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Floristic diversity of weeds and herbicide use practices in rice-growing systems in the Zouan-Hounien department (Western Côte d'Ivoire)

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Abstract

Weeds constitute a major constraint to rice production in Côte d'Ivoire and promote increasing reliance on herbicides. This study aimed to characterize the weed flora of rice fields and to inventory the herbicides used in the Zouan-Hounien department (Western Côte d'Ivoire). Surveys were conducted with 53 rice farmers between March and June 2023, complemented by floristic surveys carried out using 4 m^2 quadrats. A total of 80 weed species belonged to 57 genera and 27 families, were recorded, with a predominance of Poaceae and Cyperaceae. The structure of the weed communities highlighted 29 highly aggressive species, 22 aggressive, and 29 less aggressive, dominated by *Fimbristylis littoralis*, *Cyperus difformis*, *Panicum laxum*, and *Ludwigia abyssinica*. Shannon diversity indices ranged from 3.09 to 3.68 bits, while Sørensen similarity coefficients (≥ 50%) indicated a relative floristic homogeneity between localities. Furthermore, 37 commercial herbicides were recorded, of which 23 were actually used by rice farmers, mainly glyphosate-based formulations. The most frequently used herbicides were Tête Rouge 360 SL and Herbextra 720 SL. These results highlight a high weed diversity associated with a heavy reliance on chemical control, emphasizing the need to promote integrated weed management strategies in rice cultivation.

Keywords: Rice cultivation; Weeds; Floristic diversity; Herbicides; Zouan-Hounien; Côte d'Ivoire

1. Introduction

Rice (*Oryza sativa* L.) is one of the main global foodstuffs and represents an essential source of calories for more than half of the world's population. In sub-Saharan Africa, its consumption is experiencing sustained growth due to population increase, urbanization, and dietary changes, making rice a strategic crop for food security [1]. However, in several West African countries, production remains insufficient to meet a constantly increasing domestic demand, leading to a strong dependence on imports [2].

In Côte d'Ivoire, despite favorable agroecological conditions, national rice production does not yet meet consumption needs. This situation has led to the implementation of public policies aimed at the intensification and modernization of the rice sector, notably through the National Rice Development Strategy [3]. However, the performance of rice production systems remains limited by several biotic constraints, among which weeds play a major role.

Weeds are one of the main factors reducing rice yields due to their strong competition with the crop for water, nutrients, light, and space. In some situations, yield losses can exceed 50% when their management is inadequate [4]. Moreover, some weed species can serve as alternative hosts to various rice pests and pathogens, including the Rice Yellow Mottle Virus (RYMV), one of the major viral diseases affecting African rice cultivation [5].

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To limit losses related to weed growth and to address the constraints of manual weeding, producers are increasingly resorting to herbicides. Although these products improve the effectiveness of weed control, their uncontrolled use can alter the floristic composition of weed communities, promote the emergence of herbicide resistance, and lead to undesirable environmental effects [6,7].

In the Zouan-Hounien department, located in the Western Côte d'Ivoire, information on the floristic diversity of rice weeds and local herbicide use practices remain poorly documented, despite the socio-economic importance of rice farming for rural populations. A better understanding of weed flora and chemical control practices, however, appears essential to develop sustainable management strategies adapted to local conditions.

Thus, this study aims to analyze weeds floristic diversity and herbicide use practices in the rice-growing systems of the Zouan-Hounien department (West of Côte d'Ivoire). More specifically, its objectives are: (i) to inventory and characterize the weed flora associated with rice fields; (ii) to assess the structure and diversity of weed communities; and (iii) to inventory the herbicides used as well as their application methods by rice farmers.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Zouan-Hounien department, located in the Tonkpi region in wester Côte d'Ivoire, between 6°46' and 7°05' North latitude and 8°06' and 8°26' West longitude. The department belongs to the humid forest zone and features rugged terrain. The soils, mostly ferralitic, are favorable for agricultural activities, particularly lowland and rainfed rice farming. The study area benefits from a humid tropical mountain climate, where the average annual rainfall is estimated between 1,599 and 1,604 mm, with temperatures ranging from 24 to 28 °C [8].

The investigations were conducted in six localities of the department, namely Zouan-Hounien, Bin-Houyé, Banneu, Goulaleu, Téapleu, and Yélleu, chosen due to the significance of their rice-growing activities. Fieldwork, including surveys of rice farmers and floristic surveys, was carried out between March and June 2023, a period corresponding to the main rice-growing season in the study area.

