedicinal survey of selected medicinal plants in Nigeria. Scientific Research and Essays. 7(9), 989-999.

[24] Olonode, E.T., Aderibigbe, A.O., Bakre, A.G., 2015. Anti-nociceptive activity of the crude extract of *Myrianthus arboreus* P. Beauv (Cecropiaceae) in mice. Journal of Ethnopharmacology. 171, 94-98.

[25] Agwa, O.K., Chuku, W., Obichi, E.A., 2011. The *in vitro* effect of *Myrianthus arboreus* leaf extract on some pathogenic bacteria of clinical origin. Journal of Microbiology and Biotechnology Research. 1(4), 77-85.

[26] Agyare, C., Ansah, A.O., Ossei, P.P.S., et al., 2014. Wound healing and anti-infective properties of *Myrianthus arboreus* and Alchornea cordifolia. Medicinal Chemistry. 4, 533-539.

[27] Konda, K., Bavukinina, N.M., Mbembe, B.R., et al., 2015. Traditional medicinal plants of the Democratic Republic of Congo-Preliminary Data. IRSS: Kinshasa.

[28] Djolu, R.D., Ngbolua, K.N., Masengo, C.A., et al., 2021. Survey on Monkeypox virus circulation at the wild animal-human interface in Ubangi Ecoregion (Democratic Republic of the Congo): The case study of Businga Territory. Akinik Publication: New Delhi. pp. 83-95.
DOI: https://doi.org/ed.book.1324

[29] Ngbolua, K.N., Djolu, D.R., Iteku, B.J., et al., 2022. Survey on knowledge and on some cases of Monkeypox: A zoonotic disease endemic to Ubangian eco-region of Democratic Republic of the Congo. Britain International of Exact Sciences (BIoEx) Journal. 4(3), 137-148.
DOI: https://doi.org/10.33258/bioex.v4i3.737

[30] Bobuya, P.N., Ngbolondo, J.M., Zwave, K.A., et al., 2022. Ethnobotanical value of *Myrianthus arboreus* used in traditional medicine by the Ngbaka Tribe (South-Ubangi), Democratic Republic of the Congo. Budapest International Research in Exact Sciences (BirEx) Journal. 4(4), 341-350.
DOI: https://doi.org/10.33258/birex.v4i4.7128

Journal of Botanical Research
https://journals.bilpubgroup.com/index.php/jbr

ARTICLE

Weed Species Composition in Paddy Field of Usur Town, Bade Local Government, Yobe State, Nigeria

Mohammed Alhaji Bello[1*], Halima Mohammed Abba[2], Umar Mohammed[3]

[1] *Department of Biological Science Education, School of Sciences, Umar Suleiman College of Education Gashua, P.M.B. 02, Yobe State, Nigeria*

[2] *Department of Botany, Faculty of Sciences, Gombe State University, Gombe State, 760211, Nigeria*

[3] *Department of Agricultural Science Education, School of Vocational Education, Umar Suleiman College of Education Gashua, P.M.B. 02, Yobe State, Nigeria*

ABSTRACT

Farmers are eager to know the various types of weeds in paddy fields. This will help in choosing the best weed management practice for effective weed control as well as reducing rice yield losses. The objectives of the study are to identify the weeds species affecting the rice field, to assess the composition of weeds species, to classify the weed species into different families, genera, species, common names, Hausa names, lifecycles, life forms, native/exotic species, propagation and uses, and to determine the dominant weed species. Random vegetation surveys were conducted. Weeds observed were photographed, and prepared as herbarium specimens. Standard key manuals and checklists were utilized for weed identification and later organized using the Angiosperm Phylogeny Group (APG) classification system. A total number of 72 plants species distributed within 16 families and 50 genera were inventoried. The annuals (66.67%) were the dominant weed followed by perennials (33.33%) while biennials were the least. The broad leaves were the dominant weed (44.61%) identified followed by Poaceae (27.7%) and Sedges (11.11%). Results obtained from this study could be useful in choosing the best management practice and in making a decision on the choice of herbicides and directing research towards improved weed control measures.

Keywords: Rice; Dominant weeds; Exotic species; Native species; Weed classification

*CORRESPONDING AUTHOR:
Mohammed Alhaji Bello, Department of Biological Science Education, School of Sciences, Umar Suleiman College of Education Gashua, P.M.B. 02, Yobe State, Nigeria; Email: alaminsadiya@yahoo.com

ARTICLE INFO
Received: 24 February 2023 | Revised: 25 March 2023 | Accepted: 27 March 2023 | Published Online: 5 April 2023
DOI: https://doi.org/10.30564/jbr.v5i2.5507

CITATION
Bello, M.A., Abba, H.M., Mohammed, U., 2023. Weed Species Composition in Paddy Field of Usur Town, Bade Local Government, Yobe State, Nigeria. Journal of Botanical Research. 5(2): 29-48. DOI: https://doi.org/10.30564/jbr.v5i2.5507

1. Introduction

A weed is a plant not valued for utility or beauty, but it is not a historically stable category because neither usefulness nor attractiveness is a stable category [1]. Weed is an unwanted and undesirable plant that interferes with a variety of human activities through the utilization of land and water resources. In agriculture, weed is grown in association with crops and snatches major parts of water, light, nutrients, space and carbon dioxide (CO_2) available to the crops, providing hosts and vectors for plant pathogens, giving them the opportunity to infect and degrade the quality of the desired plants. As a result of competition with the crop, the production of crops is affected. Therefore control of weeds is important in agriculture. According to Gerasimova & Mitova, weeds are a component of biological diversity in agricultural systems (agrobiodiversity) and one of the greatest limiting factors in efficient organic crop production [2]. The composition of weeds forms the base of the food chain for herbivores and other heterotrophs, supporting many species of pests and beneficial insects, particularly pollinators [3]. Similarly, farmland benefits from nutrient recycling, and several other soil conservation functions of diverse weed species in an ecosystem [4]. Studies on the floristic composition of weed communities and distribution of weed species provide weed biologists with the quantitative information that is necessary for designing weed management programs and provide baseline data for measuring changes in the weed flora in the future. Moreover, such studies are helpful in determining how a weed population changes over time in response to selective pressures due to field management practices [5].

The floristic composition and distribution of weeds within the crop fields depend on the cultural practices within the agricultural fields, crop type, tillage systems, soil type, moisture availability, location and season [6]. Weeds can also harbor plant pathogens and pests, spread infection in crop plants and thus degrade their quality [7]. Weeds have spaciously flourished all over the world imparting a tremendous cost on paddy production [8]. Nevertheless, weed management techniques on farmland vary based on several factors; changes in agronomic practices influence weed diversity as many of these practices such as tillage, crop rotation, and fertilization have a direct influence on the floristic composition and diversity, and density of weed communities [9].

Weeds have some characteristics, such as short seed dormancy, high seed germination rate, environmental plasticity, high seedling growth and reproductive capacity, short life cycle, self-compatibility, efficient and well-organized methods of seed dispersal, allelopathy and tolerance to abiotic and biotic stresses. Therefore, due to these reasons weeds are becoming dominant all over the world [10]. A weed is a native or introduced (alien) species that has a perceived negative ecological or economic effect on agricultural or natural systems. Climatic, edaphic and biotic factors prevailing in each of the agro-ecological regions influence the formation of vegetation in that area [10].

In Nigeria rice has become an important strategic and daily food crop. The potential land area for rice production is between 4.6 and 4.9 million ha [11]. However, only about 1.7 million hectares are presently cropped to rice. The main production ecologies for rice in Nigeria are rain-fed lowland, rain-fed upland, irrigated lowland, deep water boating and mangrove swamp [11]. Rice is grown under different ecological conditions as it is grown in upland, medium land and lowland with different cultural techniques through direct seedling, transplanting and system of rice intensification (SRI) under puddle conditions. Rain-fed lowland rice has the largest share of the rice area (50%) and rice production for small-scale farmers with farm holdings of less than one (1) hectare cultivate most of the rice produced in Nigeria. Rice production and productivity at the farm level are constrained by several factors, one of which is the problem of weeds [11].

Nigeria is currently the largest rice-producing country in Africa, this is a result of the efforts by the current Government administration of (President Muhammad Buhari) he placed more emphasis on agrarian production which provides seeds, types of equipment, and chemicals for the control of weeds which increases the annual rice production from 5.5 million tons in 2015 to 5.8 million tons in 2017 [12]. In 2018, rice paddy production in Nigeria increased from 325,000 tons in 1969 to 6.81 million tons 2018 growing at an average annual rate of 8.76% [13]. Samba [14] stated that, poverty does not allow farmers to widely use the herbicide for weed control because of their high cost, therefore weed infestation is an important agronomic constraint, and successful weed control is essential for improving crop production. Rice yield losses caused by weeds depend on species composition, density and duration of infestation including the associated environmental conditions such as pH and salinity that may vary according to locations [15].

Weeds are considered to be one of the major biotic constraints in achieving higher crop productivity that cause a reduction of 10%-90% to grain yield. Weedy rice (*Oryza* spp.) is the most difficult weed control in rice, causing as much as 90% yield loss or abandonment of severely infested fields. Weeds are responsible for heavy yield losses in rice, to the extent of complete crop failure under severe infestation conditions in Usur, Bade Local Government Area (L.G.A.) Improvements in the productivity of crops can be achieved by combating problematic weeds associated with the agricultural fields. Therefore, it is of vital importance for every country to keep a record of the composition and distribution of its weeds, and identify whether they are native or exotic/introduced/aliens/invaders. Thus, there is an urgent need to carry out a study especially in Yobe State and Bade L.G.A. in particular where the flora is not well documented.

The aim of this study is to determine the weed species composition in the rice field of Usur, Bade L.G.A. Yobe State. The objectives of the study are to identify the weeds species affecting the rice field, to assess the composition of weeds species, to classify the weed species into different families, genera, species, common names, Hausa names, lifecycle, life forms, native/exotic species, propagation and uses, and to determine the dominant weed species.

2. Material and methods

2.1 Description of the study area

Bade L.G.A. lies along latitude 12° 50’ N and longitude 10° 55’ E with an altitude of 335 m above sea level. The experiment was conducted in the Usur village rice field about 6 kilometers from Bade L.G.A. headquarters, Gashu’a town. Bade Local Government Area is found in Yobe state which is the northeast geopolitical zone in Nigeria. It has an area of 809.661 km^2 with a population of 139,804 (NPC, 2010) (**Figure 1**).

Vegetation

The vegetation of the study area is sparse vegetation, and the major vegetation type is Sudan Savannah with scattered acacia trees. There is also an area of Sahel Savannah consisting of sandy soils and thorn scrub located far north [16]. The plants include short trees about 5-10 m e.g. *Anogeissus leiocarpa, Acacia seyel, Balanites aegyptica, Faidherbia albida* and grasses *Cenchus biflorus, Heteropogon contortus* [16,17].

Climate

The climate is characterized by high temperatures and seasonal rainfall. The mean minimum temperature ranges between 10 °C and 20 °C in December/January, while the mean maximum is about 34-40 °C in March/May [18].

Bade L.G.A. experienced an annual rainfall of 500 mm to 1000 mm, the mean rainfall is between 300-500 mm per annum and is unimodal and last mostly from June to September, while the dry season starts from October to May [18].

Soil

The soil of Usur, Bade L.G.A. is sandy loamy in texture, high in bulk density, low porosity and weak structure and very low in organic matter content. The physical properties are sand 619.43g kg^{-1}, silt 321.83g kg^{-1}, clay 58.73 kg^{-1}, texture content SL, bulk density 1.64 $mg \cdot m^{-3}$ and porosity 38.33%, mean weight diameter 0.78 mm and soil organic matter 1.48 $g \cdot kg^{-1}$, the soil of the area is lixisols [19].

2.2 Instrument/materials used

Garmin eTrex 10 Worldwide Handheld (GPS) Navigator Model No. 010-00970-00 (taking the position of land).

Plant press/newspapers (for collection of weed samples).

100 m tape (for measuring farm distance).

A4 paper/pencil (for taking data).

Hand trowel (for digging out weed roots).

Mapping stick.

2.3 Data collection

An area of 10 hectares of farmland was sampled.

The research method selected for the study is a random vegetation survey [20,21].

The weeds species sample was collected from the month of June to October, 2020. The first weed inventory was made in July 15 days after rice plant emergence and continued subsequently within a periodicity of 15-20 days until after harvest in October, 2020 [20,21].

2.4 Identification of weed species

Botanical identification of weed species in rice fields was done using external morphological characteristics of plant parts involving fruits, flowers, leaves, and stem bark and sap were used for identification and also with the help of weed floras, manuals, and checklists [22,23].

The specimens were collected and compared with herbarium specimens of the Botany Department Gombe State University, Gombe where herbarium vouchers numbers were given for each specimen. All the weed specimens that were given herbarium voucher numbers were arranged alphabetically according to the distribution of the family.

The identified weed species were represented alphabetically according to their scientific names, genera, and families, common names and life forms and their uses. The life forms of plant species were recognized using Raunkiaer classification system [24]. A botanical weed composition was calculated using density data. Weed composition is the proportion (%) of various weeds species in relation to the total in a given area.

The identified voucher specimen was deposited in the herbarium of the Department of Botany, Gombe State University, Gombe.

2.5 Data analysis

Data analysis of collected and identified weeds (**Figure 1**) was organized according to the classification systems established in the Angiosperm Phylogeny Group III Guidelines (APG III, 2009) and African Plant Data Base [14].

The weed composition is the proportion (%) of various weed species in relation to the total in a given area.

$$\% \, Composition \, Spp. \, A = \frac{Number \, of \, Spp.A}{Totao \, number \, of \, individuals} \times 100 \quad (1)$$

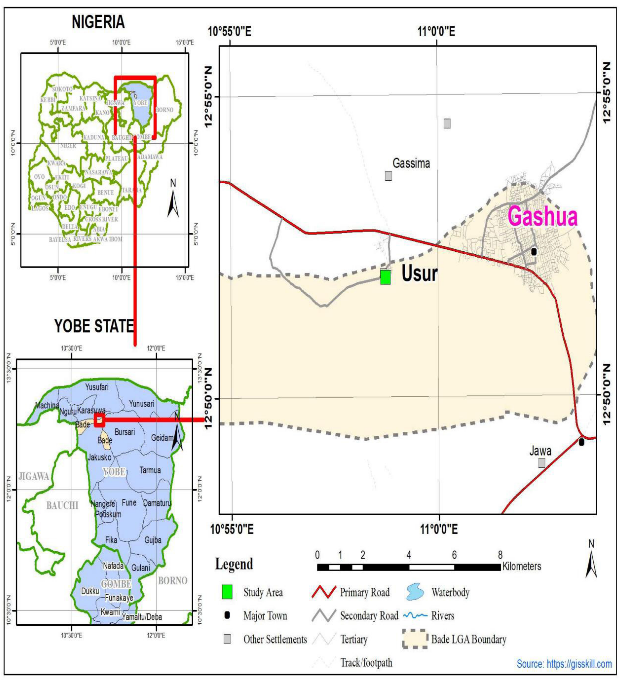

Figure 1. Map showing the study site in Usur.

Source: Field work 2020.

3. Results

The results indicated that a total number of seventy-two (72) weed species belonging to sixteen (16) families and fifty (50) genera were identified in the study area (**Table 1**). The study also shows the morphology of the weed species, Broadleaf (61.1%), Poaceae (27.8%) and Sedges (11.1%) (**Table 2**). The family that had the highest number of species was Poaceae (27.78%) and 14 genera followed by Asteraceae with 8 species (11.11%) and 6 genera and Cyperaceae with (8) species and 5 genera each. Malvaceae 7 (9.72%) species and 3 genera, Fabaceae had 6 species (8.33%) and 5 genera, Amaranthaceae 5 species (6.94%) and 3 genera, Rubiaceae 3 species (4.17%) and Lamiaceae 3 species (4.17%) each; Cleomaceae 2 species (2.78%), Commelinaceae 2 species (2.78%), Euphorbiaceae 2 species (2.78%) and Solanaceae 2 species (2.78%) each. The least numbers of species were Araceae 1 specie (1.39%), Onagraceae 1 specie (1.39%), Portulaceae 1 specie (1.39%) and Sphenocleaceae 1 specie (1.39%) each (**Table 3**). The weed's lifecycle shows annuals with 48 species representing 66.67% of the total weed species, therefore, representing the dominant weeds, perennials 24 (33.33%) and Biennial least (**Table 4**). The lifeform shows Therophytes 69 weeds species with (95.87%) as the dominant weeds, Geophytes 3 (4.17%) (**Table 5**).

Table 2 shows the life forms as follows. Furthermore, 61.1% were reported to be Broadleaf, 27.8% were Poaceae and 11.1% were Sedges.

Table 3 shows the composition of identified weeds Poaceae had the highest value (27.78%) while Araceae, Onagraceae, Portulaceae and Sphenocleaceae had the lowest (1.39%) each.

Table 4 showed the composition of weed species based on life cycle (annual, biennial and perennial). These weeds were found in wet or dry lands (open fields, cultivated lands, abandoned opened fields. The annuals 48 (66.67%) are the dominant weeds followed by perennials 24 (33.33%). Biennial (0%) was the least.

These weeds were found in wet or dry lands (open fields), cultivated lands, and abandoned in open fields. The 69 Therophytes (95.87%) are the dominant weeds followed by 3 Geophytes (4.17%) (**Table 5**).

4. Discussion

A total number of seventy-two (72) weed species belonging to sixteen (16) families and fifty (50) genera were recorded in the study area. A similar study was carried out by Radha and Manokari [26] in his study of a checklist of medicinally important weeds growing in the horticulture fields of Palayamkottai, Tirunelveli district, and Tamil Nadu where he obtained 41 weed species. The result obtained in this study was higher because of the differences in location and size of the study area. The study is not consistent with the works of Panda [10] who obtained two hundred and seventy-seven 277 species belonging to 198 genera and that of Ekeke et al. [21] who obtained a total of 322 weeds species belonging to 172 genera and 145 families. This is probably because of the differences in geographical location and soil types. The study also revealed the family that had the highest number of species was 20 Poaceae and this is consistent with the works of Panda [10] who also obtained Poaceae with the highest number of species (29). The study is also consistent with the works of Ekeke et al. [21] who obtained the Poaceae family as the highest species composition of 72 species. Samba [14] also reported that the Poaceae family was the most represented family with the highest species (24.2%); Poaceae are known to be the dominant family in most Sudan Savanna vegetation types due to their mode of dispersal. The success traits of poaceae result from their tolerance of grazing herbivory and fire, their varied means of reproduction and their versatility in photosynthesis. The growing point or meristem of poaceae lies at the base of each stem between the leaves so that regrowth is possible, poaceaes produce by seed through cross pollination and by two other methods, self-pollination and asexual reproduction. Poaceae display a variety of adaptations for the dispersal and establishment of seeds which posse's hair, spines and barbs on their spikelets.

Table 1. Weed species of rice in Usur Bade L.G.A Yobe State.

S/N	Family	Genus	Species	Common Names	Hausa Names	Life cycle	Native/ Exotic Spp	Life form	Prop.	Uses
1	Amaranthaceae (Broad-Leaves)	*Alternanthera*	*Alternanthera ficoidea* (L.)	Joseph coat	Chiyawan zomo	Perennial (P) herb, evergreen	E	T	Seed	Antiviral, tonic, hepatitis
2		*Alternanthera*	*Alternanthera sessilis* (Linn.) DC	Sessile joy	Mai kai dubuu	Perennial (P) herb, creeping	E	T	Seed	Asthma, lung infection, liver disease, snake antidote, antiseptic, pile Leprosy, fever
3		*Amaranthus*	*Amaranthus graecizans* (L.)	Spreading pig weed	Namijin gaasayaa, Rukubu	Glabrous annual (A) herb	N	T	Seed	Inflammatory, scorpion stings, snake bites, edema, ulcer, diarrhe
4		*Amaranthus*	*Amaranthus spinosus (*Linn.)	Spiny pig weed	Namijin gaasayaa;	A robust erect herb annual (A)	E	T	Seed	Kidney.jaundice, antiviral microbial, worms antimalari-al, [25].
5		*Gomphrena*	*Gomphrena celosoides* Mart.	Prostrate globe Amaranth	Goga masi	Decumbent Perennial (P)	E	T	Seed	Infertility, liver disease, antifungal/ bacteria, dysmenorrhea, analgesic,
6	Araceae (Broad-Leaves)	*Peltandra*	*Peltandra virginica* (L.) Schott	Arrow-arum	Duuman rafi Gwaandaii	Emergent perennial (P)	E	G	Seed veg.	Stabilize sediment, toxic, cause kidney failure, bread making
7	Asteraceae (Broad-Leaves)	*Ageratum*	*Ageratum conyzoides* Linn	Chick weed	Bambani	Erect annual (A) herb	E	T	Seed	Burns wound, ulcer kidney, diarrhea, gonorrhea
8		*Blainvillea*	*Blainvillea gayana cass*	Blainvillea		Annual (A) herb	E	T	Seed	Malaria, headache

Table 1 continued

S/N	Family	Genus	Species	Common Names	Hausa Names	Life cycle	Native/ Exotic Spp	Life form	Prop.	Uses
9		*Chrysanthemum*	*Chrysanthemum indicum* Linn.	African wild daisy	Rariyar kasa	Erect perennial (P) herb	E	T	Seed	Blood tonic, migraine, antibacterial, hypertension
10		*Eclipta*	*Eclipta alba* (L.)	False daisy	Rimin sauro	Erect, herb prostrate annual (A)	E	T	Seed/ veg.	Eye, Hair problems, dental Leprosy, Worm, Anemia
11		*Eclipta*	*Eclipta prostata* L.	False daisy	Rimin sauro	Erect herb prostrate annual (A)	E	T	Seed/ veg.	Catarrh, convulsion, elephantiasis,
12		*Lactuca*	*Lactuca virosa* L.	Wild lettuce	Nonokwarai	Annual (A) herb	E	T	Seed	Infertility, yaws, arthritis, skin disease sedative, analgesic
13		*Vernonia*	*Vernonia ambigua* Kotschy&peyr	Iron weed	Taba-Taba or Tattaba	Erect Annual (A) herb	N	T	Seed	Anti-inflammatory, schistosomiasis anti-plasmodia anticancer
14		*Vernonia*	*Vernonia perrottettii* Sch. Bip. Ex. Walp	Iron weed	Burzu	Erect (A) annual herb	N	T	Seed	Anti-inflammatory, antimicrobial, bilharzia, Anticancer
15	Cleomaceae (Broad-leaves)	*Cleome*	*Cleome gynandra* Linn.	African cabbage	Gaasayaa	Erect branched annual (A)	N	T	Seed	It cures Fevers, rheumatism, & pile scorpion bite, headache
16		*Cleome*	*Cleome viscosa* Linn.	Spider flower	Diyar-unguwa gasiyaa	Erect herb annual (A) sticky	N	T	Seed	Wounds and ulcers, ear disease, liver, pimples, inflammation, .

Table 1 continued

S/N	Family	Genus	Species	Common Names	Hausa Names	Life cycle	Native/ Exotic Spp	Life form	Prop.	Uses
17	Commelinaceae (Broad-Leaves)	*Commelina*	*Commelina benghalensis* (L.)	Wondering jew	Balaasa; Balaasaana;Bulabula;	Creeping stem herb annual (A)	N	T	Seed/ Veg.	Fever, rabies leprosy, ophthalmic, epilepsy, snake bites, burns.
18		*Commelina*	*Commelina diffusa* Burm. F	Spreading day flower	Balaasa, Balaasaya	Prostrate herb, (P) climbing	N	T	Seed/ Veg.	Yellow fever, eyewash, oedema, gonorrhea, fodder
19	Cyperaceae (Sedges)	*Cyperus*.	*Cyperus esculentus* Linn.	Yellow nut-sedge	Ayaa	Perennial (P) herbs	N	G	Seed/ Veg.	Tonic, flatulence, diarrhea, dysentery, menstrual discharge
20		*Cyperus*	*Cyperus iria* Linn.	Rice field flatsedge	Aya-ayaa	Smooth tufted (A) Annual	N	T	Seed	Astringent, stimulant, stomachic
21		*Cyperus*	*Cyperus rotundus* Linn.	Nut grass	Ayaa-ayaa; Jiji; gwaigwaya	Smooth erect (P) perennial	N	G	Seed/ Veg.	Dysentery, epilepsy, fever, diabetes, inflammation, diarrhea,
22		*Fimbristylis*	*Fimbristylis dichotoma* (L.) Vahl	Forked fimbry	Geemun beeraa; Riidin tuujii	Erect tufted, (P) perennial	N	T	Seed/ Veg.	Anti-inflammatory, fever, antidiarrheal, dysentery,
23		*Kyllinga*	*Kyllinga erecta* Schumach.	Spike sedge	Ayaa-ayaa, Turare	Erect, robust (P) Perennial	N	G	Seed/ Veg.	Retain placenta, malaria, whooping cough,

Table 1 continued

S/N	Family	Genus	Species	Common Names	Hausa Names	Life cycle	Native/ Exotic Spp	Life form	Prop.	Uses
24		*Kyllinga*	*Kyllinga Squamulata* Thonn. ex Vahl	Kyllinga nemoralis	Ayaa-ayaa, Turare	Weak tufted (A) Annual	N	T	Seed	Analgesic, antimalarial, Roots as fumigant, whooping cough
25		*Rhychospora*	*Rhychospora corymbosa* (L.) Britton.	Golden beak sedge	Kudunduru iya	Robust (P) perennial	N	T	Seed	Abdominal pain, colic
26		*Schoenoplectus*	*Schoenoplectus senegalensis* (Steud.)	Bull rush	Gudun bijimi	Small tufted (A)	N	T	Seed	Use to stop bleeding, snake bite, abscesses
27	Euphorbiaceae (Broad-Leaves)	*Euphorbia*	*Euphorbia hirta* Linn.	Asthma plant	Nonon kurchiya	A hairy herb (A) annual	E	T	Seed	Asthma, cough, venereal disease, dysentery, diarrhea, stomachache.
28		*Phallantus*	*Phallantus amarus* Schum. &Thonn.	Gale of the wind	Geron-tsuntsayee	A Small annual (A) herbs	E	T	Seed	Antimicrobials, fever, skin disease, worms, diarrhea.
29	Fabaceae: Papilionoideae (Broad-Leaves)	*Aeschynomene*	*Aeschynomene indica* Linn.	Budda pea	Fidilin kanaawa	Sub-shrub erect (A) herb	N	T	Seed	Use as spermicide and charcoal are use as gun powder
30	Fabaceae: Caesalpiniodeae	*Chamaecrista*	*Chamaecrista* mimosoides (L.) Greene	Japaneese tea	Bakiskis, Balsama, Balasa, B.	Erect herb or low shrub (A)	N	T	Seed	Pain-killers, ear/eye, diarrhea, dysentery, antidotes, paralysis, epilepsy, convulsions
31	Fabaceae: Papilionoideae	*Crotalaria*	*Crotalaria retusa* Linn.	Devil bean or Rattle weed	Birana	Erect, herb angular annual (A)	E	T	Seed	Skin disease scabies, fevers, colic, dysentery, flatulence, liver

Table 1 continued

S/N	Family	Genus	Species	Common Names	Hausa Names	Life cycle	Native/ Exotic Spp	Life form	Prop.	Uses
32	Fabaceae: Papilionoideae	*Indigofera*	*Indigofera hirsuta* (L.)	Hairy indigo	Aniyar makomiya	Erect herb spreading annual (A)	N	T	Seed	Cough, analgesic, yaws, liver disorder, epilepsy, poison antidote, kidney &, opthalmia
33	Fabaceae: Caesalpiniodeae	*Senna*	*Senna obtusifolia* (L.) H.S. Irwin & Barneby	Sickle pod	Ubulo, Tafasa	Erect herb branched (A)	E	T	Seed	Skin disease infections, sores, ulcers, leprosy vomiting, snake bites, soup, arthritis, itching stomachache
34	Fabaceae Caesalpiniodeae	*Senna*	*Senna occidentalis* (L.) Link	Coffee weed	Tasba, Majamfari, Rai-doore	Perennial	E	T	Seed	Mental disorder,leprosy rheumatisms worms, hypertension , stomachache, dysentery, pains
35	Lamiaceae (Broad-Leaves)	*Leucas*	*Leucas martinicensis* (Jacq.) Ait. f.	Wild tea	Daidoyar gona, kanbarawo	Erect, herb aromatic annual (A)	N	T	Seed	Snake bite antidote, epilepsy
36		*Leucas*	*Leucas cephalotes* (Roth) Spreng.	Guma	Dandoyar gona, sarakuwar sauro	Stem erect herb annual (A)	E	T	Seed	Diabetes, fever, typhoid, filarial
37		*Ocimum*	*Ocimum gratissimum* Linn.	African basil	Daidoya, Daidoya ta gida	Erect round (P) Perennial	N	T	Seed	Stomachache, pains antiseptic, fever conjunctivitis, wounds, rheumatic
38	Malvaceae (Broad-leaves)	*Corchorus*	*Corchoru aestuans* (L.)	Mallow jute	Laalo	Erect, herb prostrate annual (A)	N	T	Seed	Used to treat pneumonia & stomach-ache

Table 1 continued

S/N	Family	Genus	Species	Common Names	Hausa Names	Life cycle	Native/ Exotic Spp	Life form	Prop.	Uses
39		*Corchorus*	*Corchorus olitorius* (L.)	Jews mallow	Laalo	An erect annual (A) herb	N	T	Seed	Liver disorder, aches, dysentery, fever, tumors.
40		*Corchorus*	*Corchorus tridens* (L.)	Jute mallow	Laalo	Erect herb branched annual (A)	N	T	Seed Stem, fibers	Fishing, antioxidant, therapeutic to stress.
41		*Sida*	*Sida cordifolia* (L.)	Flannel weed	Farar hankufa, kardafi	Erect sub- shrub (P) perennial	N	T	Seed	Asthma, diarrhea, tuberculosis,, cold, headaches, worm cough, gonorrhea, flu
42		*Sida*	*Sidarhombifolia*(L.)	Arrow leaf sida	Faskara saiwo	Erect, (P) ever-green perennial	N	T	Seed	leaves used to relieve headache. root is used to treat rheumatism.
43		*Sida*	*Sida acuta* Burm.f.	Wire weed	Garmani, kaka,namijin hankufa	Aerial, erect (P) perennial	N	T	Seed	Asthma, TB, Cold, flu, kidney,infection liver disease
44		*Waltheria*	*Waltheria indica* Linn.	Sleepy Morning	Hankufa	Several erect (P) perennial	E	T	Seed	Inflammation, malaria,
45	Onagraceae (Broad-Leaves)	*Ludwigia*	*Ludwigia hyssopifolia* (G. Don) Excell	Seed box	Lallen balbela	Erect, glabrous herb (A)	E	T	Seed	Jaundice, flatulence, dysentery diarrhea, syphilis,
46	Poaceae (Grass)	*Brachiaria*	*Brachiaria falcifera* (Trin.). Stapf	Signal grass	Garaji, Makarin fako	Tufted herb perennial (P)	E	T	Seed	It add positive input beef and milk in animals (oral interview)
47		*Brachiaria*	*Brachiaria lata* (Schumach) C.E.Hubbard	Signal grass	Guraji Aluwar kwadi;	Loosely grass (A) annual	N	T	Seed	Seed as famine food fodder is palatable for animals,

Table 1 continued

S/N	Family	Genus	Species	Common Names	Hausa Names	Life cycle	Native/ Exotic Spp	Life form	Prop.	Uses
48		*Cenchrus*	*Cenchrus biflorus* Roxb.	Hedgehog grass	Karangiya	grass (A) annual	N	T	Seed	Anti-asthmatic, roots is antioxidant, anticancer,
49		*Chloris*	*Chloris pilosa* Schumach.	Finger grass	Kafar fakara Tafan gauraka	Tapering & erect annual (A)	N	T	Seed	rheumatism, antibacterial, treat skin disorder, cure diabetes
50		*Cynodon*	*Cynodon dactylon (*Linn.) pers.	Bahamas grass [23]	Kirikirii, Taja-maza	Glabrous grass (P) perennial	N	T	Seed/ Veg.	Skin disease, Nose bleeds (haemorrhage) fainting, food poison. menstrual bleeding
51		*Dactyloctenium*	*Dactyloctenium aegyptium*(L.) P. Beauv.	Crow foot grass	Gude-Gude, kutuku	Tufted creeping grass (A)	N	T	Seed	decoction to remedy lumbago, childbirth dysentery
52		*Digitaria*	*Digitaria horizantalis* Wild	Crab grass	Karanin dawaki	Prostrate, tuft annual (A)	N	T	Seed	Anti diabetic, antibiotic, anti thyroid, antioxidant, forage/ fodder
53		*Echinochloa*	*Echinochloa colona* Linn. Link	Jungle rice	Sabe	Tufted, erect annual (A)	N	T	Seed	Spleen problem, wound healing, antioxidant and antimicrobial
54		*Echinochloa*	*Echinochloa crusgali* (L.) P. Beauv	Barnyard grass	Sabe	Robust, tufted annual (A)	E	T	Seed	spleen troubles cancer and wounds, tonic
55		*Eleusine*	*Eleusine indica* (L.) Gaertn.	Goose grass	Tuujii	Tufted annual (A)	N	T	Seed	anti-dysenteric, diarrhea, menstruation, ringworm,

Table 1 continued

S/N	Family	Genus	Species	Common Names	Hausa Names	Life cycle	Native/ Exotic Spp	Life form	Prop.	Uses
56		*Eragrostis*	*Eragrostis ciliaris* (L) R.Br.	Love grass	Tsintsiiyaa, Komayya	Tufted (A) loosely	N	T	Seed	Wounds, stomach pain, whitlows, broom, forage
57		*Eragrostis*	*Eragrostis tenella* (Linn.) P. Beauv.	Japaneese love grass	Tsintsiiyaa, Kamayya.	Delicate tufted annual (A)	N	T	Seed	Rheumatic pain, antioxidant, grains nutritious, forage
58		*Eragrostis*	*Eragrostis tremula* Hochst. ex Steud.	Annual love grass	Burburwa, Hansta-hansa, Komyya	A loosely tufted (A) annual	N	T	Seed	Recover memory lost, forage
59		*Heteropogon*	*Heteropogon contortus* (L.)	Spear grass	Silka, Tsika	Tufted, (P) perennial	N	T	Seed	Blood relax for horse, cure measles, arthritis
60		*Paspalum*	*Paspalum scrobiculatum* (Linn.)	Kodo millet	Tumbin jaki	tufted (P) Perennial	N	T	Seed	Cure pile, menstrual
61		*Pennisetum*	*Pennisetum pedicellatum* Trin.	Desho grass, kyasuwa	Daura, kaafii-riimii, Hura	Erect jointed (A) Annual	N	T	Seed	Treat mumps, wounds, stop bleeding, fodder
62		*Pennisetum*	*Pennisetum polystachion* (L.) Schult	Foxtail, Feathery pennisetum	Hura, kaafii-riimii	Tufted grass (A) annual	E	T	Seed	Heal cuts & wounds, conjunctivitis, earache, analgesic [23]
63		*Polypogon*	*Polypogon monspeliensis* (L.) Desf.	Annual beard grass	Gamba	Erect annual (A)	E	T	Seed	Epilepsy
64		*Oryza*	*Oryza barthii* A. Chev	African wild rice	Shinkafar –tafki, Lallaki	Erect to semi-erect annual (A)	N	T	Seed	Breeding of cultivated rice, grazing, thatching, famine food, anticancer
65		*Oryza*	*Oryza longistaminata* A. chev&Roehr	Wild rice	Shinkafar kwadi	Robust, erect (P) perennial	N	T	Seed Veg.	Grazing and thatching, famine food, anticancer

Table 1 continued

S/N	Family	Genus	Species	Common Names	Hausa Names	Life cycle	Native/ Exotic Spp	Life form	Prop.	Uses
66	Portulaceae (Broad-Leaves)	*Portulaca*	*Portulaca oleracea* Linn.	Duck weed	Baabaa-jibjii; Halsen saniya;	Erect, prostrate stem (P)	N	T	Seed/ Veg.	Ear, syphilis, abscesses, boils, Jaundice, diabetes, Urinary disorder
67	Rubiaceae (Broad-Leaves)	*Oldenlandia*	*Oldenlandia corymbosa* Linn.	Diamond flower	Raatsa-hanji	Glabrous, erect herb annual (A)	N	T	Seed	Depression stomachache fever, viral infection appendicitis
68		*Oldenlandia*	*Oldenlandia herbacea* Linn. Roxb.	Diamond flower	Raawaya Raatsa-hanji	Much- branched erect (A)	N	T	Seed	ulcer, rheumatic fever, swelling, asthma
69		*Spermacoce*	*Spermocoe stachydea* (DC.) Hutch. &Dalz	False button weed	Alkamar tururuwa	Erect, robust (A) Annual	N	T	Seed	Kidneys, diuretics, menstrual, veneral diseases, conjunctivitis,
70	Solanaceae (Broad-Leaves)	*Physalis*	*Physalis angulate* Linn.	Goose berry	Lababuje, Tomatir kaji	Erect herb branch annual (A)	E	T	Seed	Analgesic,diarrhea, menstrua disorder asthma, vomiting,
71		*Solanum*	*Solanum nigrum* (L.)	Black night shade	Gautan kudi	Soft wooded herb (A)	E	T	Seed	Indigestion, piles
72	Sphenocleaceae (Broad-Leaves)	*Sphenoclea*	*Sphenoclea zeylanica* Gaertn.	Goose weed	Yadiya	Erect herb hairless (A)	N	T	Seed	Ulcer, Antimicrobial, stings of animals

Key: M-Monocotyledon, D-Dicotyledon, T-Therophyte, Geo-Geophyte, S-Sedges, G-Grass, B-Broad leaf,

A- Annual, Bi- Biennial, P-Perennial, L.F.- Lifeform, N-Native, E-Exotic, Spp-Species.

Table 2. The composition of identified weed species based on morphology.

Morphology	Number of species	Percentage Composition (%)
Grasses	20	27.78%
Sedges	8	11.11%
Broad leaf	44	61.11%
Total	72	100%

Table 3. The composition of identified weeds species based on family.