2.2. Survey of Rice Farmers and Data Collection

A semi-structured survey was conducted with 53 rice farmers selected from various localities in the Zouan-Hounien department. The farmers surveyed included members of rice cooperatives as well as independent producers. The rice farmers affiliated with farmers' organizations were identified from lists provided by local cooperatives, while independent producers were chosen randomly.

Data were collected using a standardized questionnaire concerning:

- The sociodemographic characteristics of farmers (age, gender, origin, membership or not in farmers' organization);
- The characteristics of the rice farms (cultivated areas, cultivated varieties, farming systems);
- The weed management practices in the rice fields.

This information made it possible to better characterize the production systems and the local methods of weed management.

2.3. Floristic Inventory of Weeds

The floristic inventory of weeds was carried out in the rice fields of surveyed producers in the Zouan-Hounien department. Depending on the spatial distribution of farms surveyed localities were subdivided into two or three sampling blocks. In each block, rice fields were randomly selected among the identified farmers, each field constituting a sampling unit.

Within each plot, three 2 m × 2 m (4 m^2) quadrats were randomly placed between the ridges in order to standardize floristic observations. All weed species present in the quadrats were systematically recorded and noted on floristic survey sheets. Botanical specimens of taxa not identified in the field were collected, dried in newspaper, and then preserved for the creation of a reference herbarium. The taxonomic identification of the weed species was carried out using the identification keys from [9,10].

2.4. Inventory of Herbicides Used in Rice Cultivation

The inventory of herbicides used was conducted based on information collected from the surveyed rice farmers, supplemented by investigations carried out with agrochemical product traders in the main markets of the Zouan-Hounien department.

The data collected concerned the: commercial names of the herbicides used, active ingredients, commercial formulations, application rates, the frequency of use, and the application periods in rice-growing systems. Special attention was given to the types of formulations available on the local market, notably liquid and solid formulations (granules and powders) used in field preparation, pre-emergence, and post-emergence operations. The information collected made it possible to identify the main active substances used by producers and to characterize local practices of chemical weed control.

2.5. Analysis of Floristic Diversity

The data from the floristic surveys were organized in Microsoft Excel 2021 and then analyzed using the PAST software (Paleontological Statistics, version 4.03). The analysis focused on the taxonomic composition of the recorded weeds, the relative frequencies (RF), and the specific contributions (Sc), which were used to assess the ecological importance of the species and classify them into aggressiveness categories according to the thresholds of [11]. Floristic diversity was evaluated using the indices of specific diversity (SDI), generic diversity (GDI), Shannon (H′), and Pielou's evenness (E), while Sørensen's similarity coefficient (SC) was used to appreciate the degree of floristic resemblance among the surveyed localities.

2.6. Analysis of rice cultivation practices and herbicide use

The data from surveys of rice farmers and the inventory of herbicides used were organized and processed using Microsoft Excel 2021. The characteristics of the producers and rice cultivation practices were analyzed using descriptive statistics (frequencies, proportions, and means) and then illustrated using histograms. Data related to herbicides were subjected to a descriptive analysis focusing on commercial names, active ingredients, formulations, and usage methods reported by the rice farmers. This analysis allowed to establish an inventory of herbicides used in the rice farming systems of the Zouan-Hounien department.

3. Results

3.1. Characteristics of rice farmers and rice cultivation practices

The survey conducted among 53 rice farmers in various localities of the Zouan-Hounien department made it possible to characterize the sociodemographic profile of the producers as well as certain cultivation practices associated with rice farming. The data collected highlight an agricultural population mostly ranging from young to adult, with ages between 26 and 67 years. The 26–45 age group represented the largest proportion of respondents (69.81%), followed by producers aged 46–56 years (26.41%), while the older age groups remained poorly represented (Figure 1). Rice production was mainly carried out by men (92.45%), with women representing only 7.55% of the farmers surveyed. From an ethnocultural point of view, the surveyed operations were mainly conducted by the indigenous Yacouba populations (64.15%), followed by the allochthonous Mahouka (30.19%) and the Burkinabe allogens (5.66%). The organizational structuring of the producers remained limited, with 86.79% of them not affiliated with any group or cooperative, compared to 13.21% involved in a peasant organization.

The lowland rice-planted areas were relatively small, with an estimated average of 0.6 ha per farm. The cultivated varieties mainly included Bouaké AM, Wita 9, Bouaké 189, Wita 12, and Nerica. The Bouaké AM variety was the most widespread (37.84%), followed by Wita 9 (35.95%) and Bouaké 189 (20.55%). The Wita 12 (3.77%) and Nerica (1.89%) varieties remained marginally cultivated. The analysis of rice field preparation and maintenance methods made it possible to identify four main groups of producers (Figure 2). The most numerous (43.40%) used a herbicide before manual stump removal with a machete or a daba, followed by hoe plowing before sowing. A significant proportion (39.62%) adopted a similar approach but carried out sowing without prior plowing. Furthermore, 15.09% of producers practiced manual weeding followed by plowing before sowing, while only 1.89% resorted to manual weeding without plowing. In total, 58.49% of producers plowed before sowing, compared to 41.51% who sowed without prior soil work.

Regarding weed management, the majority of producers (81.13%) adopted an integrated approach combining manual weeding with chemical control. The remaining operators (18.87%) relied exclusively on a single method. The analysis of practices showed a high prevalence of herbicide use, adopted by 89.99% of the sample (either as a single treatment or combined). At the same time, manual weeding remains a major practice, used by 91.14% of producers as an exclusive or complementary strategy. Finally, the exclusive use of a single technique concerns 8.86% of producers for chemical control and 10.01% for manual weeding, respectively.