Family	No's of Genus	% of Genus	No's of species	% of speci
Amaranthaceae	3	6%	5	6.94%
Araceae	1	2%	1	1.39%
Asteraceae	6	12%	8	11.11%
Cleomaceae	1	2%	2	2.78%
Commelinaceae	1	2%	2	2.78%
Cyperaceae	5	10%	8	11.11%
Euphorbiaceae	2	4%	2	2.78%
Fabaceae	5	10%	6	8.33%
Lamiaceae	2	4%	3	4.17%
Malvaceae	3	6%	7	9.72%
Onagraceae	1	2%	1	1.39%
Poaceae	14	28%	20	27.78%
Portulaceae	1	2%	1	1.39%
Rubiaceae	2	4%	3	4.17%
Solanaceae	2	4%	2	2.78%
Sphenocleaceae	1	2%	1	1.39%
Total	50	100%	72	100%

Table 4. The composition of weed species based on life cycle (annual, biennial, and perennials).

Family	No. Spp	Annual	Biennial	Perennial
Amaranthaceae	5	√ √	0	√ √ √
Araceae	1	0	0	√
Asteraceae	8	√ √ √ √ √ √ √	0	√
Cleomaceae	2	√√	0	0
Commelinaceae	2	√	0	√
Cyperaceae	8	√	0	√ √ √ √ √ √ √
Euphorbiaceae	2	√ √	0	0
Fabaceae	6	√ √ √ √ √	0	√
Lamiaceae	3	√ √	0	√
Malvaceae	7	√ √ √	0	√ √ √ √
Onagraceae	1	√	0	0
Poaceae	20	√√√√√√√√√√√√√√√	0	√ √ √ √√
Portulaceae	1	√	0	0
Rubiaceae	3	√ √ √	0	0
Solanaceae	2	√ √	0	0
Sphenocleaceae	1	√	0	0
Total	50	48 (66.67%)	00	24 (33.33%)

Table 5. The composition of identified weeds species based on life form.

	Family Name	Geophytes	Therophytes
1	Amaranthaceae	0	5
2	Araceae	1	0
3	Asteraceae	0	8
4	Cleomaceae	0	2
5	Commelinaceae	0	2
6	Cyperaceae	2	6
7	Euphorbiaceae	0	2
8	Fabaceae	0	6
9	Lamiaceae	0	3
10	Malvaceae	0	7
11	Onagraceae	0	1
12	Poaceae	0	20
13	Portulaceae	0	1
14	Rubiaceae	0	3
15	Solanaceae	0	2
16	Sphenocleaceae	0	1
Total		03 (4.17%)	69 (95.83%)

Broadleaves (61.1%), Sedges (11.1%) and Poaceae (27.7%) were obtained from the study area. The result was consistent with the works of Unaeze et al. [27] who also obtained Broadleaves with a maximum number (61.50%). A study has also shown that the more diverse the land use system, the more diverse the weed community with less dominant and troublesome species. This however suggests that the farming and bush clearing activities within the study area have contributed to the presence of the different types of weed species present in the area and thus is evident as most of the weed species in the study area are found in wetlands.

Annuals were the dominant weeds identified in the study area. This is because many of the weeds in the rice-growing areas have annual growth periods. The annual weed seeds are capable of germination under unsuitable conditions and are able to complete their life cycle from seed to seed during the growing season. A study has shown that the release of arable land after harvesting the rice leads to the re-growth of weeds, which in turn increases seed banks and buds in the soil and begins to grow in the subsequent crop seasons. The work is consistency with that of Panda [10] who obtained annual weeds species over Perennial species in Odisha, India. The dominance of annuals probably indicates that they grow in disturbed areas and stable environments. Similarly our study is in a disturbed area which in turn leads to a dominance of annuals.

The dominant lifeform in the present study was 69 Therophytes (95.83%) and the lowest was 3 Geophytes (4.17%). Therophytes are any plant that survives unfavorable seasons in the form of seeds only. They are typically found in deserts and other arid regions. The highest lifeform value was recorded on Poaceae (20) weed species. The therophytes are annual weeds that complete their life cycle in a short period when conditions are favourable and survive harsh conditions as seeds. Therophytes could also be attributed to the short life cycles that enable them to cope with the unstable conditions of agricultural habitats. In addition, therophytes allocate much of their resources to the reproductive structures and produce flowers early in their life cycle to ensure some seed production even in a year when the growing season is cut short due to the application of weed management techniques; also therophytes are able to set seeds without a pollinating agent. This is consistent with the work of Samba [14] on his work taxonomic diversity and abundance of weed flora in upland rice fields of the southern groundnut Basin, Senegal. The weed flora is largely dominated by therophytes which include 95% of the recorded species; According to Bourgeois et al. [28] therophytes were the mostly weeds because of some adaptability among the higher specific leaf area, earlier and longer flowering, sunny and dry environment. The study is also consistent with the works of Gomaa [29] in his work Floristic Composition of Weed Vegetation in Citrus Orchards in Aljouf Region, Kingdom of Saudi Arabia which stated that therophytes represented the dominant lifeform (66.7%) of the total flora followed by Geophyte (12.1%). Geophytes are plants typically with underground storage organs, where the plants hold energy and water. Geophytes also include plants with tubers, corms or rhizomes. Geophytes also include plants with bulbs, tubers, corms or rhizomes usually found in Cyperaceace. The Geophytes were the second life form in the Usur rice field of the current study area. Geophyte such as *Cyperus esculentus, Kyllinga erecta, Peltandra virginica* are well adapted to agricultural systems because they are able to resume growth from underground perennating organs after the destruction of their above vegetative shoots resulting from weed management methods [29].

The result also revealed that many of the weeds are used as traditional medicine, food, fodder, and other purposes (**Table 1**). Many of the weeds were used as food such as *Amaranthus spinosus, Portulaca oleraceae, Cassia obtusifolia, Corchorus aestuans, Corchorus olitorius, Corchorus tridens, Alternanthera sessilis, Chrysanthemum indicum.* Although many farmers are not aware of the value of these plants as sources of food, this is similar to the works of Panda [10] who also obtained *Amaranthus Amaranthus sessilis, spinosus, Portulaca oleracea* plants were used as sources of food. Other types of weed example are *Alternanthera spp, Brachiaria falcifera, Brachiaria lata, Eragrostis ciliaris, Echinochloa crusgali, Chloris pilosa, Digitaria horizantalis, Dactyloctenium aegyptinum, Cenchrus biflorus, Pennisetum pediculatum, Pennisetum polystachion, Paspalum scrobiculatm* were used as forage/fodder for animals. They provide sources of nutrition; this is consistent with the works of Abba, et al. [30] in their study of Herbaceous species diversity in Kanawa forest reserves, Gombe State, Nigeria where they also mentioned the use of *Chloris pilosa, Digitaria horizantalis, Eragrostis ciliaris, Pennisetum pediculatum* as forage or fodder. It is also consistent with the works of Panda [10] who reported the use of *Echinochla crusgali, Alternanthera* spp. used for fodder.

The uses of weed in traditional medicine are well known. In the study area different weed species such as *Alternanthera sessilis, Ageratum conyzoides, Portulaca oleracea, Sida acuta, Cleome viscosa, Commelina benghalensis, Paspalum scrobiculatum, Eurphorbia hirta, Vernonia ambigua, Cassia occidentallis, Oldenlandia spp. Waltheria rhombifolia, Physalis angulata, Amaranthus ficoides, Amaranthus spinosus, Solanum nigrum, Eleusine indica, Corchorus olitorius Cenchrus biflorus, Corchrus aestuans, Corchorus tridens, Chloris pilosa, Portulacaoleracea, Ludwigia hyssopifolia*are are used to cure a different ailment.

Recently the beneficial aspect of weeds is being reported and was used for the treatment of various ailments. In the study area, *Aternanthera sessilis, Euporbia hirta* are used to treat Asthama. *Sida acuta, Ageratum conyzoides and Cassia occidentalis* are used to cure kidney disease; *Cassia occidentalis, Portulaca oleracea* are used to cure diabetes; *Alternanthera sessilis, Corchrus olitorius, Sida acuta* and *Eclipta prostate*are used to cure liver disease; *Physalis angulate, Paspalum scobiculaum, Cyperus esculentus, and Cynodon dactylon* are used to cure mentual disorder; *Commelina benghalensis, Eclipta alba, Cassia obtusifolia, Cassia occidentalis, Alternanthera sessilis* are used to cure leprosy; *Corchorus olitorius, Cleome viscosa, Commelina benghalensis, Alternanther sessilis* are used to cure fever others include *Sida cordifolia, Phallantus amarus* are used to cure diarrhea; *Euphorbia hirta, Ageratum conyzoide-s*are used to cure cut and woundhealing*; Leucas martinicensis, Commlina benghalensis, Alternanthera sessilis* are used to cure snake bite, *Phallantus amarus* cures diarrhea. The result findings are also consistent with the works of Abiodun, et al. [31] in their study of Medicinal Weed Diversity and Ethno-medicinal weeds in Odigbo, Ondo State, Nigeria where they also mentioned the use of *Alternanthera sessilis* cure asthma; *Sida acuta, Cassia occidentalis* cure kidney diseases and diabetes; *Physalis angulate* cure menstrual disorder; *Cassia obtusifolia* and *Cassia occidentalis* cure leprosy. Also is consistent with the works of Abd El-Ghani [32] in their study of Traditional Plants of Nigeria: An Overview, where they also mentioned the used of *Ageratum conyzoides* are used to cure ulcer, *Euporbia hirta* cure asthma and *Eclipta prostate* cure liver disease. The research findings are also consistent with the works of Radha and Manokari [26] in their study of A Checklist of Medicinally Important Weeds grows in the Horticulture fields of Palayamkottai, Tirunelveli district, and Tamil Nadu, India where they also mentioned the used of *Euphorbia hirta* cure asthma; *Portulaca oleracea* cure diabetes; *Alternanthera sessilis, Commelina benghalensis,* and *Eclipta alba* cures leprosy; *Corchorus olitorius, Althernanthera sessilis, Cleome viscosa,* and *Commelina benghalensis* cures fever; *Sida cordifolia* cure diarrhea. It is also consistent with the works of Panda [10] on their study where they also mentioned the use of *Phallantus amarus* used to cure diarrhea.

For instance weeds like *Aeschynomene indica, Eragrotis ciliaris* and *Eragrotis tenella, pennisetum polystachion, Heteropogon contortus, Corchrus aestuans, Corchorus tridens* were used for various household purposes, likewise some of them like *Eragrotis tremula* were used for various rituals by an inhabitant of Usur, Bade L.G.A.

Invasive specie are non-native species that significantly modify or disrupt the ecosystem they colonized and outcome native species for food and habitats, which triggers population declines through natural migration or through human introduction.

5. Conclusions and recommendation

This study concluded that seventy-two weed species were identified belonging to sixteen families and fifty genera was recorded in the study area. The study also revealed the composition of the weeds, the family that had the highest number of weed species was Poaceae followed by Asteraceae and Cyperaceare, Malvaceae, and the lowest was Araceae, Onagraceae, Portulaca, and Sphenocleaceae respectively.

The life cycle shows annual weeds species were the dominant followed by Perennial and least Biennial.

The study also shows the life forms as follows. Furthermore, Broadleaf was reported to be the highest number followed by Poaceae and the least was Sedges. The research also recorded twenty-five exotic weed species and forty-seven native species which are dominant. The area is polluted by chemicals, which is the addition of any substance or any form of energy to the environment at a rate fast than it can be dispersed, diluted, decamped, recycled or stored in some harmless form attributes to biodiversity loss by creating health problems in exposed organisms. In some cases, exposure may occur in a dose high enough to kill outright or create reproductive problems that threaten the species' survival.

The findings reveal that, the composition of the life form shows therophytes had the highest value that dominates the weed species; the lowest value was recorded by Geophytes. The research also shows weed species reproduction is mostly reproduced by seed. The highest reproduction reproduces by seed were fifty-nine weeds and the least was vegetative reproduction thirteen. The result also shows the majority of the weed species were used for medicinal uses for curing different ailments such as ulcers, diabetes, hypertension, gonorrhea, skin diseases, kidney disease, leprosy, liver diseases, catarrh, menstrual disorder, burns, wound, etc. For example *Euphorbia hirta* cures asthma and lung infection; *Corchorus olitorius* cures fever and liver disease; *Alternanthera sessilis* cures leprosy; *Amaranthus spinosus* cure ulcer.

Phytosociological studies, further reveal the densely populated weed specie is *Cyperus rotundus,* the frequently populated weed specie is *Cyperus rotundus.* The weed species with the highest importance value index (IVI) is *Cyperus rotundus* and the lowest value was recorded on *Cenchrus biflorus*. The phytosociological attributes could not be unconnected to their similarity in their families, morphology and development attributes. Most of the weed species with the highest density, frequency and abundance were of the poaceae family and sedges. These weeds have high fecundity producing hundreds of thousands of seeds during a single growing season and reproduce through vegetative propagules and seeds and have vegetative mimicry with crops in addition to long-time seed dormancy.

1) The study also recommends no single control tactic provides reason by control of *Cyperus species* an integrated approach that involves biological, cultural, chemical options will be most effective.

2) The study recommends further research should be conducted on the effect of weed on the growth and yield of rice in Usur, Bade L.G.A. Yobe State.

Conflict of Interest

There is no conflict of interest.

References

[1] Balick, M.J., Cox, P.A., 2020. Plants, people, and culture: The science of ethnobotany. Garland Science: New York.

[2] Gerasimova, I., Mitova, T., 2020. Weed species diversity and community composition in organic potato field. Bulgarian Journal of Agricultural Science. 26(3), 507-512.

[3] Fried, G., Petit, S., Dessaint, F., 2009. Arable weed decline in Northern France: Crop edges as refugia for weed conservation? Biological Conservation. 142(1), 238-243.

[4] Dada, O.A., Oladiran, E.M., Olubode, O.S., et al., 2017. Influence of weeding regimes on composition and diversity of weed species in upland rice (Oryza sativa L.) field. Nigerian Journal of Ecology. 16(1), 62-74.

[5] Nkoa, R., Owen, M.D., Swanton, C.J., 2015. Weed abundance, distribution, diversity and community analyses. Weed Science. 63(SP1), 64-90.

[6] Tiwari, P., Rautela, B., Rawat, D.S., et al., 2020. Weed floristic composition and diversity in paddy fields of Mandakini Valley, India. International Journal of Botany Studies. 5(3), 334-341.

[7] Sinha, M.K., 2017. Studies on weed diversity and its associated phytosociology under direct dry seeded rice systems in Koria District (CG) India. Advances in Plants and Agriculture Research. 7(2), 246-252.

[8] Kraehmer, H., Jabran, K., Mennan, H., et al., 2016. Global distribution of rice weeds-a review. Crop Protection. 80, 73-86.

[9] Ahmad, Z., Khan, S.M., Abd_Allah, E.F., et al., 2016. Weed species composition and distribution pattern in the maize crop under the influence of edaphic factors and farming practices: A case study from Mardan, Pakistan. Saudi Journal of Biological Sciences. 23(6), 741-748.

[10] Panda, T., Mishra, N., Rahimuddin, S., et al., 2020. An annotated checklist of weed flora in Odisha, India. Bangladesh Journal of Plant Taxonomy. 27(1), 85-101.

[11] Dahiru, R., Hallah, B.M., Abubakar, M.A., et al., 2017. A review on weed control methods of lowland rice production in Nigeria. Semiarid Journal of Academic Research and Development (SJARD). 1(1), 12-20.

[12] Udemezue, J.C., 2018. Analysis of rice production and consumption trends in Nigeria. Journal of Plant Sciences and Crop Production. 1(3), 305.

[13] RIFAN, 2019. Nigeria Now Producing 8m Tons of Rice Annually-RIFAN [Internet] [cited 2020 Apr 24]. Available from: https://allafrica.com/stories/201903210472.html

[14] Ka, S.L., Gueye, M., Mbaye, M.S., et al., 2020. Taxonomic diversity and abundance of weed flora in upland rice fields of Southern Groundnut Basin, Senegal. Journal of Research in Weed Science. 3(1), 48-56.
DOI: https://doi.org/10.26655/JRWEEDSCI.2020.1.5

[15] Mamora, S.H., 2021. Floristic Composition and Diversity of Weeds in Organic Rice Fields in Langkong, M'lang, Cotabato. Southeastern Phil-

ippines Journal of Research and Development. 26(1), 35-48.

[16] Wakawa, L., Suleiman, A., Ibrahim, Y., et al., 2017. Tree species biodiversity of a sahelien ecosystem in North-East Nigeria. Bartın Orman Fakültesi Dergisi. 19(2), 166-173.

[17] Bello, A.M., Audu, I.W., Aihong, A.B., 2013. Curtailing fuel wood extraction: An agent of global warming for the sustainable development in Nigeria. African Journal of Physical Sciences. 6(4), 146-150.

[18] Hassan, Y., Jambo, U.M., Jajere, A.A., et al., 2019. Flood vulnerability assessment in Gashua: Issues and prospectives. International Journal of Scientific Research and Review. 7(03).

[19] Alhassan, I., Gashua, A.G., Sunday, D.O.G.O., et al., 2018. Physical properties and organic matter content of the soils of Bade in Yobe State, Nigeria. International Journal of Agriculture Environment and Food Sciences. 2(4), 160-163.

[20] Ellenberg, D., Mueller-Dombois, D., 1974. Aims and methods of vegetation ecology. Wiley: New York. pp. 547.

[21] Ekeke, C., Ogazie, C.A., Agbagwa, I.O., 2019. Checklist of weeds in university of Port Harcourt and its environs. Journal of Applied Sciences and Environmental Management. 23(4), 585-592.

[22] Akobundu, I.O., Agyakwa, I., 1998. A handbook of west african weeds, 2nd Edition. International Institute of Tropical Agriculture: Ibadan. pp. 564.

[23] Balogun, O.H., 2015. Weeds, forage and useful trees: Some common weeds/plants of West Africa and their medicinal uses. Shallom Publication: Challenge-Idi Odo, Ibadan.

[24] Raunkiaer, C., 1934. The life forms of plants and statistical plant geography. Oxford University Press: Oxford.

[25] Abiodun, A.A., Tunji, B.H., 2019. Medicinal weed diversity and ethno-medicinal weeds in Odigbo local government area, Ondo State, Nigeria. Journal of Medicinal Plants. 7(5), 81-85.

[26] Radha, P., Manokari, M., 2017. A checklist of medicinally important weeds grows in the horticulture fields of Palayamkottai, Tirunelveli district, and Tamil Nadu. International Journal of Herbal Medicine. 5(6), 108-113.

[27] Unaeze, H.C., Okeke, C.C., Nwaobiri, B.C., 2019. Farmer's responses on integrated farming as risk-averse mechanisms to climate change in Etche Local Government Area of Rivers State, Nigeria. Journal of Environmental Issues and Agriculture in Developing Countries. 11(1-3).

[28] Bourgeois, B., Munoz, F., Fried, G., et al., 2019. What makes a weed a weed? A large scale evaluation of arable weeds through a functional lens. American Journal of Botany. 106(1), 90-100.

[29] Gomaa, N.H., 2017. Floristic composition of weeds vegetation in citrus orchards in Aljouf Region, Kingdom of Saudi Arabia. Journal of Bio-Molecular Sciences (JBMS). 5(1), 15-23.

[30] Abba, H.M., Jahun, S.F., Mohammed, G.A., et al., 2015. Herbaceous species diversity in Kanawa forest reserve (KFR) in Gombe state, Nigeria. American Journal of Agriculture and Forestry. 3(4), 140-150.

[31] Abiodun, A.A., Tunji, B.H., 2019. Medicinal weed diversity and ethno-medicinal weeds in Odigbo local government area, Ondo State, Nigeria. Journal of Medicinal Plants. 7(5), 81-85.

[32] Abd El-Ghani, M.M., 2016. Traditional medicinal plants of Nigeria: An overview. Agriculture and Biology Journal of North America. 7(5), 220-247.

BILINGUAL PUBLISHING GROUP

Journal of Botanical Research
https://journals.bilpubgroup.com/index.php/jbr

ARTICLE

Diversity of Endophytic Fungi in Banana Cultivars of Assam India

***Jibanjyoti Panda*[1]*, P. Vetrivelkalai*[2]*, B. Bhagawati*[3]*, Nibha Gupta*[1*]**

[1] *Plant Pathology and Microbiology Division, Regional Plant Resource Centre, Bhubaneswar, 751015, India*
[2] *Department of Nematology, Tamil Nadu Agricultural University, Coimbatore, 641003, India*
[3] *Department of Nematology, Assam Agricultural University, Jorhat, 785013, India*

ABSTRACT

Endophytic fungal isolates (139 no.) were obtained from 143 (62 roots, 18 fruits and 54 leaves) samples of 15 different varieties of banana collected from 10 sites in Assam, India during 2018-2019. Overall isolation frequency from surface-sterilized tissue ranged from 10%-80% (as per site) and 6%-70% (as per variety of banana). All isolates were segregated into 40 different types on the basis of macromorphological and micro morphological characteristics. Forty different fungal taxa were isolated belonging to 14 genera including *Absidia, Arthrinium, Aspergillus, Bipolaris, Cladosporium, Curvularia, Dendrophion, Fusarium, Humicola, Mortierella, Mucor, Penicillium, Paecilomyces, Verticillium* and one mycelium sterile. Among them, *Cladosporium cladosporioidies* and *Paecilomyces* sp. frequently occurred in most of the sites surveyed whereas *Cladospoirum cladosporioides* and *Aspergillus* sp. 8, *Fusarium graminseram* were most frequently isolated from different varieties. However, all sites differed in their fungal diversity. Banana samples from Narigoan and Jorhat have been found with maximum fungal species followed by marigoan samples so as to Banana varieties Amrit Sagar endowed 27 no. of fungi followed by Jehaji and Honda which were associated with a maximum 14 fungal sp. Isolation frequency and relative abundance of *Cladosporium cladosporiodes* (80%, 4.6), *Paecilomyces farinosus* (80%, 4.6) followed by *Penicillium ruburm*, *Aspergillus* sp. 8 & 9 (70%, 4.02) were recorded as maximum comparatively in different sites. However, Aspergillus sp. 8, Mortieralla sp. and *Pacilomyces farinosus* are isolated frequently from different banana varieties (73.33%, 4.93).

Keywords: Banana; Fungi; Endophytes; Assam; Phyllosphere; Rhizosphere

*CORRESPONDING AUTHOR:
Nibha Gupta, Plant Pathology and Microbiology Division, Regional Plant Resource Centre, Bhubaneswar, 751015, India; Email: nguc2003@yahoo.co.in

ARTICLE INFO
Received: 20 March 2023 | Revised: 12 April 2023 | Accepted: 13 April 2023 | Published Online: 21 April 2023
DOI: https://doi.org/10.30564/jbr.v5i2.5582

CITATION
Panda, J., Vetrivelkalai, P., Bhagawati, B., et al., 2023. Diversity of Endophytic Fungi in Banana Cultivars of Assam India. Journal of Botanical Research. 5(2): 49-58. DOI: https://doi.org/10.30564/jbr.v5i2.5582

1. Introduction

Bananas are important agricultural products in most tropical countries and are consumed all over the world. It is a staple food and a source of income in many countries [1,2]. But nowadays, productivity is decreasing due to many diseases and attacks by a variety of pests. Nematodes are the main organism, which is responsible for causing many serious diseases. These plant parasites infect the banana roots and work as a barrier to the transpiration of macronutrients into the plant. This situation makes an adverse environment for the growth of plants [1]. *Pratylenchusgoodeyi, Radopholussimilis, P. coffeae, Helicotylenchusmulticinctus,* and *Meloidogyne spp.* are the most nematodes responsible for many diseases in banana variety, because banana varieties are the host of root-knot nematodes [3]. Although the nematodes or root-knot nematodes have a short life period, affecting host plants they can reduce yield capacity by 20-30% as well as make a rupture in the root, which helps the secondary pathogens enter [4,5].

Endophytes with a wide variety were found to be associated with a banana tree [6]. Recently, many workers are perusing an interest in endophytes and their major role in the plant. Endophytic microbes are used as biological agents to control most of the disease. These microorganisms also play an important role in plant growth as well as the bio-remediation of many pollutes [7-9]. Such bioagents may also use instead of synthetic fertilizers and pesticides, due to their cost-effective contribution to sustainable agriculture [10].

Since the last six decades, it has been found that many endophytic bacteria are associated with trees maintaining the symbiotic relationship and it was coming to exitance for the first time in the case of banana trees in the 1990s onwards. Gradually, research has been made for the diversity study of these endophytic bacteria as well as the properties and functions of bananas. A few genera of such bacteria also was reported in bananas like *Azospirillum, Bacillus, Burkholderia, Citrobacter, Enterobacter, Klebsiella, Ochrobactrum, Pantoea, Serratia and Staphylococcus* [11,12]. As bacterial endophytes there are many fungal endophytes also found. Few of them remain in dormant condition and carry forward their life cycle only in a suitable environment i.e., the stress condition of the host plant [13]. As bacterial endophytes there are many fungal endophytes also found. Few of them remain in dormant condition and carry forward their life cycle only in a suitable environment i.e., the stress condition of the host plant [14].

Recently, it has been observed that endophytes help in plant growth and also act as antinematicidal against plant parasitic nematodes [15]. Endophytes isolated from banana roots were found to be effective against the disease *Fusarium* wilt [16]. There are many findings of a variety of beneficial endophytes from banana tissue. There are different community structures of endophytes for the different disease levels of a banana tree [17]. Investigating the distribution of culturable endophytes in roots and effective screening for endophytes could improve our knowledge of the antagonistic ability against root-knot nematodes at different disease degrees of banana roots. In the north-east, India, mainly in the state of Assam banana cultivation is preferred by many cultivars due to its climatic and commercial demand. A wide range of banana varieties is cultivated, which directly influences the climatic zone as well as the economical strategy. Therefore, in the present study an attempt has been made to find out the endophytic diversity associated with the banana cultivar of Assam.

2. Materials and methods

Banana samples were collected from a different banana cultivar of Assam. Root, leaf and fruit samples were collected from banana trees. For root sampling, 3-4 cm of upper layer soil was removed with the help of small digging material or a knife to find out the target roots. Then roots were cut with the help of a sharp knife, and excess soil present on the root in a sticky condition was removed and kept in zip-locked poly bags. For obtaining leaf samples, dust present on a leaf was washed initially. Then leaves were cut randomly by using a knife or scissors and kept in air tight sampling bag to avoid contamination. In the case of fruit sampling, samples were collected randomly from the banana bunch. Fruits were detached from the bunch by cutting and kept in a sampling bag. After all sampling, samples were labelled properly and brought forward for the next step of the study.

Samples were brought to the laboratory of plant pathology and microbiology division, Regional Plant Resource Centre, Bhubaneswar and a surface sterilization procedure was followed [16,18,19]. A series of solvents were prepared like 70% ethanol, and 2.5% sodium hypo-chlorite along with sterile distilled water was also prepared. At first, all the samples were cleaned with running tap water to avoid unwanted materials from the surface. After that different plant sample was cut into pieces and placed in 70% ethanol for 3 minutes to the removal of surface microbe. After 3 min, a sample was transferred into a container containing 2.5% sodium hypochlorite solution and kept for 5 min then treated with 70% ethanol again for 1min. The sterilized sample was washed three to four times with sterile distilled water.

After surface sterilization, all root samples were macerated separately by adding sterile distilled water as required and kept in a sterile sample container. So that, all the endophytes will come out from the cell. All the leaf samples were macerated separately to obtain a maximum number of endophytes. But in the case of the fruit samples, the cover (peel) of fruits was cut into thin and 1-3 cm long pieces for the endophytic isolation.

Potato dextrose agar (PDA), Sabouraud agar (SDA) and Nutrient agar (NA) plates were made in duplicate. Two plates of PDA, SDA and NA each were used for one root sample. Macerated root samples were spread over the media plate and kept in an incubator at 30 °C. After an incubation period of 2-3 days, microbial growth was found in the form of mixed culture (fungal & bacterial culture). The same process was followed for the macerated leaf samples and microbial growth was observed in mixed culture. In the case of the fruit, pre-sterilised cover (peel) of the fruit was inoculated in the media plate. In one plate five to seven pieces of peel were placed and kept for an incubation period. After an incubation period, endophytic (bacterial and fungal) growth was observed. From these mixed cultured plates, the process of purification was started. From the mixed plate, each fungal endophyte was reinoculated in a media plate containing an antibiotic agent (Streptomycin sulphate) to avoid bacterial contamination, while same time bacterial endophytes were inoculated in the Nutrient agar media without an antibiotic agent. This purification process was followed 3-4 times till the pure culture was obtained.

Pure cultures of fungal isolates were identified on the basis of macromorphological and micromorphological characteristic features. Cultural characteristics such as colony shape, the shape of the spore, attachment of the spore and pigmentation were taken into consideration for identification. Microscopic observation was performed by preparing slide culture through a light microscope [20-24]. Isolation frequency (IF) of all endophytes was expressed from the point of view of location as well as variety wise. Relative abundance (Ra) and similar index of endophytes were also determined both for locations and varieties.

3. Results and discussion

A documentary survey was conducted in Assam, in which 10 different sites including Jorhat, Golaghat, Shivsagar, Nagaon, Narigoan, Mali, Marigoan, Kahikuchi, Boko and Golpara were covered. All total 15 variety of banana species Manohar, Big Jehaji, Athiya, Assam malbhog, Dwarf Jehaji, Malbhog, Hoanda, SeniChampa, Kashkol, Gobintulshi, Garndnaine, Amrut sagar, Bhim, Jehaji and Seni were found namely. Around 143 (62 roots, 18 fruits and 54 leaves) samples were collected and 139 fungal endophytes were isolated. All isolates were segregated into 46 different types on the basis of macromorphological and micromorphological characteristics, which includes *Aspergillus* sp. (11 no.), 14 types of *Fusarium* sp. (14 no.) and *Penicillium* sp. (6 sp.), *Cladosporium* sp. (3 no.), 2 no. Of *Curvularia* sp., *Hemicola* sp., and one of *Curvularia* sp., *Mucor* sp. and *Tricoderma* sp. obtained. The occurrence of the endophytes was expressed in terms of the location from where the samples were collected (**Table 1**) and sample variety (**Table 2**).

Table 1. Distribution of endophytic fungi in different samplings sites covered from banana plantations of Assam.

S.No.	Endophytic fungi	Sampling Sites									
		1	2	3	4	5	6	7	8	9	10
1	*Absidia sp.*	•			•	•	•				•
2	*Arthrinium phaecosporum*			•		•					
3	*Aspergillus niger*	•	•		•	•	•	•			
4	*Aspergillus sp. 1*							•			
5	*Aspergillus sp. 2*							•		•	
6	*Aspergillus sp. 3*										•
7	*Aspergillus sp. 5*		•		•	•		•			
8	*Aspergillus sp. 7*				•			•		•	
9	*Aspergillus sp. 8*	•		•	•	•		•	•	•	
10	*Aspergillus sp.4*				•						
11	*Aspergillus sp.6*	•		•	•	•	•	•			
12	*Aspergillus sp.9*	•	•	•	•	•		•		•	
13	*Aspergillus terreus*				•						
14	*Bipolaris australiensis*	•			•	•		•		•	
15	*Cladosporium cladopsoroides*	•	•	•	•	•	•	•	•	•	•
16	*Cladosporium herbarum*		•					•		•	
17	*Cladosporium oxysporum*	•		•	•	•		•			
18	*Cladosporium sp.*							•		•	
19	*Curvularia lunata*	•		•	•	•	•				
20	*Curvularia trifoli*	•									•
21	*Dendryphion inserminatum*							•		•	
22	*Fusarium avenaceum*								•		
23	*Fusarium ciliatum*			•	•	•					
24	*Fusarium graminearum*	•		•	•	•	•				
25	*Fusarium incarnatum*							•		•	
26	*Fusarium oxysporum*	•		•	•	•					
27	*Fusarium poi*							•		•	
28	*Fusarium udum*	•						•	•	•	•
29	*Humicola dimorphospora*							•		•	•
30	*Mortierella chlamydosporium*	•	•		•	•		•			
31	*Mortierella sp.*		•	•	•	•		•		•	
32	*Mucor fragalis*	•			•	•					
33	*Myceloid*			•	•	•		•		•	
34	*Paecilomyces farinosus*	•		•	•	•	•	•		•	•
35	*Penicilliuim vinaceum*							•			
36	*Penicillium citronigram*		•	•	•	•					
37	*Penicillium funiculosum*			•	•	•	•				
38	*Penicillium glabarum*		•					•			
39	*Penicillium rubrum*	•	•	•	•	•	•	•			
40	*Verticillium lecanii*			•	•		•				

Abbreviations: • = presence of fungi, sites of sampling: 1-Kahikuchi, 2-Shivsagar, 3-Narigoan, 4-Nagaon, 5-Marigoan, 6-Mali, 7-Jorhat, 8-Golpara, 9-Golaghat, 10-Boko.

Table 2. Distribution of endophytic fungi in different varities of banana grown in Assam.

S.No.	Fungi	Varities of banana														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	*Absidia sp.*	•	•							•			•	•	•	•
2	*Arthrinium phaecosporum*					•									•	
3	*Aspergillus niger*	•		•	•	•	•		•	•				•		•
4	*Aspergillus sp. 1*		•						•							
5	*Aspergillus sp. 2*	•									•					
6	*Aspergillus sp. 3*													•		
7	*Aspergillus sp. 5*	•		•	•		•			•						
8	*Aspergillus sp. 7*	•			•			•			•					
9	*Aspergillus sp. 8*	•		•	•	•	•	•	•	•		•		•		•
10	*Aspergillus sp..4*															•
11	*Aspergillus sp.6*	•	•			•			•	•		•	•			
12	*Aspergillus sp.9*	•		•	•	•	•		•	•	•			•		•
13	*Aspergillus terreus*				•											
14	*Bipolaris australiensis*	•			•		•		•		•					
15	*Cladosporium cladopsoroides*	•	•	•		•		•	•	•	•	•	•	•	•	•
16	*Cladosporium herbarum*			•							•					
17	*Cladosporium oxysporum*	•		•			•		•	•				•		
18	*Cladosporium sp.*	•							•					•		
19	*Curvularia lunata*	•	•					•		•			•		•	•
20	*Curvularia trifoli*	•			•											
21	*Dendryphion inserminatum*	•		•					•	•	•			•		
22	*Fusarium avenaceum*													•		
23	*Fusarium ciliatum*	•		•			•		•							
24	*Fusarium graminearum*	•	•	•	•			•	•	•		•	•	•	•	•
25	*Fusarium incarnatum*	•		•					•							
26	*Fusarium oxysporum*	•				•		•				•				•
27	*Fusarium poi*	•	•	•						•				•		
28	*Fusarium udum*	•			•			•			•			•	•	
29	*Humicola dimorphospora*	•									•					
30	*Mortierella chlamydosporium*					•	•		•							•
31	*Mortierella sp.*	•		•	•	•		•	•	•	•	•		•		•
32	*Mucor fragalis*												•		•	
33	*Myceloid*	•			•	•		•			•	•				•
34	*Paecilomyces farinosus*	•	•					•	•	•	•	•	•	•	•	•
35	*Penicilliuim vinaceum*										•					
36	*Penicillium citronigram*	•			•							•				
37	*Penicillium funiculosum*					•		•		•			•		•	•
38	*Penicillium glabarum*								•	•						
39	*Penicillium rubrum*	•	•	•		•		•	•	•		•	•			•
40	*Verticillium lecanii*				•	•				•			•			

Abbreviations: • = presence of fungi, varieties of banana: 1-Amrut Sagar, 2-Assam Malbhog, 3-Bhim, 4-Athiya, 5-Big Jehaji, 6-Seni, 7-Dwarf Jehaji, 8-Jehaji, 9-Honda, 10-Grandnine, 11-Gobintulshi, 12-Kashkol, 13-Malbhog, 14-SeniCahampa, 15-Manohar.

Isolation frequency (IF) was determined for all locations where endophytes were obtained. A total ten number of locations were observed, where many varieties of endophytes were isolated (**Table 3**). The rate of IF was estimated highest i.e. 80% in the case of *Penicillium* sp. and *Fusarium* sp. 9. Just below to it, 70% of IF was recorded for *Fusarium* sp. 10, *Aspergillus* sp. 1 and *p. digitatum.* Apart from this most of the endophytes were recorded with an average IF rate of 20%-60% and 10% which was the least IF, was estimated the case of *Aspergillus* sp. 4, *Aspergillus* sp. 7, *Fusarium* sp. 13, *Penicillium* sp. 2, etc. **Relative abundance (Ra)** was calculated for all endophytes found in these ten locations (**Table 3**) and a relative picture came to that of IF. *Fusarium* sp. 9 and *Penicillium* sp., these two are found with the highest Ra rate of 4.60%. *Fusarium* sp. 10, *Aspergillus* sp. 1, *Aspergillus* sp. 2 and *P. digitatum,* these four endophytes were observed with a Ra rate of 4.02%. *Aspergillus* sp. 9 and *Hemicola*sp. 1, were recorded with an average range of 3.45%. Most of the endophytes were found within this rate of Ra. Few endophytes such as *Aspergillus* sp. 4, *Aspergillus* sp. 7, *Fusarium* sp. 13, *Penicillium* sp. 2 were noted with a very low rate and that rate is determined to be 0.57%. It is obtained from the above analysis that, *Penicillium* sp. and *Fusarium* sp. 9 are high in IF rate as well as Ra rate. At the same time *Aspergillus* sp. 4, *Aspergillus* sp. 7, *Fusarium* sp. 13, *Penicillium* sp. 2 were found with a low rate of Ra and IF.

Isolation frequency (IF) was studied for the presence of endophytes from 15 different varieties (**Table 3**). It is found that the rate of IF ranges from 6.67% to 73.33% in the form of many endophytes found in all varieties. *Aspergillus* sp. 2, *Hemicola* sp. 1, *Penicillium* sp. were found with the highest percentage of IF rate and were estimated at about 73.33%. *Aspergillus* sp. 1 and *p. digitatum*these two species were observed to have the 2nd highest value of 66.67%. *Aspergillus* sp. 9 and *Fusarium* sp. 10 each recorded with IF rate of 60% and the same time another two species, *Curvularia*sp. 1 and *Fusarium* sp. 8 were each found with an equal rate of IF, 46.67%. Few endophytes noted with very least rate of IF (6.67%) obtained in case of *Aspergillus* sp. 4, *Aspergillus* sp. 6, *Aspergillus* sp. 7 and *Fusarium* sp. 13. **Relative abundance (Ra)** was calculated by the available number of endophytes obtained from the 16 different varieties (**Table 3**). As found in case of IF, highest Ra (4.93%) was determined in *Aspergillus* sp. 2, *Hemicola*sp. 1 and *Penicillium* sp. Apart from this, *Aspergillus* sp. 1 and *p. digitatum*are the species found to be a Ra value of 4.48% less than the 1st one. Two species, *Aspergillus* sp. 9 and *Fusarium* sp. 10 each recorded with an IF rate of 60% and at the same time another two species, *Aspergillus* sp. 4, *Aspergillus* sp. 6, *Aspergillus* sp. 7, *Penicillium* sp. 2 and *Fusarium* sp. 13 which were found with very low Ra values i.e., 0.45%. All the findings reflect that, *Aspergillus* sp. 2, *Hemicola* sp. 1 and *Penicillium* sp. are the species having both high rates. Some *Aspergillus* sp. and *Penicillium* sp. were also found with a very low rate of IF and RA.