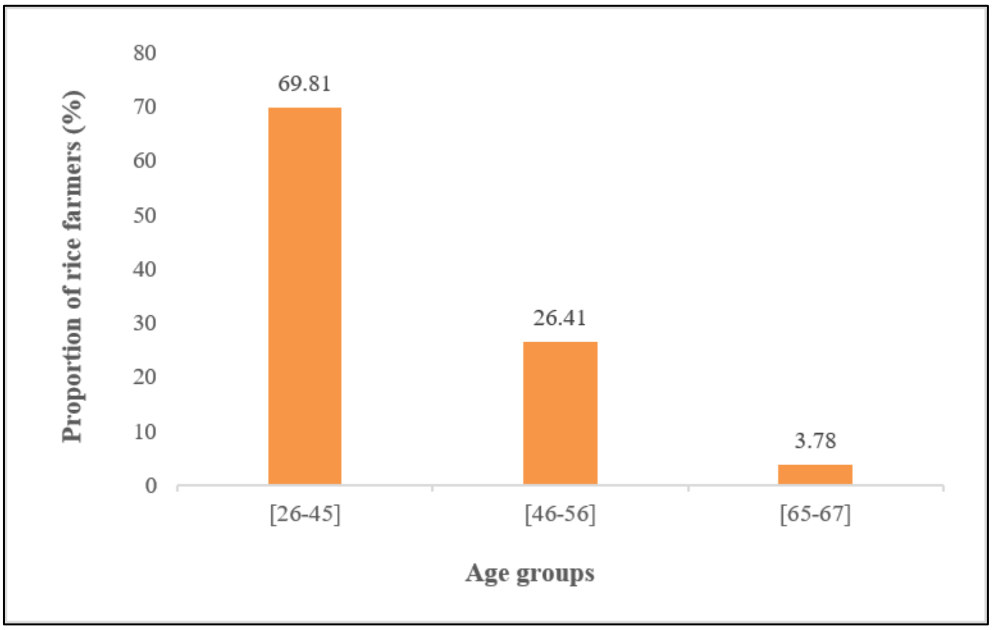

Figure 1 Compensation of rice farmers by age group

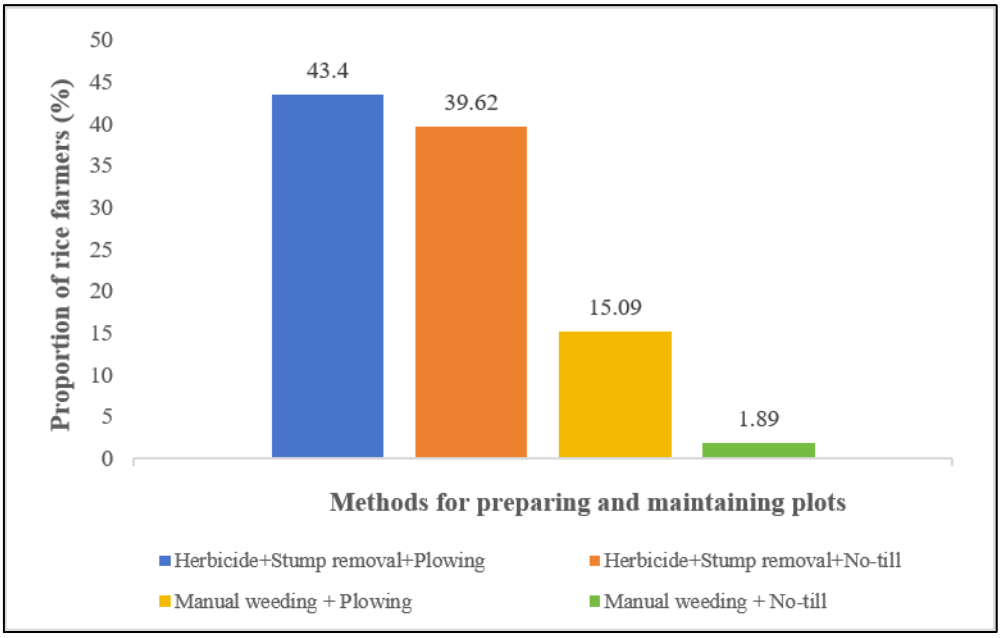

Figure 2 Distribution of rice farmers according to the method of preparation and maintenance of plots

3.2. Floristic Organization of Weed Communities

3.2.1. Composition and Floristic Richness of Weeds

Floristic surveys carried out in the rice fields of the Zouan-Hounien department made it possible to inventory a total of 80 weed species, distributed across 57 genera and 27 botanical families. Floristic richness varied according to localities, with 34 species recorded in Banneu and Bin-Houyé, 37 in Goulaleu, 45 in Zouan-Hounien, 53 in Téapleu, and 56 in Yélleu. The most represented families were Poaceae and Cyperaceae, accounting for 20.5% and 17.5% of the inventoried species respectively, followed by Asteraceae (6.25%). Together, these families comprised 37 species, or 46.25% of the recorded flora. Monocotyledons represented 52.5% of the inventoried species compared to 42.5% for dicotyledons and 5% for pteridophytes.

3.2.2. Structure of Weed Communities

The analysis of specific contributions (Sc) made it possible to classify the recorded weeds into three categories of aggressiveness (Tables 1): 29 very aggressive species (Sc > 4%), 22 aggressive species (1 ≤ Sc ≤ 4%), and 29 less aggressive species (Sc < 1%). The very aggressive weeds were dominated by *Fimbristylis littoralis* (9.85%), *Cyperus difformis* (9.69%), *Panicum laxum* (9.63%), and *Ludwigia abyssinica* (8.68%), reflecting their strong contribution to the floristic structure of rice plots. Species classified as aggressive had intermediate specific contributions, while the less aggressive weeds contributed weakly to the composition of weed communities.

Table 1 Structure of weed communities of rice according to aggressiveness classes in the Zouan-Hounien department

Aggressiveness class	Species	RF (%)	Sc (%)
Very aggressive (Sc > 4 %)	*Ageratum conyzoides* L.	42,94	7,97
	Alternanthera sessilis (L.) R. Br. ex Roth	29,79	5,53
	Ammannia auriculata Willd.	38,08	5,1
	Bacopa crenata (P.Beauv.) Hepper	27,84	4,2
	Bacopa decumbens (Fernald) F.N. Williams	38,46	5,15
	Ceratopteris cornuta (P. Beauv.) Lepr.	28,29	5,26
	Commelina benghalensis L.	47,62	6,37
	Commelina diffusa Burm.f.	28,49	4,3
	Cyperus difformis L.	52,24	9,69
	Cyperus esculentus L.	23,21	4,31
	Cyperus exaltatus Retz	67,52	4,92
	Cyperus pustulatus Vahl	31,74	5,89
	Echinochloa colona (L.) Link	49,84	7,53
	Echinochloa crus-pavonis (Kunth) Schult.	50,64	7,65
	Fimbristylis littoralis Gaudich	53,09	9,85
	Heteranthera callifolia Rchb. ex Kunth	26,76	4,98
	Ipomoea aquatica Forssk.	37,49	5,02
	Kyllinga erecta Schum.	57,07	4,16
	Kyllinga pumila Michx.	22,65	4,21
	Lipocarpha chinensis (Osbeck) Kern	28,38	4,28
	Ludwigia abyssinica A.Rich.	64,84	8,68
	Ludwigia hyssopifolia (G.Don) Exell	45,51	6,09
	Panicum laxum Sw.	51,79	9,63
	Pentodon pentandrus (Schumach. & Thonn.) Vatke	52,16	6,98
	Phyllanthus pentandrus Schumach. & Thonn.	22,85	4,24
	Sacciolepis africana C.E. Hubb. & Snowden	29,85	5,55
	Sphenoclea zeylanica Gaertn.	44,49	4,05
	Spilanthes uliginosa Sw.	59,07	4,3