Index of Similarity or Similar Index (SI)

There are many numbers of endophytes were obtained from all ten locations and 16 different varieties studied. One endophyte may have been obtained from one or two or so many locations. On the basis of the principle, Similar Index (SI) were estimated using the standard formula of $SI = 2C/(S_1 + S_2)$, where SI = similar index, C = Common species in the site, S_1 = site 1/location1 and S_2 = site 2/location2. SI was estimated both for the location (**Table 4**) and varieties (**Table 5**) wise. If we put a view on the SI value obtained from the location analysis, ten locations Jorhat, Golaghat, Shivsagar, Nagaon, Narigoan, Mali, Marigoan, Kahikuchi, Boko and Golpara were studied and most SI found in case of endophytes obtained from Jorhat and Golaghat i.e., 0.78 **(Table 4**). But the highest SI value (0.85) was obtained in both Nagaon and Marigoan. Marigoan and Kahikuchi are the two places where the index of similarity was found to be 0.74 and 0.71 was estimated in the case of Nagaon and Narigoan. The lowest value for SI was obtained between Nagaon and Boko i.e., 0.11 and a value of 0.12 was recorded in Mali and Golpara.

Table 3. Isolation frequency (IF) and Relative abundance (Ra) of endophytes found all locations studied.

		Sampling Sites			Varieties of Banana		
S. No.	Fungi	No of endophytes	Isolation frequency (IF)	Relative abundance (Ra)	No of endophytes	Isolation frequency (IF)	Relative abundance (Ra)
1	*Absidia sp.*	5	50	2.87	7	46.67	3.14
2	*Arthrinium phaecosporum*	2	20	1.15	2	13.33	0.9
3	*Aspergillus niger*	6	60	3.45	9	60	4.04
4	*Aspergillus sp. 1*	1	10	0.57	2	13.33	0.9
5	*Aspergillus sp. 2*	2	20	1.15	2	13.33	0.9
6	*Aspergillus sp. 3*	1	10	0.57	1	6.67	0.45
7	*Aspergillus sp. 5*	4	40	2.3	5	33.33	2.24
8	*Aspergillus sp. 7*	3	30	1.72	4	26.67	1.79
9	*Aspergillus sp. 7*	7	70	4.02	11	73.33	4.93
10	*Aspergillus sp.4*	1	10	0.57	1	6.67	0.45
11	*Aspergillus sp.6*	6	60	3.45	7	46.67	3.14
12	*Aspergillus sp.8*	7	70	4.02	10	66.67	4.48
13	*Aspergillus terreus*	1	10	0.57	1	6.67	0.45
14	*Bipolaris australiensis*	5	50	2.87	5	33.33	2.24
15	*Cladosporium cladopsoroides*	8	80	4.6	9	60	4.04
16	*Cladosporium herbarum*	3	30	1.72	2	13.33	0.9
17	*Cladosporium oxysporum*	5	50	2.87	6	40	2.69
18	*Cladosporium sp.*	2	20	1.15	3	20	1.35
19	*Curvularia lunata*	5	50	2.87	7	46.67	3.14
20	*Curvularia trifoli*	2	20	1.15	2	13.33	0.9
21	*Dendryphion inserminatum*	2	20	1.15	6	40	2.69
22	*Fusarium avenaceum*	1	10	0.57	1	6.67	0.45
23	*Fusarium ciliatum*	3	30	1.72	4	26.67	1.79
24	*Fusarium graminearum*	5	50	2.87	5	33.33	2.24
25	*Fusarium incarnatum*	2	20	1.15	3	20	1.35
26	*Fusarium oxysporum*	4	40	2.3	5	33.33	2.24
27	*Fusarium poi*	2	20	1.15	5	33.33	2.24
28	*Fusarium udum*	5	50	2.87	6	40	2.69
29	*Humicola dimorphospora*	3	30	1.72	2	13.33	0.9
30	*Mortierella chlamydosporium*	5	50	2.87	4	26.67	1.79
31	*Mortierella sp.*	6	60	3.45	11	73.33	4.93
32	*Mucor fragalis*	3	30	1.72	2	13.33	0.9
33	*Myceloid*	5	50	2.87	7	46.67	3.14
34	*Paecilomyces farinosus*	8	80	4.6	11	73.33	4.93
35	*Penicilliuim vinaceum*	1	10	0.57	1	6.67	0.45
36	*Penicillium citronigram*	3	30	1.72	3	20	1.35
37	*Penicillium funiculosum*	4	40	2.3	6	40	2.69
38	*Penicillium glabarum*	2	20	1.15	2	13.33	0.9
39	*Penicillium rubrum*	7	70	4.02	10	66.67	4.48
40	*Verticillium lecanii*	3	30	1.72	4	26.67	1.79

As compared to location data, it is found that the rate of SI was slightly low in the case of varieties (15 nos.) investigated (**Table 5**). The rate of SI found to be highest between Big Jehaji and Manohar was estimated at 0.69 and the lowest rate of SI was 0.11 in the case of Gobintulshi and Seni. Jehaji and Bhim showed a better rate of SI of 0.67 at the same time 0.64 SI was found to be in Honda and Amrut sagar. Amrut sagar was recorded with the same type of SI rate with many varieties. 0.61 and 0.60 SI rate was observed in Amrut sagar with Malbhog and Jehaji, respectively. Kashkol was recorded with the same SI value of 0.15 for Grandnine and Malbhog. One most common variety i.e., Assmamalbhog found with SI rate of 0.17 for Big jehaji.

The highest Index of Similarity (SI) value (0.85) was obtained in both of Nagaon and Marigoan among the all locations and the lowest value for SI were obtained in between Nagaon and Boko i.e., 0.11 and a value of 0.12 was recorded in Mali and Golpara. But from a variety of points of view, the rate of SI was found to be the highest between Big Jehaji and Manohar estimated at 0.69 and the lowest rate of SI was 0.11 in the case of Gobintulshi and Seni.

Table 4. Similarity index of the fungal communities colonizing in different banana cultivars of Assam.

		Sampling sites									
		1	2	3	4	5	6	7	8	9	10
1	Kahikuchi										
2	Shivasagar	0.27									
3	Narigaon	0.50	0.33								
4	Nagaon	0.67	0.37	0.71							
5	Marigaon	0.74	0.39	0.28	0.85						
6	Mali	0.56	0.27	0.56	0.55	0.53					
7	Jorhat	0.54	0.47	0.42	0.54	0.56	0.30				
8	Golpara	0.32	0.00	0.16	0.06	0.19	0.12	0.24			
9	Golaghat	0.37	0.29	0.37	0.39	0.36	0.20	0.78	0.26		
10	Boko	0.37	0.00	0.15	0.11	0.18	0.32	0.23	0.33	0.32	

Abbreviations: 1-Kahikuchi, 2-Shivasagar, 3-Narigaon, 4-Nagaon, 5-Marigaon, 6-Mali, 7-Jorhat, 8-Golpara, 9-Golaghat, 10-Boko.

Table 5. Index of similarity of endophytes found in all 15 varieties.

	Varieties of Banana														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Amrut Sagar															
Assam Malbhog	0.38														
Bhim	0.55	0.16													
Athiya	0.52	0.00	0.41												
Big Jehaji	0.40	0.17	0.43	0.44											
Seni	0.35	0.00	0.52	0.45	0.38										
Dwarf Jehaji	0.45	0.45	0.30	0.38	0.56	0.10									
Jehaji	0.60	0.29	0.67	0.38	0.45	0.54	0.27								
Honda	0.64	0.52	0.61	0.29	0.47	0.34	0.48	0.56							
Grandnine	0.58	0.23	0.39	0.40	0.28	0.17	0.43	0.35	0.38						
Gobin tulshi	0.47	0.48	0.23	0.32	0.42	0.11	0.81	0.34	0.44	0.30					
Kashkol	0.33	0.50	0.16	0.08	0.43	0.00	0.45	0.21	0.52	0.15	0.38				
Malbhog	0.61	0.37	0.50	0.39	0.27	0.32	0.28	0.51	0.58	0.48	0.29	0.15			
Seni Cahampa	0.29	0.50	0.08	0.08	0.26	0.00	0.55	0.07	0.39	0.31	0.19	0.60	0.30		
Manohar	0.55	0.31	0.39	0.33	0.69	0.33	0.64	0.47	0.59	0.38	0.52	0.54	0.42	0.38	

Abbreviations: 1-Amrut Sagar, 2-Assam Malbhog, 3-Bhim, 4-Athiya, 5-Big Jehaji, 6-Seni, 7-Dwarf Jehaji, 8-Jehaji, 9-Honda, 10-Grandnine, 11-Gobin tulshi, 12-Kashkol, 13-Malbhog, 14-Seni Cahampa, 15-Manohar.

Conflict of Interest

There were no conflict of interest in the publication of this content.

Acknowledgments

This research was funded by Department of Biotechnology, Govt. of India, New Delhi under network project under NER-BPMC-DBT-NER/AGRI/33/2016. The laboratory and administrative support received from the Chief Executive, Regional Plant Resource Centre, Bhubaneswar is also gratefully acknowledged.

References

[1] Mendoza, A.R., Sikora, R.A., 2009. Biological control of *Radopholussimilis* in banana by combined application of the mutualistic endophyte *Fusarium oxysporum* strain 162 the egg Pathogen *Paecilomyceslilacinus* strain 251 and the antagonistic bacteria *Bacillus firmus*. BioControl. 54, 263-272.

[2] Wang, B.B., Yuan, J., Zhang, J., et al., 2013. Effects of novel bioorganic fertilizer produced by *Bacillus amyloliquefaciens* W19 on antagonism of *Fusarium* wilt of banana. Biology and Fertility of Soils. 49, 435-446.

[3] Kisaakye, J., Fourie, H., Coyne, D., et al., 2023. Endophytic fungi improve management of the burrowing nematode in banana (Musa spp.) through enhanced expression of defence-related genes. Nematology. 25(4), 427-442.

[4] Nyang'au, D., Atandi, J., Cortada, L., et al., 2021. Diversity of nematodes on banana (Musa spp.) in Kenya linked to altitude and with a focus on the pathogenicity of Pratylenchus goodeyi. Nematology. 24(2), 137-147.

[5] Caboni, P., Aissani, N., Demurtas, M., et al., 2016. Nematicidal activity of acetophenones and chalcones against *Meloidogyne incognita*, and structure-activity considerations. Pest Management Science. 72, 125-130.

[6] Yang, D., Wang, L., Wang, T., et al., 2021. Plant growth-promoting rhizobacteria HN6 induced the change and reorganization of Fusarium microflora in the rhizosphere of banana seedlings to construct a healthy banana microflora. Frontiers in Microbiology. 12, 685408.

[7] Xiang, D., Yang, X., Liu, B., et al., 2023. Bio-priming of banana tissue culture plantlets with endophytic Bacillus velezensis EB1 to improve Fusarium wilt resistance. Frontiers in Microbiology. 14, 1146331.

[8] Dudeja, S.S., Suneja, P., Paul, M., et al., 2021. Bacterial endophytes: Molecular interactions with their hosts. Journal of Basic Microbiology. 61(6), 475-505.
DOI: https://doi.org/10.1002/jobm.202000657

[9] Germaine, K.J., Liu, X., Cabellos, G.G., et al., 2009. Bacterial endophyte-mediated naphthalene phytoprotection and phytoremediation. FEMS Microbiology Letters. 296(2), 226-234.

[10] Aung, T.N., Nourmohammadi, S., Sunitha, E.M., et al., 2011. Isolation of endophytic bacteria from green gram and study on their plant growth promoting activities. International Journal of Pharma Bioscience and Technology. 2, 525-536.

[11] Rosenblueth, M., Martinez, L., Silva, J., et al., 2004. Klebsiella variicola, a novel species with clinical and plant-associated isolates. Systematic and Applied Microbiology. 19, 827-837.

[12] Thomas, P., Swarna, G.K., Roy, P.K., et al., 2008. Identification of culturable and originally non-culturable endophytic bacteria isolated from shoot tip cultures of banana cv. Grand Naine. Plant Cell, Tissue and Organ Culture. 93, 55-63.

[13] Kambach, S., Sadlowski, C., Peršoh, D., et al., 2021. Foliar fungal endophytes in a tree diversity experiment are driven by the identity but not the diversity of tree species. Life (Basel). 11(10), 1081.

[14] Qiao, W., Tang, T., Ling, F., 2020. Comparative transcriptome analysis of a taxol-producing endophytic fungus, Aspergillus aculeatinus Tax-6, and its mutant strain. Scientific Reports. 10, 10558.

[15] Bogner, C.W., Kariuki, G.M., Elashry, A., et al.,

2016. Fungal root endophytes of tomato from kenya and their nematode biocontrol potential. Mycological Progress. 15, 1-17.

[16] Cao, L.X., Qiu, Z.Q., You, J.L., et al., 2005. Isolation and characterization of endophytic streptomycete antagonists of Fusarium wilt pathogen from surface-sterilized banana roots. FEMS Microbiology Letters. 247, 147-152.

[17] Xia, X., Lie, T.K., Qian, X., et al., 2011. Species diversity, distribution, and genetic structure of endophytic and epiphytic trichoderma associated with banana roots. Microbial Ecology. 61, 619-625.

[18] Ganeshan, K., Vetrivelkalai, P., Bhagawati, B., et al., 2021. Endophytic fungi as potential biocontrol agents against root-knot nematode, Meloidogyne incognita in Banana. Current Journal of Applied Science and Technology. 40(29), 7-18.

[19] Petrini, O., 1986. Taxonomy of endophytic fungi of aerial plant tissues. Microbiology of the phyllosphere. Cambridge University Press: Cambridge. pp. 175-187.

[20] Tafinta, I.Y., Shehu, K., Abdulganiyyu, H., et al., 2013. Isolation and identification of fungi associated with the spoilage of sweet orange *Citrus sinensis* fruit in Sokoto state. Nigerian Journal of Basic and Applied Sciences. 21(3), 193-196.

[21] Raper, K.B., Thom, C., Fennel, D.I., 1984. A manual of the Penicillia. International Books and Periodicals Supply Service: New Delhi. pp. 1-851.

[22] Nagamani, A., Kunwar, I.K., Manoharachary, C., 2005. Hand book of Soil Fungi. International Pvt. Ltd.: New Delhi. pp. 1-461.

[23] Watanabe, T., 2010. Pictorial atlas of soil and seed fungi. Morphologies of cultured fungi and Key to species, third edition. CRC Press, Taylor & Francis Group: London. pp. 1-399.

[24] Zhang L., Zhang H., Huang Y., et al., 2021. Isolation and evaluation of rhizosphere actinomycetes with potential application for biocontrolling Fusarium wilt of banana caused by Fusarium oxysporum f. sp. cubense tropical race 4. Frontiers in Microbiology. 25(12), 763038.

Journal of Botanical Research
https://journals.bilpubgroup.com/index.php/jbr

REVIEW

An Insight of Parasitic Weeds in Africa and Scientific Developments: A Review

Christopher Kalima Phiri[1*] ***, Vernon H. Kabambe***[2]***, James Bokosi***[2]

[1] *Agriculture Department, LakeView College, Malawi Adventist University, P.O. Box 148, Ntcheu, Malawi*
[2] *Crop and Soil Sciences Department, Lilongwe University of Agriculture and Natural Resources, P.O. Box 219, Lilongwe, Malawi*

ABSTRACT

Parasitic weeds are a major threat to food security in Africa and control measures mostly done by smallholder farmers are not effective in eradicating the parasites. This results in a yield loss up to 100%. Parasitic weeds comprise *Alectra vogelii*, *Striga* spp., *Orobanche* spp., *Rafflesia* spp., and *Phoradendron* spp. Parasitic attachment is successful when three necessary conditions have been fulfilled namely the compatible host, suitable environment, and parasitic weed. These species parasite plant species through special attachment features such as modified leaves, suckers, haustoria, or modified roots. In Africa, the variability of parasitic weeds is largely driven by environmental factors such as temperature, rainfall, soil type, and crop husbandry practices. Warmer temperatures create more hospitable conditions for certain parasitic weeds, and allowing them to spread to new areas. Parasitic weed control is vital for effective crop production and the control strategies can be achieved through integrated weed control method that embraces mechanical, cultural, chemical, and biological methods. However, the most effective and crucial method is the cultivation of resistant varieties that provide long-term protection against parasitic weeds. Studies have been done on host-parasite attachment where dodder can send out new roots to infected neighbouring plants and spread their parasitic behaviour. More insight and knowledge should offer new goals for control within the life cycle of the parasitic weeds and their metabolic activities. Lastly, disciplines such as agronomy, plant breeding, nutrition, economics, and IT should play their roles effectively in combating parasitic weeds.

Keywords: *Alectra vogelii; Striga* spp.*; Orobanche* spp.; Haustoria; Food security; Environmental factors

*CORRESPONDING AUTHOR:
Christopher Kalima Phiri, Agriculture Department, LakeView College, Malawi Adventist University, P.O. Box 148, Ntcheu, Malawi; Email: christopherphiriphiri90@gmail.com

ARTICLE INFO
Received: 11 March 2023 | Revised: 26 April 2023 | Accepted: 27 April 2023 | Published Online: 17 May 2023
DOI: https://doi.org/10.30564/jbr.v5i2.5535

CITATION
Phiri, C.K., Kabambe, V.H., Bokosi, J., 2023. An Insight of Parasitic Weeds in Africa and Scientific Developments: A Review. Journal of Botanical Research. 5(2): 59-75. DOI: https://doi.org/10.30564/jbr.v5i2.5535

1. Introduction

1.1 Background information

Parasitic weeds comprise *Alectra vogelii*, *Striga* spp., *Orobanche* spp., *Rafflesia* spp., and *Phoradendron* spp., which are the main limitation to agricultural efficiency in Africa [1]. These weeds reduce crop yield up to 100% when susceptible cultivars are grown in infested farmland [2-4] which is common among resource-poor farmers. Interestingly, these parasitic weeds can extract nutrients and water from their host plants, resulting in compromised yield quality and quantity. Over the past few decades, significant research efforts have been dedicated to addressing this challenge [3,5-8] and minimising crop loss. The biology and ecology of parasitic weeds are complex, as they comprise multiple interactions between the compatible host plant, the parasite, and the suitable environment [9-12]. Therefore, the interaction of the three components results in either infestation of parasitic weeds or not and can be related to a disease triangle as illustrated below in the diagram (**Figure 1**).

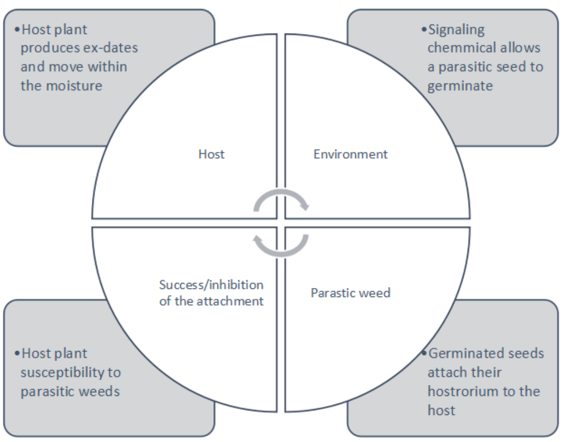

Figure 1. Host-parasite interaction.

This implies that the environment needs to be well nourished for the interaction to be successful. The interaction undergoes four stages: germination, haustorium formation, attachment, and vascular connection [10,13]. Interestingly, the use of trap crops induces the interaction but once cropped in the triangle interaction is disrupted (**Figure 1**). A deep understanding of these interactions is essential for effective management. Recent advances in molecular biology and bioinformatics have enabled researchers to gain insight into the molecular basis of parasitic weed interactions [14-16]. This has resulted in novel approaches to the management of these weeds, including the development of resistant crop varieties [17], the use of biocontrol agents [18], and the application of herbicides [19-21]. In addition, much research has been conducted on the economic and social impacts of parasitic weeds in Africa [22,23]. However, these weeds reduce crop yield and crop nutrition which also signifies why malnutrition problems continue to hamper African countries. This review provides an overview of parasitic weeds variability, their botany, host-parasite interaction mechanisms, climate change impacts, control strategies, roles of selected disciplines in agriculture, and education in the control of the parasitic weeds and highlights some advances in understanding and managing these weeds.

1.2 Strain variability of parasitic weeds in Africa

Parasitic weeds are a major threat to food security in Africa. The strain variability of these parasitic weeds in Africa is largely driven by environmental factors such as temperature, rainfall, soil type, and crop husbandry practices [24] as *Alectra* seed sourced from Mali, Nigeria, and Cameroon, was observed in attacking all groundnuts, cowpea genotype Blackeye, but not cowpea line B301, mung bean or Bambaranut. However, Botswana collections differed in attacking B301 and mung bean [24] while cowpea landrace B301 was resistant to *A. vogelii* in Kenya but susceptible to *Alectra* collections sourced from Malawi, Botswana, and some areas of South Africa which suggest apparent strain variability. The strain variability of parasitic weed can also be attributed to the presence of multiple host species in the same environment, as well as the presence of different species of the same weed in different areas [25,26]. Additionally, the spread of parasitic weeds in Africa may be impacted by changes in agricultural practices, such as the introduction of new crop varieties or the use of different herbicides or pesticides. Apparent strains of parasitic weeds in Africa include *Striga asiatica*, *Striga hermonthica*, *Cuscuta campestris*, *Orobanche* spp., *Striga gesnerioides*, *Striga lutea*, *Alectra* spp., *Rhamphicarpa fistulosa*, *Striga orobanchioides* and *Sesamia calamistis* [27,28].

1.3 Botany of parasitic weeds

Parasitic weeds are species of plants that use other plants as a source of photo-assimilates, water, and nutrients for survival [29]. The parasitic weed becomes a metabolic sink for photoassimilates and they encourage more transpiration for the translocation of growth resources [30,31]. These parasitic plants can be either root or stem parasites, and they are divided into two categories: Holoparasites and hemiparasites. Holoparasites, such as dodder, witchweed, and broomrape, are completely dependent on their hosts for sustenance and cannot survive without them [32]. Hemiparasites, on the other hand, can photosynthesize but still rely on their hosts for at least some of their nutrients. Examples of hemiparasites include mistletoe and Indian paintbrush [12].

Interestingly, parasitic weeds have a diversity of seed characteristics that help them to survive and compete with other plants in their environment. The traits consist of seed dormancy, seed longevity, seed size, seed dispersal, high seed production per plant, germination strategies, and seed coat structure [33,34]. Furthermore, parasitic weeds produce more seeds which also stay in the soil for a longer period compared to other normal weeds and the trait ensures generation succession. Seed dormancy is an attribute that allows seeds to remain quiescent for a while before germinating [35,36]. The character protects seeds from environmental shocks and increases their probability of survival and germination in the future. Seed longevity is another attribute that permits the seeds to remain viable for a longer period [37]. This trait helps ensure that the seeds are still viable when conditions become favourable for germination as illustrated by the parasitic triangle (**Figure 1**). Furthermore, prolonged longevity acts as a mechanism for survival in harsh environments. Seed size is a significant trait for parasitic weeds, as smaller seeds are more expected to be dispersed and travel farther distances through wind, animal bodies, agricultural implements, crop produce, and water [38]. Seed dispersal is important for parasitic seeds to spread and colonize new niches and once favourable conditions are available they germinate and attach themselves to the host plants.

Germination strategies are also important for parasitic weeds, as they need to be able to germinate quickly and effectively once signaling exudates of host plants have been released into the soil and they travel together with the soil moisture [39]. Once parasitic seeds germinate and attach to the host they compete with host plants for growth resources. However, germination is often influenced by the presence of other plants, which provide the necessary exudates, nutrients, and energy for the development and attachment of these parasitic weeds [40]. Sunlight, temperature, and moisture levels can also affect germination. The ideal conditions for the germination of parasitic weeds vary depending on the species, but they generally need warm, moist conditions with adequate light [41]. The best time of the year for parasitic weed seeds to thrive well is usually in the late spring or early summer when the soil is sufficiently moist and warm [42]. It also takes advantage of well-drained soil which prevents root rot.

Parasitic weeds have a seed coat structure that is adapted to the environment in which they live as such some can thrive there for a longer period [6,43]. In general, the seed coat of parasitic weeds is usually thicker and tougher than that of non-parasitic plants, which helps them to survive in harsh conditions. The seed coat may also be covered in tiny spikes or hooks that help the seed to attach itself to the host plant. In addition, the seed coat of parasitic weeds can also contain chemical compounds that help them to penetrate the host plant's tissues and extract nutrients [44]. Lastly, the seed coat structure of *Alectra vogelii* is an example that lacks a palisade layer of the macroscelerids making them easily permeable to water [45]. Postulated changes during the ripening and seed conditioning period are various structural and metabolic changes in the seed coat associated with increased softening of the seed coat making it more permeable to water, increased signaling enzymes, and protein changes [46]. However, when conditions are not favourable the seed coat facilitates seed dormancy which allows the seeds to stay in the soil for a long period.

2. An overview of parasitic weeds

2.1 Soil condition suitable for parasitic weeds

Soil low in organic matter and high in minerals is most suitable for parasitic weeds such as dodder, witchweed, and broomrape [27,47]. These weeds extract nutrients and water from the host plants they parasitise, and they thrive in soils that lack organic matter. Poorly drained, sandy soils with a high water table are also ideal for parasitic weeds as they become more competitive on available growth resources through an increased transpiration mechanism triggered. They also prefer soils with high levels of calcium, potassium, and phosphorus [48]. Additionally, parasitic weeds often require adequate moisture to develop and thrive.

2.2 Parasitic weeds vs non-parasitic weeds

Parasitic weeds are plants that derive their nutrition from the host plant, unlike other weeds which are capable of extracting minerals, and water from the soil [5,21] and undergoing photosynthesis. Parasitic weeds also have specialized roots/stems that penetrate the root/stem system of the host plant to absorb nutrients and water, while other weeds typically rely on the soil for minerals and water. Additionally, most parasitic weeds are highly specialized and are adapted to feed on specific plants, while most other weeds are generalists that can survive in a variety of settings. Furthermore, parasitic weeds produce more seeds that can stay in the soil for a longer period compared to non-parasitic weeds [3,41]. Significant crop yield reductions in parasitic weeds especially *Striga* and *Alectra* infestation occur before the weed sprouts above ground while with normal weeds it occurs mostly when both the crop and weeds are growing.

2.3 Commonly attacked crop specie by parasitic weeds

Parasitic weeds can attack a wide range of crops, including wheat, corn, cotton, soybeans, oats, barley, sorghum, alfalfa, cowpeas, beans, green gram, and vegetables [3]. Other crops commonly attacked by parasitic weeds include potatoes, tomatoes, peppers, and lettuce. Previously, pigeon peas were considered immune to *Alectra vogelii* but they were found to be infested in screen house experiments [49], and flax too as an introduced crop variety in Malawi.

2.4 Mechanisms used by parasitic weeds to attack host plants

Parasitic weeds attack host plant species by attaching themselves to the root/stem systems of the host plants and stealing their nutrients, water, and energy [3,4,50], and one of the attachments is illustrated on susceptible IT82E-16 cowpea cultivar (**Figure 2**). This process is known as parasitism and is facilitated by the presence of haustoria—specialized organs that the parasitic weed uses to penetrate the cells of the host plant. Parasitic weeds also employ other mechanisms such as allelopathy [34,51], in which they release chemicals that inhibit the growth of the host plant, and rhizomes, in which they can spread rapidly through the soil.

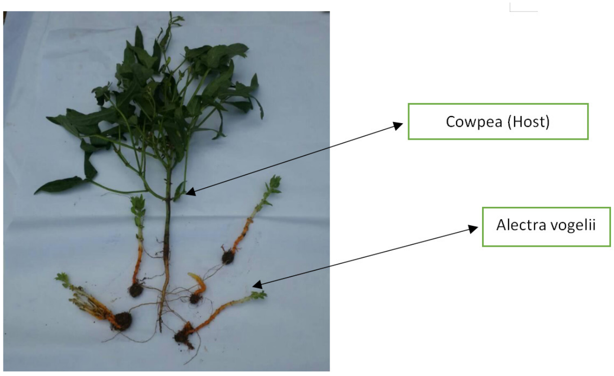

Figure 2. IT82E-16 cowpea variety attacked by *Alectra vogelii* (Parasitic weed).

2.5 Chemical compounds released by parasitic weeds

Parasitic weeds produce a variety of compounds that are specific to the crop species they are parasitic on. These compounds can include chemicals such as phytotoxins, allele chemicals, and enzymes [52,53]. Phytotoxins are toxic compounds that can inhibit the growth of crop species, while allele chemicals are chemicals that interfere with the growth of neighbouring plants of the same species [54] and they include alkaloids, polypeptides, amines, glycosides, oxalates, and resins. Enzymes, on the other hand, can break down cell walls in the crop species, allowing the parasitic weed to gain access to nutrients.

3. An overview of attachment mechanisms and control strategies for parasitic weeds

3.1 Pre-attachment mechanisms of parasitic weeds

Pre-attachment mechanisms of parasitic weeds are strategies used by parasitic plants to increase the likelihood of successful infection of their host plants [28,50]. These strategies are used to ensure that the parasites can obtain the resources they need to survive and reproduce. **Figure 3** illustrates pre-attachment mechanisms.

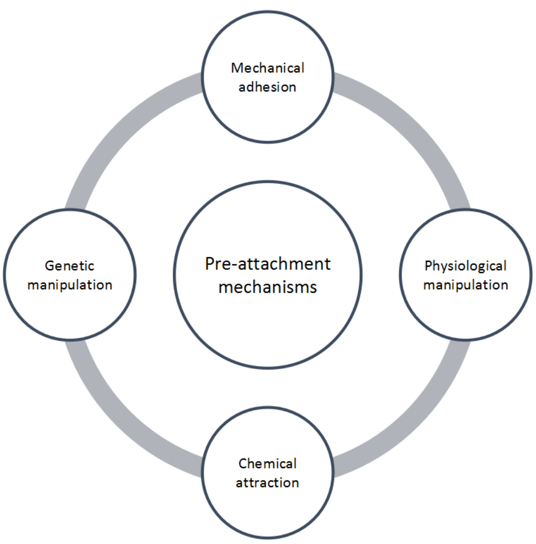

Figure 3. Pre-attachment mechanisms of host parasites.

- Chemical attraction is where parasitic weeds may produce volatile compounds that attract their host species [55]. This is common in parasitic plants that use animals as vectors to spread their seeds.
- Physiological manipulation generally occurs when parasitic weed release chemicals that interfere with the metabolic and physiological processes of their host species [56]. This can prevent the host from defending itself against the parasite or make it easier for the parasite to attach itself to the host.
- Mechanical adhesion occurs when parasitic weeds produce specialized organs, such as haustoria, that allow the parasite to attach itself to the host [44].
- Genetic manipulation involves the production of toxins that alter the genetic makeup of their host species, making them more susceptible to infection [13]. These pre-attachment mechanisms are essential for the survival and reproduction of parasitic weeds and are important for understanding how these plants interact with their hosts.

3.2 Attachment mechanisms of parasitic weeds

Parasitic weeds attach to their hosts using modified root structures called haustoria. Haustoria penetrate the host plant's vascular system, allowing the parasitic weed to steal nutrients, water, and other resources from the host [44]. The haustoria can also be used to transfer nutrients from the host to the parasite. Some parasitic weeds also produce tiny thread-like structures called 'sinkers' [57] which penetrate the host plant's epidermis and enable the parasite to gain access to its resources. Other attachment mechanisms include suckers, which are specialized structures that form on the stem of the parasite and attach to the stem of the host, and rootlets, which are specialized roots that attach to the root of the host.

3.3 Post-attachment mechanisms of parasitic weeds

The post-attachment mechanisms of parasitic weeds vary depending on their mode of attachment, which can be through seed, stem, root, or leaf organs [44,50,24]. **Figure 4** provides illustrations of some of these mechanisms.

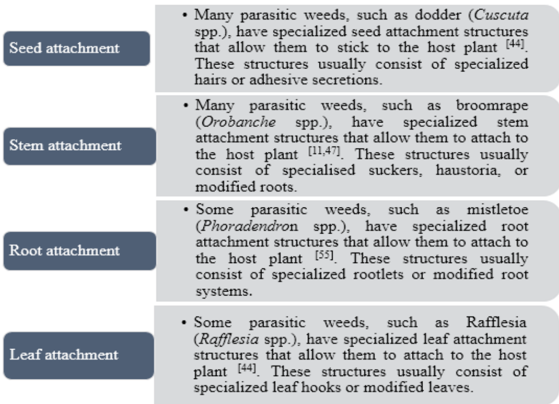

Figure 4. Depicts the various mechanisms that parasitic weeds use after attaching themselves to their host, including both physiological and structural adaptations.

3.4 Uniqueness of host-parasite interaction

The interaction between crop species and parasitic weeds is special as it involves a complex relationship between both species [58]. This relationship includes the exchange of resources, competition for resources, and the potential for both species to affect the other's survival and reproduction [4]. Parasitic weeds can cause significant damage to crops and can even cause crop failure [2,17]. Furthermore, the parasitic weeds produce more seeds at the expense of host species photo-assimilates and such seeds thrive well in the soil for a longer period. On the other hand, crop species can also benefit from the presence of parasitic weeds as they can provide them with nutrients and other resources [55]. The relationship between crop species and parasites is a complex and dynamic one, making it special.

3.5 Failure in attachment mechanisms of parasitic weeds

Failure in attachment mechanisms of parasitic weeds can be attributed to a wide range of factors, including environmental conditions, the physical characteristics of the host plant, the biology of the parasite, and biological control methods [10,14]. Environmental conditions, such as temperature and moisture levels, can affect the ability of the parasite to attach to the host plant. Physical characteristics of the host plant, such as its age, growth habit, and the presence of wax or other surface barriers, can make it difficult for the parasite to attach. The biology of the parasite, such as its life cycle (**Figure 5**), chemical signals, and the presence of specific receptors, can dictate how successful it is in attaching to the host plant [59]. Finally, biological control methods, such as the introduction of natural enemies, can disrupt the attachment process of parasitic weeds [12].

3.6 Impact of climate change on the spread of parasitic weeds

Warmer temperatures can increase the rate of germination and growth of parasitic weed seeds thereby, increasing soil seed bank [60,61]. Raising temperatures can also cause plants to become more vulnerable to infestations by parasitic weeds. Warmer temperatures can increase the survival of parasitic weed seeds in the soil, allowing them to remain viable for longer periods, and increasing the likelihood of infestations [50]. Climate change can also affect the spread of parasitic weeds by altering the habitats in which they thrive. Warmer temperatures can create more hospitable conditions for certain parasitic weeds, allowing them to spread to new areas. Warmer temperatures and increased levels of atmospheric carbon dioxide can lead to more favourable conditions for seed germination, allowing parasitic weeds to spread more quickly than they otherwise would. As temperatures increase, the range of some parasitic weed species can expand, leading to infestations in areas where they were previously uncommon.

Climate change can also affect the availability of resources, such as water, that can support parasitic weed growth [62,63]. In addition to temperature, precipitation patterns, and weather extremes can also influence the spread of parasitic weeds. Changes in precipitation patterns can cause weather extremes that can make some areas more vulnerable to infestations by parasitic weeds. Excessive rainfall can cause flooding, creating standing water that can provide more hospitable condi-

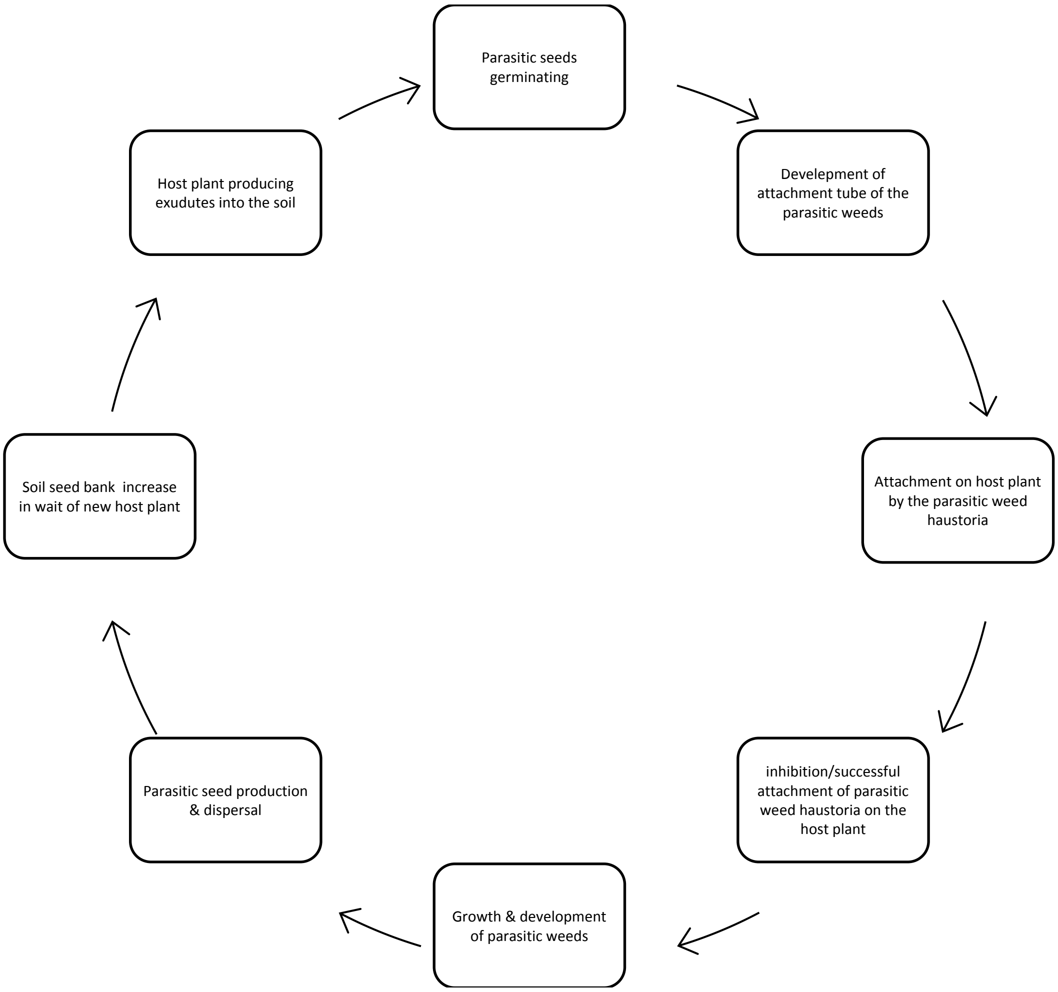

Figure 5. Life cycle of parasitic weeds (*Alectra vogelii*).

tions for parasitic weed growth [64]. On the other hand, drought conditions can reduce the soil moisture levels needed for crop species development. These impacts of climate change can lead to a decrease in crop yields and a decrease in the quality of agricultural lands. To combat the spread of parasitic weeds, farmers must implement practices such as crop rotation, tillage, and the use of herbicides [50].