	Vossia cuspidata (Roxb.) Griff.	27,89	4,21
Aggressive (1 ≤ Sc ≤ 4 %)	*Acroceras zizanioides* (Kunth) Dandy	29,32	2,14
	Chromolaena odorata (L.) R.M.King & H.Rob.	12,15	2,25
	Cyclosorus striatus (Schum.) Ching	9,49	1,27
	Cyperus haspan L.	29,2	2,13
	Cyperus iria L.	8,38	1,12
	Cyrtosperma senegalensis (Schott) Engl.	15,62	2,09
	Dissotis erecta (Guill. & Perr.) Dandy	15,24	2,04
	Eichhornia natans (P.Beauv.) Solms	29,87	2,72
	Eichhornia diversifolia (Vahl) Urb.	16,93	2,56
	Eleusine indica (L.) Gaertn.	12,97	2,41
	Hydrolea glabra Schumach. & Thonn.	21,35	2,86
	Ischaemum rugosum Salisb.	8,76	1,63
	Leersia hexandra Sw.	6,5	1,21
	Leptochloa caerulescens Steudel	5,88	1,09
	Ludwigia octovalvis (Jacq.) P.H.Raven	15	2,78
	Nymphaea alba L.	34,47	3,14
	Nymphaea lotus L.	12,15	2,26
	Polygonum salicifolium (Brouss. ex Willd.) Assenov.	31,09	2,83
	Portulaca oleracea L.	5,82	1,08
	Pycreus lanceolatus (Poir.) C.B.Clarke	19,86	1,45
	Scleria depressa (C.B.Clarke) Nelmes	13,33	2,01
	Scleria verrucosa Willd.	17,76	2,38
Not aggressive (Sc < 1 %)	*Aeschynomene afraspera* J. Léonard	7,16	0,96
	Ammannia baccifera L.	9,4	0,86
	Brachiaria deflexa (Schumach.) C.E.Hubb. ex Robyns	4,43	0,32
	Cassia mimosoides L.	10,08	0,92
	Combretum bipindense Engl. & Diels.	6,47	0,59
	Commelina forskalaei Vahl	4,29	0,8
	Diplachne fusca (L.) P.Beauv. ex Roem. & Schult.	5,69	0,86
	Dissotis rotundifolia (Sm.) Triana	7,38	0,99
	Echinochloa obtusiflora Stapf	2,88	0,54
	Echinochloa pyramidalis (Lam.) Hitchc. & Chase	3,64	0,33
	Emilia coccinea (Sims) G. Don	5,87	0,53
	Fuirena umbellata Rottb.	6,73	0,9
	Hyptis lanceolata Poir.	4,79	0,35
	Ipomoea heterotricha F.Ditr.	7,29	0,53
	Isachne kiyalaensis Robyns	11,14	0,81

	Mariscus longibracteatus Cherm.	10,45	0,95
	Marsilea minuta L.	3,2	0,48
	Oldenlandia corymbosa L.	6,34	0,58
	Panicum capillare L.	4,29	0,31
	Paspalum vaginatum Sw.	2,51	0,38
	Persicaria lapathifolia (L.) Delarbre	4,93	0,36
	Phaius tankervilleae (Banks) Blume	5,62	0,51
	Phyllanthus amarus Schum. & Thonn.	8,47	0,77
	Phyllanthus tenellus Roxb.	9,07	0,66
	Pteridium aquilinum L.	6,51	0,59
	Rhynchospora corymbosa (L.) Britton	6,03	0,81
	Setaria barbata (Lam.) Kunth	5,87	0,53
	Sida urens L.	7,92	0,72
	Symphyotrichum subulatum (L.) G.L.Nesom	4,43	0,32

RF: Relative frequency; Sc: Specific contribution

3.2.3. Floristic Diversity of Weeds

The specific diversity indices (SDI) varied between 1.23 and 1.40 depending on the localities (Table 2). The highest value was observed in Yéléu (1.40), while the lowest was recorded in Goulaleu (1.23). The generic diversity indices (GDI) ranged from 1.58 to 1.91 (Table II), with a maximum value observed in Téapleu (1.91) and a minimum in Goulaleu (1.58).

The values of the Shannon diversity index (H') varied from 3.09 to 3.68 bits depending on the localities (Table 3). The highest value was recorded in Téapleu (3.68 bits), followed by Yélleu (3.64 bits), while the lowest was observed in Banneu (3.09 bits). Pielou's evenness indices (E) ranged from 0.31 to 0.34 (Table III), with a maximum value observed in Téapleu (0.34).

Table 2 Index of species and genus diversity of weeds recorded in the different localities

Index	Localities					
	Banneu	**Bin-Houyé**	**Goulaleu**	**Téapleu**	**Yélleu**	**Zouan-Hounien**
SDI	1,31	1,26	1,23	1,26	1,40	1,25
GDI	1,73	1,59	1,58	1,91	1,74	1,89

SDI: Specific diversity index; GDI: Generic diversity index

Table 3 Values of Shannon's diversity index and Pielou's evenness according to the studied locations

Localities	Index	
	Shannon (bits)	**Equitabilité de Piélou**
Banneu	3,09	0,32
Bin-Houye	3,19	0,32
Goulaleu	3,21	0,31
Téapleu	3,68	0,34
Yélleu	3,64	0,32
Zouan-Hounien	3,34	0,32

3.2.4. Floristic similarity of weeds

The Sørensen similarity coefficients ranged between 50.00 and 73.47% (Table 4). The highest values were observed between Téapleu and Zouan-Hounien (73.47%), Goulaleu and Yélleu (73.12%), as well as between Téapleu and Yélleu (71.56%). The lowest coefficients were recorded between Banneu and Bin-Houyé (50.00%), Bin-Houyé and Goulaleu (53.52%), and Bin-Houyé and Zouan-Hounien (55.67%). All the coefficients obtained were equal to or greater than 50%.

Table 4 Sørensen floristic similarity coefficients between the studied localities

Localities	Similarity coefficient					
	Banneu	Bin-Houyé	Goulaleu	Téapleu	Yélleu	Zouan-Hounien
Banneu		50	67,61	66,67	64,44	65,82
Bin-Houyé			53,52	57,47	57,78	55,67
Goulaleu				66,67	73,12	58,54
Téapleu					71,56	73,47
Yélleu						65,35
Zouan-Hounien						

3.3. Herbicide Usage Profile in Rice Cultivation

The survey conducted in the Zouan-Hounien department made it possible to record 37 marketed herbicides, of which 23 were actually used by the rice farmers surveyed. These products differed in their brand names, application doses, and formulations, which were mostly liquid. The characteristics of the herbicides recorded are presented in Table 5.

Among the recorded herbicides, seven were the most frequently used. The herbicide "Tête Rouge 360 SL" had the highest usage frequency (41.51%), followed by "Herbextra 720 SL" (37.75%) and "Rangro 480 SL" (20.75%). The products "Lamachette 480 SL" (15.09%) and "Tuer fort 480 SL" (13.21%) ranked fourth and fifth in usage, respectively. "Herbus Plus 720 SL" and "Lamachette 757 WG" showed identical usage frequencies (11.32%).

Conversely, several herbicides remained sparsely used, notably “Bibana 360 SL,” “Glycot 700 SG,” “Glyphader 75,” “Malogbê 200 WP,” “Ripro 720 SL,” “Rizcot 432 EC,” “Solution 480 SL,” “StopHerb 360 SL,” “Weed Kill 720 SL,” and “Weed Out 360 SL,” each representing a usage frequency of 1.87%.

Table 5 List of herbicides used by rice farmers

Trade name	Active ingredients	Formulation	Dosage	Usage rate (%)
Bazaryl 432 EC	Propanil+Triclopyr	Liquid	360 g/l+72 g/l	5,66
Bibana 360 SL	Glyphosate	Liquid	360 g/l	1,87
Calliherbe 720 SL	2,4-D amine salt	Liquid	720 g/l	5,66
Extra 720 SL	2,4-D amine salt	Liquid	720 g/l	5,66
Glycot 700 SG	Ammonium glyphosate salt	Granulated	700 g/kg	1,87
Glyphader 75 SG	Glyphosate ammonium salt	Granulated	75 g/kg	1,87
Herbextra 720 SL	2,4-D amine salt	Liquid	720 g/l	37,75
Herbigro 720 SL	2.4-D amine salt	Liquid	720 g/l	13,21
Herbus plus 720 SL	2,4-D amine salt	Liquid	720 g/l	11,32
Lamachette 480 SL	Glyphosate isopropylamine salt	Liquid	480 g/l	15,09
Lamachette 757 WG	Ammonium glyphosate salt	Granulated	757 g/kg	11,32
Mmalogbê 200 WP	Metsulfuron Methyl	Powder	200 g/kg	1,87