3.7 Effects of parasitic weeds on crop species in Africa

Parasitic weed's effects on crops in Africa can be devastating and they also fuel malnutrition. Parasitic weeds, such as *Striga*, *Alectra*, *Orobanche*, and *Cuscuta*, attach themselves to crop roots and extract nutrients, water, and photo-assimilates from the plants, resulting in reduced growth, yield, and quality of the crop yield [65]. This can lead to reduced yields and decreased income for smallholder farmers who rely on the enterprise as means of survival. In addition, parasitic weeds can reduce the availability of nitrogen, phosphorus, and other essential nutrients, leading to soil degradation and loss of fertility. Furthermore, parasitic weeds can reduce crop diversity, which can limit the ability of farmers to adapt to changing environmental conditions [66]. Finally, parasitic weeds can create favourable conditions for other pests and diseases, increasing the risk of crop losses and resulting in economic loss [67]. Some governments opt to import certain crops for processing and consumption in fear of introducing parasitic weeds [67] in their farming community. This is considered so as there are increased costs in controlling and eradicating the parasitic weeds which make the yield products to be expensive as there are extra costs for farmers and producers. Parasitic weeds can disrupt ecosystems where in local ecosystems native plant species are displaced which creates an imbalance in the food chain thereby affecting biodiversity. This is why some communities will abandon the cultivation of certain crops as their yields are declining due to parasitic weeds. Lastly, parasitic weeds can spread disease from one plant to another, leading to decreased crop yields and increased pest infestations [50]. Parasitic weeds once infest crops they invite many troubles in crop production thereby, affecting the economy of the smallholder farmers.

3.8 Impacts of parasitic weeds on the nutrition of crop species

Parasitic weeds can have a significant impact on the nutrition of crop species. These weeds can compete with crops for nutrients, water, and light, reducing crop yields and quality [68]. Depending on the species of parasitic weed, some can reduce the availability of key nutrients like nitrogen, phosphorus, and potassium [55]. They can also negatively impact the quality and yield of grain crops, as they compete with the crop for available resources like water and light. In addition, they can reduce the grain's protein content which affects both human and animal dietary needs [69]. All these results in malnourished communities as food products are limited in terms of basic minerals for health wise. Therefore, managing parasitic weeds is essential for maintaining the quality and nutrient content of grain crops.

3.9 Common control measures of parasitic weeds in Africa

Parasitic weeds are a major agricultural problem throughout the world and cause significant crop losses and economic losses. Control of these weeds is essential for successful crop production and can be accomplished through a combination of cultural, mechanical, chemical, and biological methods [17,37]. The following are methods commonly used in the control of parasitic weeds in Africa:

- Crop rotation is a good way to reduce or eliminate the spread of parasitic weeds in Africa [19,23]. It involves planting a different crop in the same field each year and rotating them in a three- to four-year cycle plan. This prevents the weeds from becoming too well-established and reduces the amount of nutrients available to them. However, when host plants are cropped on the land they produce their seeds which will thrive in the soil and only germinate once new hosts are available. Additionally, intercropping can be used to reduce the spread of parasitic weeds on the farmland.
- Hand weeding is a labour-intensive but effective method of controlling parasitic weeds [70,71] in Africa. It involves manually pulling out weeds by their roots and disposing of them safely. This only controls the above-ground germinated weeds and reduces the chances of seed development but they are not more effective in parasitic weed controls as much of the damage is done below ground before emergence.
- Herbicides are used to selectively control certain types of parasitic weeds [72,3,50] in Africa. These chemicals must be properly applied and used by following the manufacturer's instructions to be effective. Although chemical control is used, it should be done with caution, as it can have negative impacts on the environment. However, the method is expensive as smallholder farmers fail to afford the inputs due to poverty.
- Cover crops are planted to prevent the spread of parasitic weeds in Africa [73]. They help to reduce the amount of nutrients available to the weeds and can also be harvested for livestock feed or other uses.
- Mulch is a great way to prevent the spread of parasitic weeds in Africa [50]. This acts as a barrier to keep the weeds from gaining access to nutrients, moisture, and sunlight.
- Crop resistance is a key part of controlling parasitic weeds. Crop resistance involves the development of crop varieties that are better able to resist or tolerate the effects of parasitic

weeds [19,74,21]. This can be done through breeding for specific traits or through the use of biotechnological approaches such as genetic engineering. Crop resistance is achieved through the selection of traits such as improved root growth, thicker cuticles, and enhanced photosynthetic capacity [75].

- The use of fertilizers in controlling parasitic weeds is a common practice [70,76]. Fertilizers are typically applied in a broadcast method, which applies the fertilizer evenly over the entire area. This helps to reduce the number of weeds that can be established, as the fertilizer helps to create a stronger, more competitive plant community. Additionally, certain nitrogen-based fertilizers can be applied in a banded method, which places the fertilizer directly onto the weed-infested area. This method can be especially effective for reducing the spread of parasitic weeds, as the fertilizer helps to reduce the nitrogen availability in the soil and make it less hospitable for the weeds [77]. Additionally, certain herbicides and other weed control methods can be applied in conjunction with the fertilizer application to help further reduce the spread of parasitic weeds.
- Genetic tolerance is a unique approach to the control of parasitic weeds. Genetic tolerance is an approach that involves breeding plants that are tolerant to the effects of the weed and thus better able to compete with it [25]. It involves using genetic engineering to introduce genes into the weed species that make them more resistant to the herbicides used to control them. This can reduce or even eliminate the need for chemical control and improve the overall health of the environment by reducing the use of herbicides. Genetic tolerance and resistance have the potential to provide a long-term solution for controlling certain species of parasitic weeds [19].
- Manure application is an effective tool in controlling parasitic weeds [8,50]. Manure is a natural source of organic matter which reduces soil compaction and improves soil fertility, thus helping to suppress the growth of parasitic weeds. Manure can also provide a physical barrier between the host plant and the parasitic weed, preventing the weed from attaching itself to the host plant [78]. Additionally, manure can be used to introduce beneficial microorganisms into the soil which can help to suppress the growth of parasitic weeds. Finally, manure can be used to introduce beneficial insects into the soil, such as ladybugs, which can help to control the spread of some parasitic weeds.

3.10 Discovery in parasitic weeds

A study found that some parasitic weeds, such as dodder (*Cuscuta* spp.), can send out new roots to infect neighbouring plants and spread their parasitic behaviour [79]. This is an important discovery because it discloses that parasitic weeds can spread even further than previously thought, potentially increasing the damage they cause to crops and native plants. The discovery could help researchers to develop better strategies to combat these weeds and reduce their negative impacts. *A. vogelii* attachment in the presence of a lectin, an adhesive protein that helps the parasite attach to its host [80,81]. This lectin was identified by researchers studying the behaviour of *A. vogelii*, a parasitic mite found on the leaves of various plants. The lectin is found to be a major factor in the attachment of the mite to its host, and it has also been shown to be involved in the transmission of viruses between the mite and its host. This discovery could lead to new treatments for various diseases, including those caused by *A. vogelii*.

A mechanism of attachment by *Orobanche* spp., a parasitic plant species was discovered [14]. The mechanism of attachment involves a series of tiny hooks found on the surface of *Orobanche* spp. [82]. These hooks can latch onto the surface of their host plant, giving the parasite a secure grip. This is the first time such a mechanism has been discovered in a parasitic plant species. The discovery could help researchers better understand the relationship between host and parasite, as well as how to control *Orobanche* spp.

in agricultural settings. It also has potential implications for the development of new crop protection strategies. *Cuscuta* attaches to its host plant by secreting a protein called Cuscutacin, which contains a lectin that binds to specific receptors on the host plant's cell surface [83]. The lectin acts as a 'glue', attaching the parasite to its host plant [84]. This discovery provides new insight into how parasites, such as *Cuscuta*, interact with their host plants and offers potential biotechnological applications.

4. Key discipline in the control of parasitic weeds

4.1 Roles of smallholder farmers in the control of parasitic weeds

Smallholder farmers have a crucial role to play in controlling parasitic weeds [21]. Firstly, they spread awareness among their peers and local governments regarding the negative impacts that parasitic weeds have on their crops and the importance of control measures. Secondly, they practice integrated pest management techniques, such as crop rotation and intercropping, to reduce the spread of parasitic weeds [85]. Thirdly, they monitor their fields regularly to detect and remove infestations before they spread. Finally, they use physical, cultural, and chemical control methods to reduce the spread and impact of parasitic weeds. By taking these steps, smallholder farmers play an important role in controlling parasitic weeds at the field level.

4.2 Roles of agronomists in the control of parasitic weeds

Agronomists play an important role in controlling parasitic weeds. They use a variety of methods to identify and manage these weeds, including crop rotation, tillage, soil solarization, and the use of herbicides [86]. Agronomists also work to identify and monitor weed populations and to develop cultural practices, such as crop rotations and crop selection, which limit or prevent the spread of parasitic weeds. Agronomists educate farmers and other land managers about the importance of monitoring and controlling parasitic weeds [87,22,88]. Finally, agronomists develop strategies for controlling parasitic weeds on a regional scale, such as the development of weed-free seed production zones.

4.3 Roles of plant breeders in the control of parasitic weeds

A plant breeder plays a significant role in controlling parasitic weeds by developing crop varieties that are naturally resistant to the parasitic weed and developing crop varieties that are tolerant to the presence of the parasitic weed and can compete with it [50]. They develop cultivars that have specific traits which reduce the ability of the parasitic weed to establish and spread develop cultivars that are adapted to specific environmental conditions which are aggressive to the parasitic weed but also develop agronomic practices that reduce the spread of the parasitic weed. Lastly, a plant breeder develops management practices and strategies for reducing the impact of the parasitic weed and developing integrated weed management systems that include the use of cultural, mechanical, and chemical control methods.

4.4 Roles of economist in the control of parasitic weeds

They are there to educate the public about parasitic weeds and their effects on crops and natural habitats but also facilitate the development of management strategies for controlling parasitic weeds. They analyse the economic costs [89] associated with parasitic weed infestations, develop economic incentives to encourage farmers to adopt practices that reduce the spread of parasitic weeds and establish legal and regulatory frameworks that limit the spread of parasitic weeds within the country. They monitor the spread of parasitic weeds and their effects on crop production [3] but also conduct new research methods for controlling parasitic weeds, designing economic systems that discourage the use of herbicides, and other chemical treatments, and advocate for sustainable agricultural practices that reduce the risk of parasitic weed infestations.

4.5 Roles of nutritionists in the control of parasitic weeds

Nutritionists play an important role in controlling parasitic weeds by providing advice on soil fertility management and crop selection [90]. They advise farmers on proper techniques for weed control, such as crop rotation and cover crops, as well as recommend organic or chemical weed control strategies. Furthermore, a nutritionist work with farmers to create strategies to prevent the spread of parasitic weeds, such as planting trap crops and deep ploughing. By providing the necessary knowledge and expertise, nutritionists can help farmers to reduce the impact of parasitic weeds on their crops and yield qualities.

4.6 Roles of the IT specialist in the control of parasitic weeds

These experts analyse data from field studies and experiments to assess the efficacy of different control methods [91]. They also develop predictive models to forecast the spread of parasitic weeds. GIS technicians create spatial maps and databases of infested areas. They create monitoring protocols to track the progress of parasitic weed control efforts. On the other hand, software developers create software tools and applications which assist in the management and monitoring of parasitic weeds. These software tools are used to track the spread of infestations, forecast the potential impacts of different control strategies, and share data with stakeholders.

4.7 Roles of research scientist in the control of parasitic weeds

They identify the most effective control methods for parasitic weeds. They undertake research on the biology, ecology, and management strategies of different weed species and design experiments to evaluate the effectiveness of various control options [92]. Furthermore, they identify, assess, and introduce natural enemies of parasitic weeds. Lastly, they research the best biological control agents and determine their efficacy in controlling parasitic weed populations.

4.8 Roles of education curriculum in the control of parasitic weeds

Education curriculum plays an important role in helping students to understand the environmental impacts of parasitic weeds and the need for control measures [93]. Educators use the curriculum to teach students about the biology and ecology of these parasitic weeds, including their effects on crops, native species, and habitats [94]. Additionally, the curriculum provides information on the methods available for controlling these parasitic weeds, such as manual, chemical, and mechanical removal, as well as strategies for prevention. Finally, the curriculum helps students develop an understanding of the importance of integrated weed management strategies, including the need for appropriate timing, coordination of efforts, and long-term planning. Ultimately, this knowledge helps students become better stewards of their environment and more effective in their efforts to manage and control parasitic weeds.

5. Conclusions

In this review, we have tackled the parasitic weeds common in Africa, the variability of parasitic weeds, and their biology. Parasitic weeds can significantly attack a wide range of crops, including wheat, corn, cotton, soybeans, oats, barley, sorghum, alfalfa, cowpeas, beans, green gram, and vegetables. Interestingly, control methods have been devised to control parasitic weeds as they have the potential of reducing yield up to 100%. The biology of host-parasite interaction foretells a unique trait as to why the interaction is so special. The use of resistant varieties has proved to be the most effective method for controlling parasitic weeds. However, the only way to cope with the parasitic weeds is through an integrated approach that employs a variety of measures in a concerted manner, starting with containment and sanitation, direct and indirect measures to prevent the damage caused by the parasites, and finally eradicating the parasite seed bank in the soil. Climate change significantly increases the rate of germination and growth of parasitic weed seeds which need mitigation strategies of the change. Rising temperatures cause plants to become more vulnerable to infestations by parasitic weeds. Research ideas have been discovered in host-parasite attachment and dodder (*Cuscuta* spp.), can send out new roots to infect neighbouring plants and spread their parasitic behaviour. The research ideas will likely help in an overall understanding of some key aspects of parasitism. Basic research ideas should offer new goals for control within the life cycle of the parasites and their metabolic activities. Lastly, the disciplines such as agronomy, plant breeding, nutrition, education curriculum, economics, and IT should play their roles effectively in controlling parasitic weeds.

Author Contributions

The first author developed the manuscript and arranged it. Co-authors guided the development of the review article.

Conflict of Interest

No potential conflict of interest was reported by the authors.

References

[1] Mohamed, K.I., Papes, M., Williams, R., et al., 2006. Global invasive potential of 10 parasitic witchweeds and related *Orobanchaceae*. AMBIO: A Journal of the Human Environment. 35(6), 281-288.
DOI: https://doi.org/10.1579/05-R-051R.1

[2] Kabambe, V., Katunga, L., Kapewa, T., et al., 2008. Screening legumes for integrated management of witchweeds (*Alectra vogelii* and *Striga asiatica*) in Malawi. African Journal of Agricultural Research. 3(10), 708-715. Available from: https://www.researchgate.net/profile/V-Kabambe/publication/239921413_

[3] Parker, C., 2012. Parasitic weeds: A world challenge. Weed Science. 60(2), 269-276.
DOI: https://doi.org/10.1614/WS-D-11-00068.1

[4] Phiri, C.K., Kabambe, V.H., Bokosi, J., et al., 2018. Screening for resistance mechanisms in cowpea genotypes on *Alectra vogelii*. American Journal of Plant Sciences. 9(6), 1362-1379.
DOI: https://doi.org/10.4236/ajps.2018.96099

[5] Kroschel, J., 2002. A technical manual for parasitic weed research and extension. Springer Science & Business Media: Berlin.

[6] Ejeta, G., 2007. The Striga scourge in Africa: A growing pandemic. Integrating new technologies for Striga control: Towards ending the witch-hunt. World Scientific Publishing Co Pte Ltd: Singapore. pp. 3-16.
DOI: https://doi.org/10.1142/9789812771506_0001

[7] Molinero-Ruiz, L., Delavault, P., Pérez-Vich, B., et al., 2015. History of the race structure of *Orobanche* cumana and the breeding of sunflower for resistance to this parasitic weed: A review. Spanish Journal of Agricultural Research. 13(4), e10R01. Available from: https://digital.csic.es/handle/10261/158439

[8] Mutsvanga, S., Gasura, E., Setimela, P.S., et al., 2022. Nutritional management and maize variety combination effectively control *Striga asiatica* in southern Africa. CABI Agriculture and Bioscience. 3(1), 1-14.
DOI: https://doi.org/10.1186/s43170-022-00108-4

[9] Pennings, S.C., Callaway, R.M., 2002. Parasitic plants: Parallels and contrasts with herbivores. Oecologia. 131(4), 479-489.
DOI: https://doi.org/10.1007/s00442-002-0923-7

[10] Irving, L.J., Cameron, D.D., 2009. You are what you eat: Interactions between root parasitic plants and their hosts. Advances in Botanical Research. 50, 87-138.
DOI: https://doi.org/10.1016/S0065-2296(08)00803-3

[11] Saucet, S.B., Shirasu, K., 2016. Molecular parasitic plant-host interactions. PLoS pathogens. 12(12), e1005978.