Rangro 480 SL	Glyphosate isopropylamine salt	Liquid	480 g/l	20,75
Rangro 757 WG	Glyphosate	Granulated	757 g/kg	5,66
Ripro 720 SL	2,4-D amine salt	Liquid	720 g/l	1,87
Rizcot 432 EC	Propanil+Triclopyr	Liquid	360 g/l+72 g/l	1,87
Solution 480 SL	Glyphosate isopropylamine salt	Liquid	480 g/L	1,87
Stopherb 360 SL	Glyphosate	Liquid	360 g/l	1,87
Tête rouge 360 SL	Glyphosate isopropylamine salt	Liquid	360 g/l	41,51
Topextra 720 SL	2,4-D amine salt	Liquid	720 g/l	3,77
Tuer fort 480 SL	Glyphosate	Liquid	480 g/l	9,43
Weed out 360 SL	Glyphosate	Liquid	360 g/l	1,87
Weed kill 720 SL	2,4-D amine salt	Liquid	720 g/l	1,87

4. Discussion

The demographic structure of rice farmers in the Zouan-Hounien department highlights a predominance of producers belonging to the 26–45 age group (69.81%), reflecting significant involvement of economically active populations in rice farming. This trend could be explained by the growing interest of young adults in strategic food crops, particularly rice, in a context marked by the search for food security and rural economic opportunities. Similar observations have been reported in several West African agricultural systems, where farmers are mostly from the active age groups [12,13].

The strong male predominance observed in rice farms (92.45%) confirms the gendered nature of rice production in many regions of sub-Saharan Africa. This situation could be linked to women's difficulties in accessing productive resources, including land, agricultural equipment, and labor. However, their involvement in post-harvest operations and rice marketing suggests a differentiated distribution of roles within the value chain. In Côte d'Ivoire, several recent studies show that, despite a gradual reduction in productivity gaps between men and women, agricultural farms remain predominantly male-headed [12].

The massive prevalence of the combination of manual weeding and chemical control (81.13%) highlights the widespread adoption of an integrated weed management strategy by farmers in the study area. This technical complementarity reflects the operational limits inherent to each method. Indeed, the high use of herbicides (89.99% of farmers) seems to respond to the increasing scarcity of agricultural labor and the high cost of manual weeding, particularly during critical periods of crop management. Recent work in rice cultivation shows that labor availability constraints encourage an intensification in the use of herbicides, which reduce the need for manual labor and improve the temporal efficiency of farming operations [14,15]. However, the simultaneous use of manual weeding by a high proportion of producers (91.14%) suggests that chemical control alone remains insufficient to ensure satisfactory weed management, particularly due to floristic diversity, the emergence of tolerant or resistant species, and the variable effectiveness of herbicides depending on agroecological contexts [16]. Thus, the low adoption of exclusive practices, whether strictly chemical (8.66%) or solely manual (10.01%), reflects the technical and economic limits of non-combined strategies. The observed mixed model therefore appears as a techno-economic compromise that allows the operational efficiency of herbicides to be combined with the corrective precision of manual weeding.

The weed flora recorded in the rice plots of Zouan-Hounien, composed of 80 species distributed across 57 genera and 27 families, reveals a relatively high floristic richness compared to previous studies conducted in Côte d’Ivoire. [10] had identified 62 major weed species associated with Ivorian rice systems, while [17], in the rice perimeters of Daloa, reported a more limited diversity. The observed differences could be explained by the variability of agroecological conditions, the management methods of the plots, the water regime of lowlands, as well as the weeding practices applied. According to [18], the weed communities of African rice systems vary greatly depending on the cropping systems, the intensity of human interventions, and the weed control strategies.

The predominance of Poaceae and Cyperaceae, representing 22.5% and 17.5% of the recorded species respectively, confirms their ecological importance in lowland rice agroecosystems. These families include species particularly adapted to wet and disturbed environments, which facilitates their establishment in plots subject to repeated agricultural interventions. Similar trends have been reported in African rice systems, where Poaceae and Cyperaceae are among the most abundant and competitive taxonomic groups with respect to rice [18].

The structure of weed communities observed in the rice fields of the Zouan-Hounien department highlights the dominance of a small core of highly aggressive species, primarily represented by *Fimbristylis littoralis*, *Cyperus difformis*, *Panicum laxum*, *Ludwigia abyssinica*, and *Echinochloa spp*. This floristic configuration suggests a strong adaptation of these species to the hydromorphic conditions of lowland rice systems, characterized by high moisture and repeated cultural disturbances. Similar observations have been reported in several rice systems in sub-Saharan Africa, where *Cyperus difformis*, *Fimbristylis littoralis*, and *Echinochloa spp*. are among the most harmful weeds to rice [18,4].

The coexistence of a significant number of aggressive and less aggressive species also reflects a relatively high floristic diversity in the surveyed plots. This diversity could result from the heterogeneity of cultural practices, water gradients between locations, and the weed management methods implemented by producers. Indeed, the heavy use of herbicides in the study area could exert a selection pressure on certain weed species, favoring the persistence of tolerant species or those capable of quickly recolonizing the plots after treatment. Several recent studies highlight that the repeated use of herbicides with a similar spectrum gradually contributes to changing the floristic composition of weed communities by favoring certain species adapted to agricultural disturbance regimes [7,19].

Furthermore, the simultaneous presence of very common species but with variable specific contribution indicates that the spatial distribution of weeds does not always reflect their level of ecological aggressiveness. Some widely distributed species can exert moderate competitive pressure, while others, less uniformly distributed, contribute significantly to the structuring of weed communities in certain plots. This dynamics highlights the interest of combining relative frequency and specific contribution parameters for a better prioritization of target species in integrated weed management programs.

The relatively high Shannon diversity indices observed in Téapleu (3.68 bits) and Yélleu (3.64 bits) indicate significant floristic diversity of weed communities in these localities. Furthermore, Pielou's evenness indices above 0.30 suggest a relatively balanced distribution of species, reflecting an absence of strong dominance by a limited number of taxa. These observations could reflect a relatively stable ecological dynamic of the weed communities in the rice plots studied.

The Sørensen similarity coefficients, all greater than or equal to 50%, indicate a relatively significant floristic homogeneity between the studied localities. This similarity could result from similar ecological conditions, a common circulation of weed seeds, and similar cropping practices, notably the repeated use of the same herbicides. However, the variations observed between certain localities could reflect local differences related to soil characteristics, hydrological conditions, and the anthropogenic pressure exerted on the plots. High levels of floristic similarity have also been reported in several West African rice systems [20,18].

The inventory of herbicides used highlights a predominance of glyphosate-based formulations, notably Tête Rouge 360 SL, Rangro 480 SL, and Lamachette 480 SL. This trend is consistent with observations made in rice systems in sub-Saharan Africa, where glyphosate- and 2,4-D-based herbicides dominate rural agrochemical markets and are among the most used products by rice farmers, due to their commercial availability, relatively affordable cost, and perceived effectiveness in weed management [21].

However, the intensive and repeated use of glyphosate could gradually alter the floral composition of plots by favoring tolerant or resistant species and by exerting selective pressure on certain weed communities. Recent studies have highlighted that prolonged use of glyphosate is likely to cause significant ecological changes as well as increasing environmental risks [22,23].

Finally, the use of herbicide combinations observed among some producers could reflect a search for increased effectiveness against the persistence of certain weeds. Although this strategy may temporarily improve weed control, it could also increase production costs and enhance the risks of herbicide resistance. In this context, integrated weed management combining cultural, mechanical, and chemical methods appears necessary for sustainable rice farming [18].

This study presents certain limitations related to the sample size, the temporal coverage limited to a single cropping season, and the absence of experimental analyses on the agronomic effectiveness of the herbicides recorded. However, the data obtained provide a robust basis for improving local weed management strategies.

5. Conclusion

This study made it possible to document the floristic diversity of weeds and the practices of herbicide use in the rice-growing systems of the Zouan-Hounien department (West of Côte d'Ivoire). The surveyed plots were characterized by a relatively diverse weed flora, dominated by Poaceae and Cyperaceae. Several highly aggressive weed species, including *Fimbristylis littoralis*, *Cyperus difformis*, *Panicum laxum*, and *Ludwigia abyssinica*, were identified as predominant and may substantially reduce rice productivity. The study also highlights a strong dependence of producers on chemical weed control, mainly based on glyphosate-based formulations, often combined with manual weeding. Although this strategy improves weed control in the short term, its repeated use could modify the floristic structure of the plots and favor the selection of tolerant species.

These results highlight the need to promote integrated weed management approaches combining cultural, mechanical, and judicious chemical methods in order to sustainably improve rice productivity while limiting agronomic and environmental risks. Additional research on weed dynamics and the agronomic effectiveness of weeding programs would be useful to guide local management strategies.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that do not have any conflict of interest.

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