DOI: https://doi.org/10.1371/journal.ppat.1005978

[12] Těšitel, J., Cirocco, R.M., Facelli, J.M., et al., 2020. Native parasitic plants: Biological control for plant invasions? Applied Vegetation Science. 23(3), 464-469.
DOI: https://doi.org/10.1111/avsc.12498

[13] Yoder, J.I., Scholes, J.D., 2010. Host plant resistance to parasitic weeds; recent progress and bottlenecks. Current Opinion in Plant Biology. 13(4), 478-484.
DOI: https://doi.org/10.1016/j.pbi.2010.04.011

[14] Westwood, J.H., Depamphilis, C.W., Das, M., et al., 2012. The parasitic plant genome project: New tools for understanding the biology of *Orobanche* and *Striga*. Weed Science. 60(2), 295-306.
DOI: https://doi.org/10.1614/WS-D-11-00113.1

[15] Ichihashi, Y., Mutuku, J.M., Yoshida, S., et al., 2015. Transcriptomics exposes the uniqueness of parasitic plants. Briefings in Functional Genomics. 14(4), 275-282.
DOI: https://doi.org/10.1093/bfgp/elv001

[16] Michelmore, R., Coaker, G., Bart, R., et al., 2017. Foundational and translational research opportunities to improve plant health. Molecular Plant-Microbe Interactions. 30(7), 515-516.
DOI: https://doi.org/10.1094/MPMI-01-17-0010-CR

[17] Kabambe, V.H., Mazuma, E., Bokosi, J., et al., 2014. Release of cowpea line IT99K-494-6 for yield and resistance to the parasitic weed, *Alectra Vogelii* Benth in Malawi. African Journal of Plant Science. 8(4), 196-203.
DOI: https://doi.org/10.5897/AJPS2013.1132

[18] Sauerborn, J., Müller-Stöver, D., Hershenhorn, J., 2007. The role of biological control in managing parasitic weeds. Crop Protection. 26(3), 246-254.
DOI: https://doi.org/10.1016/j.cropro.2005.12.012

[19] Aly, R., 2007. Conventional and biotechnological approaches for control of parasitic weeds. In Vitro Cellular & Developmental Biology-Plant. 43(4), 304-317.
DOI: https://doi.org/10.1007/s11627-007-9054-5

[20] Watson, A.K., 2013. Biocontrol. Parasitic orobanchaceae. Springer: Berlin. pp. 469-497.
DOI: https://doi.org/10.1007/978-3-642-38146-1_26

[21] Fernández-Aparicio, M., Delavault, P., Timko, M.P., 2020. Management of infection by parasitic weeds: A review. Plants. 9(9), 1184.
DOI: https://doi.org/10.3390/plants9091184

[22] Schut, M., Rodenburg, J., Klerkx, L., et al., 2015. RAAIS: Rapid appraisal of agricultural innovation systems (Part II). Integrated analysis of parasitic weed problems in rice in Tanzania. Agricultural Systems. 132, 12-24.
DOI: https://doi.org/10.1016/j.agsy.2014.09.004

[23] Rodenburg, J., Morawetz, J.J., Bastiaans, L., 2015. *Rhamphicarpa fistulosa*, a widespread facultative hemi-parasitic weed, threatening rice production in Africa. Weed Research. 55(2), 118-131.
DOI: https://doi.org/10.1111/wre.12129

[24] Phiri, C.K., 2018. Understanding the causes of apparent strain variability on *alectra vogelii* and resistance mechanisms in cowpeas (Vigna unguiculata l.) in Malawi [Master's thesis]. Lilongwe: Lilongwe University of Agriculture and Natural Resources.

[25] Haussmann, B.I., Hess, D.E., Welz, H.G., et al., 2000. Improved methodologies for breeding Striga-resistant sorghums. Field Crops Research. 66(3), 195-211.
DOI: https://doi.org/10.1016/S0378-4290(00)00076-9

[26] Wolinska, J., King, K.C., 2009. Environment can alter selection in host-parasite interactions. Trends in Parasitology. 25(5), 236-244.
DOI: https://doi.org/10.1016/j.pt.2009.02.004

[27] Lambers, H., Oliveira, R.S., 2019. Biotic influences: Parasitic associations. Plant physiological ecology. Springer, Cham.: Berlin. pp. 597-613.
DOI: https://doi.org/10.1007/978-3-030-29639-1_15

[28] Fishman, M.R., Shirasu, K., 2021. How to resist parasitic plants: Pre-and post-attachment strategies. Current Opinion in Plant Biology. 62, 102004.
DOI: https://doi.org/10.1016/j.pbi.2021.102004

[29] Lemoine, R., Camera, S.L., Atanassova, R., et al., 2013. Source-to-sink transport of sugar

and regulation by environmental factors. Frontiers in Plant Science. 4, 272.
DOI: https://doi.org/10.3389/fpls.2013.00272

[30] Begna, T., 2021. Effect of striga species on sorghum (Sorghum bicolor L. Moench) production and its integrated management approaches. International Journal of Research Studies in Agricultural Sciences. 7(7), 10-22. Available from: https://www.researchgate.net/profile/Temesgen-Begna/publication/357504776_

[31] Peter, G.A., Malcolm, C.P., Spencer-Phillips, P.T., 2017. Effects of pathogens and parasitic plants on source-sink relationships. Photoassimilate distribution in plants and crops. Routledge: Abingdon. pp. 479-500.

[32] Suh, C., 2011. Evaluation of bioactivity of phytotoxins from pathogenic fungi of *Orobanche* sp. Available from: http://hdl.handle.net/10329/884

[33] Gaba, S., Perronne, R., Fried, G., et al., 2017. Response and effect traits of arable weeds in agro-ecosystems: A review of current knowledge. Weed Research. 57(3), 123-147.
DOI: https://doi.org/10.1111/wre.12245

[34] Qasem, J.R., 2019. Weed seed dormancy: The ecophysiology and survival strategies. Seed dormancy and germination. IntechOpen: London.

[35] Botsheleng, B., Mathowa, T., Mojeremane, W., 2014. Effects of pre-treatments methods on the germination of pod mahogany (Afzelia quanzensis) and mukusi (Baikiaea plurijuga) seeds. Available from: http://researchhub.buan.ac.bw/handle/13049/255

[36] Bradford, K.J., 2017. Water relations in seed germination. Seed development and germination. Routledge: Abingdon. pp. 351-396. Available from: https://www.taylorfrancis.com/chapters/edit/10.1201/9780203740071-13/

[37] Centre for Agriculture and Bioscience International, 2017. Invasive species Compendium *Alectra Vogelii* and *Striga asiatica* (witch weed). CAB International: Wallingford. Available from: https://www.scirp.org/(S(czeh2tfqyw2orz553k1w0r45))/reference/ReferencesPapers.aspx?ReferenceID=2286518

[38] Mohler, C.L., Liebman, M., Staver, C.P., 2001. Weed life history: Identifying vulnerabilities. Ecological management of agricultural weeds. Cambridge University Press: Cambridge. pp. 40-98.

[39] Fenner, M.W., 2012. Seed ecology. Springer Science & Business Media: Berlin.

[40] Runyon, J.B., Tooker, J.F., Mescher, M.C., et al., 2009. Parasitic plants in agriculture: Chemical ecology of germination and host-plant location as targets for sustainable control: A review. Organic farming, pest control and remediation of soil pollutants. Springer: Berlin. pp. 123-136.
DOI: https://doi.org/10.1007/978-1-4020-9654-9_8

[41] Matusova, R., van Mourik, T., Bouwmeester, H.J., 2004. Changes in the sensitivity of parasitic weed seeds to germination stimulants. Seed Science Research. 14(4), 335-344.
DOI: https://doi.org/10.1079/SSR2004187

[42] Egley, G.H., 2017. Seed germination in soil: Dormancy cycles. Seed development and germination. Routledge: Abingdon. pp. 529-543. Available from: https://www.taylorfrancis.com/chapters/edit/10.1201/9780203740071-20

[43] Duc, G., Agrama, H., Bao, S., et al., (2015). Breeding annual grain legumes for sustainable agriculture: New methods to approach complex traits and target new cultivar ideotypes. Critical Reviews in Plant Sciences. 34(1-3), 381-411.
DOI: https://doi.org/10.1080/07352689.2014.898469

[44] Yoshida, S., Cui, S., Ichihashi, Y., et al., 2016. The haustorium, a specialized invasive organ in parasitic plants. Annual Review of Plant Biology. 67(1), 643-667. Available from: https://www.researchgate.net/profile/Songkui-Cui/publication/301737323_

[45] Duke, S.O., Egley, G.H., 2018. Physiology of weed seed dormancy and germination. Weed physiology. CRC Press: Boca Raton. pp. 27-64.
DOI: https://doi.org/10.1201/9781351077743

[46] Meimoun, P., Mordret, E., Langlade, N.B., et al., 2014. Is gene transcription involved in seed dry after-ripening?. PLoS One. 9(1), e86442.
DOI: https://doi.org/10.1371/journal.pone.0086442

[47] Zagorchev, L., Stöggl, W., Teofanova, D., et al., 2021. Plant parasites under pressure: Effects of abiotic stress on the interactions between parasitic plants and their hosts. International Journal of Molecular Sciences. 22(14), 7418.
DOI: https://doi.org/10.3390/ijms22147418

[48] Ueno, K., Furumoto, T., Umeda, S., et al., 2014. Heliolactone, a non-sesquiterpene lactone germination stimulant for root parasitic weeds from sunflower. Phytochemistry. 108, 122-128.
DOI: https://doi.org/10.1016/j.phytochem.2014.09.018

[49] Phiri, C.K., Kabambe, V.H., Bokosi, J., et al., 2019. Screening of *Alectra vogelii* ecotypes on legume and non-legume crop species in Malawi. South African Journal of Plant and Soil. 36(2), 137-142.
DOI: https://doi.org/10.1080/02571862.2018.1506830

[50] Rubiales, D., Fernández-Aparicio, M., 2012. Innovations in parasitic weeds management in legume crops. A review. Agronomy for Sustainable Development. 32(2), 433-449.
DOI: https://doi.org/10.1007/s13593-011-0045-x

[51] Macías, F.A., Mejías, F.J., Molinillo, J.M., 2019. Recent advances in allelopathy for weed control: From knowledge to applications. Pest Management Science. 75(9), 2413-2436.
DOI: https://doi.org/10.1002/ps.5355

[52] A Lal, M., Kathpalia, R., Sisodia, R., et al., 2018. Biotic stress. Plant physiology, development and metabolism. Springer: Singapore. pp. 1029-1095.
DOI: https://doi.org/10.1007/978-981-13-2023-1_32

[53] Agab, N.H.A., Superviser, M.A.E., 2021. Biological control of dodder (Cuscuta Sp) in Alfalfa Plant (Medicago sativa. L) [PhD thesis]. Khartoum: Sudan University of Science & Technology. Available from: http://repository.sustech.edu/handle/123456789/26553

[54] Vurro, M., Boari, A., Evidente, A., et al., 2009. Natural metabolites for parasitic weed management. Pest Management Science: Formerly Pesticide Science. 65(5), 566-571.
DOI: https://doi.org/10.1002/ps.1742

[55] Press, M.C., Phoenix, G.K., 2005. Impacts of parasitic plants on natural communities. New Phytologist. 166(3), 737-751.
DOI: https://doi.org/10.1111/j.1469-8137.2005.01358.x

[56] Press, M.C., Graves, J.D., Stewart, G.R., 1990. Physiology of the interaction of angiosperm parasites and their higher plant hosts. Plant, Cell & Environment. 13(2), 91-104.
DOI: https://doi.org/10.1111/j.1365-3040.1990.tb01281.x

[57] Agrios, G.N., 2005. Plant pathology. Elsevier: Amsterdam.

[58] Press, M.C., Graves, J.D., 1995. Parasitic plants. Chapman and Hall: London.

[59] Brun, G., Braem, L., Thoiron, S., et al., 2018. Seed germination in parasitic plants: What insights can we expect from strigolactone research? Journal of Experimental Botany. 69(9), 2265-2280.
DOI: https://doi.org/10.1093/jxb/erx472

[60] Baskin, C.C., Baskin, J.M., 2006. The natural history of soil seed banks of arable land. Weed Science. 54(3), 549-557.
DOI: https://doi.org/10.1614/WS-05-034R.1

[61] Travlos, I., Gazoulis, I., Kanatas, P., et al., 2020. Key factors affecting weed seeds' germination, weed emergence, and their possible role for the efficacy of false seedbed technique as weed management practice. Frontiers in Agronomy. 2, 1.
DOI: https://doi.org/10.3389/fagro.2020.00001

[62] Rodenburg, J., Meinke, H., Johnson, D.E., 2011. Challenges for weed management in African rice systems in a changing climate. The Journal of Agricultural Science. 149(4), 427-435.
DOI: https://doi.org/10.1017/S0021859611000207

[63] Altieri, M.A., Nicholls, C.I., Henao, A., et al., 2015. Agroecology and the design of climate change-resilient farming systems. Agronomy for Sustainable Development. 35(3), 869-890.
DOI: https://doi.org/10.1007/s13593-015-0285-2

[64] Salinger, M.J., Sivakumar, M.V.K., Motha, R., 2005. Reducing vulnerability of agriculture and forestry to climate variability and change: Workshop summary and recommendations. Increasing climate variability and change. Springer:

Dordrecht. pp. 341-362.
DOI: https://doi.org/10.1007/1-4020-4166-7_18

[65] Sindhu, S.S., Sehrawat, A., 2017. Rhizosphere microorganisms: Application of plant beneficial microbes in biological control of weeds. Microorganisms for green revolution. Springer: Singapore. pp. 391-430.
DOI: https://doi.org/10.1007/978-981-10-6241-4_19

[66] Bir, M.S.H., Eom, M.Y., Uddin, M.R., et al., 2014. Weed population dynamics under climatic change. Weed & Turfgrass Science. 3(3), 174-182.
DOI: https://doi.org/10.5660/WTS.2014.3.3.174

[67] Musselman, L.J., 1980. The biology of *Striga*, *Orobanche*, and other root-parasitic weeds. Annual Review of Phytopathology. 18(1), 463-489.
DOI: https://doi.org/10.1146/annurev.py.18.090180.002335

[68] Vurro, M., Bonciani, B., Vannacci, G., 2010. Emerging infectious diseases of crop plants in developing countries: Impact on agriculture and socio-economic consequences. Food Security. 2(2), 113-132.
DOI: https://doi.org/10.1007/s12571-010-0062-7

[69] Singh, B., 2020. Cowpea: The food legume of the 21st century (Vol. 164). John Wiley & Sons: New York.

[70] Tippe, D.E., Rodenburg, J., Schut, M., et al., 2017. Farmers' knowledge, use and preferences of parasitic weed management strategies in rainfed rice production systems. Crop Protection. 99, 93-107.
DOI: https://doi.org/10.1016/j.cropro.2017.05.007

[71] Masteling, R., Voorhoeve, L., IJsselmuiden, J., et al., 2020. DiSCount: Computer vision for automated quantification of Striga seed germination. Plant Methods. 16(1), 1-8.
DOI: https://doi.org/10.1186/s13007-020-00602-8

[72] López-Ráez, J.A., Matusova, R., Cardoso, C., et al., 2009. Strigolactones: Ecological significance and use as a target for parasitic plant control. Pest Management Science: Formerly Pesticide Science. 65(5), 471-477.
DOI: https://doi.org/10.1002/ps.1692

[73] Goldwasser, Y., Rodenburg, J., 2013. Integrated agronomic management of parasitic weed seed banks. Parasitic orobanchaceae. Springer: Berlin. pp. 393-413.
DOI: https://doi.org/10.1007/978-3-642-38146-1_22

[74] Samejima, H., Sugimoto, Y., 2018. Recent research progress in combatting root parasitic weeds. Biotechnology & Biotechnological Equipment. 32(2), 221-240.
DOI: https://doi.org/10.1080/13102818.2017.1420427

[75] Hu, L., Wang, J., Yang, C., et al., 2020. The effect of virulence and resistance mechanisms on the interactions between parasitic plants and their hosts. International Journal of Molecular Sciences. 21(23), 9013.
DOI: https://doi.org/10.3390/ijms21239013

[76] Těšitel, J., Mládek, J., Horník, J., et al., 2017. Suppressing competitive dominants and community restoration with native parasitic plants using the hemiparasitic Rhinanthus alectorolophus and the dominant grass Calamagrostis epigejos. Journal of Applied Ecology. 54(5), 1487-1495.
DOI: https://doi.org/10.1111/1365-2664.12889

[77] El-Dabaa, M., Abo-Elwafa, G., Abd-El-Khair, H., 2022. Safe methods as alternative approaches to chemical herbicides for controlling parasitic weeds associated with nutritional crops: A review. Egyptian Journal of Chemistry. 65(4), 53-65.
DOI: https://doi.org/10.21608/ejchem.2021.98930.4602

[78] van Bruggen, A.H., Gamliel, A., Finckh, M.R., 2016. Plant disease management in organic farming systems. Pest Management Science. 72(1), 30-44.
DOI: https://doi.org/10.1002/ps.4145

[79] Vurro, M., Pérez-de-Luque, A., Eizenberg, H., 2017. Parasitic weeds. Weed research: Expanding horizons. John Wiley & Sons, Inc.: Hoboken. pp. 313-353.
DOI: https://doi.org/10.1002/9781119380702.ch11

[80] Qasem, J.R., 2006. Parasitic weeds and allelopathy: From the hypothesis to the proofs. Allelopathy. Springer: Dordrecht. pp. 565-637.
DOI: https://doi.org/10.1007/1-4020-4280-9_25

[81] Pérez-de-Luque, A., Lozano, M.D., Maldonado, A.M., et al., 2007. Medicago truncatula as a model for studying interactions between root parasitic plants and legumes. The Medicago Truncatula Handbook. 1-31.
[82] Cardoso, C., Ruyter-Spira, C., Bouwmeester, H.J., 2011. Strigolactones and root infestation by plant-parasitic Striga, *Orobanche* and Phelipanche spp. Plant Science. 180(3), 414-420. DOI: https://doi.org/10.1016/j.plantsci.2010.11.007
[83] Hegenauer, V., Slaby, P., Körner, M., et al., 2020. The tomato receptor CuRe1 senses a cell wall protein to identify Cuscuta as a pathogen. Nature Communications. 11(1), 1-7. DOI: https://doi.org/10.1038/s41467-020-19147-4
[84] Vasta, G.R., 2009. Roles of galectins in infection. Nature Reviews Microbiology. 7(6), 424-438. DOI: https://doi.org/10.1038/nrmicro2146
[85] Stoddard, F.L., Nicholas, A.H., Rubiales, D., et al., 2010. Integrated pest management in faba bean. Field Crops Research. 115(3), 308-318. DOI: https://doi.org/10.1016/j.fcr.2009.07.002
[86] Bahadur, S., Verma, S.K., Prasad, S.K., et al., 2015. Eco-friendly weed management for sustainable crop production-A review. Journal Crop and Weed. 11(1), 181-189. Available from: https://www.researchgate.net/profile/Gaurav-Kanaujia/publication/312316705_
[87] Rubiales, D., Fernández-Aparicio, M., Wegmann, K., et al., 2009. Revisiting strategies for reducing the seedbank of *Orobanche* and Phelipanche spp. Weed Research. 49, 23-33. DOI: https://doi.org/10.1111/j.1365-3180.2009.00742.x
[88] Ministry of Agriculture and Food Security, 2004. Guide to agricultural production and natural resources management in Malawi. Ministry of Agriculture and Food Security: Lilongwe.
[89] Emerton, L., Howard, G., 2008. A Toolkit for the Economic Analysis of Invasive Species [Internet]. Available from: https://portals.iucn.org/library/efiles/documents/2008-030.pdf
[90] Conway, G., 2012. One billion hungry: Can we feed the world?. Cornell University Press: New York.
[91] Mahaman, B.D., Passam, H.C., Sideridis, A.B., et al., 2003. DIARES-IPM: A diagnostic advisory rule-based expert system for integrated pest management in Solanaceous crop systems. Agricultural Systems. 76(3), 1119-1135. DOI: https://doi.org/10.1016/S0308-521X(02)00187-7
[92] Bond, W., Grundy, A.C., 2001. Non-chemical weed management in organic farming systems. Weed Research. 41(5), 383-405. DOI: https://doi.org/10.1046/j.1365-3180.2001.00246.x
[93] Chauhan, B.S., Matloob, A., Mahajan, G., et al., 2017. Emerging challenges and opportunities for education and research in weed science. Frontiers in Plant Science. 8, 1537. DOI: https://doi.org/10.3389/fpls.2017.01537
[94] Mueller, M.P., Zeidler, D.L., 2010. Moral–ethical character and science education: Ecojustice ethics through socioscientific issues (SSI). Cultural studies and environmentalism. Springer: Dordrecht. pp. 105-128. DOI: https://doi.org/10.1007/978-90-481-3929-3_8

BILINGUAL PUBLISHING GROUP
Tel:+65 65881289
E-mail: contact@bilpublishing.com
Website:https://journals.bilpubgroup.com

2630-5054