Article

Constraints to Pearl Millet (*Pennisetum glaucum*) Production and Farmers' Approaches to *Striga hermonthica* Management in Burkina Faso

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Abstract: Pearl millet (*Pennisetum glaucum*) is a staple food crop in Burkina Faso that is widely grown in the Sahelian and Sudano-Sahelian zones, characterised by poor soil conditions and erratic rainfall, and high temperatures. The objective of this study was to document farmers' perceptions of the prevailing constraints affecting pearl millet production and related approaches to manage the parasitic weeds *S. hermonthica*. The study was conducted in the Sahel, Sudano-Sahelian zones in the North, North Central, West Central, Central Plateau, and South Central of Burkina Faso. Data were collected through a structured questionnaire and focus group discussions involving 492 participant farmers. Recurrent drought, *S. hermonthica* infestation, shortage of labour, lack of fertilisers, lack of cash, and the use of low-yielding varieties were the main challenges hindering pearl millet production in the study areas. The majority of the respondents (40%) ranked *S. hermonthica* infestation as the primary constraint affecting pearl millet production. Respondent farmers reported yield losses of up to 80% due to *S. hermonthica* infestation. 61.4% of the respondents in the study areas had achieved a mean pearl millet yields of <1 t/ha. Poor access and the high cost of introduced seed, and a lack of farmers preferred traits in the existing introduced pearl millet varieties were the main reasons for their low adoption, as reported by 32% of respondents. *S. hermonthica* management options in pearl millet production fields included moisture conservation using terraces, manual hoeing, hand weeding, use of microplots locally referred to as '*zaï*', crop rotation and mulching. These management techniques were ineffective because they do not suppress the below ground *S. hermonthica* seed, and they are difficult to implement. Integrated management practices employing breeding for *S. hermonthica* resistant varieties with the aforementioned control measures could offer a sustainable solution for *S. hermonthica* management and improved pearl millet productivity in Burkina Faso.

Keywords: agro-ecology; plant breeding; integrated pest management; pearl millet; production constraints; *Striga hermonthica*

1. Introduction

Pearl millet (*Pennisetum glaucum* [L.] R. Br., $2n = 2x = 14$) is the sixth most important cereal crop in the world after wheat, rice, maize, barley, and sorghum [1]. The crop is adapted to arid and semi-arid environments and grows relatively well under low soil fertility conditions, outperforming other common cereal crops such as maize and wheat [2]. Approximately 22 million hectares of land in Africa are under pearl millet production

with mean productivity of 1 ton ha^{-1} [3]. In Burkina Faso, the mean yield under the smallholder production system is estimated at 0.85 tons ha^{-1} compared to a potential yield of 3.00 tons ha^{-1} achievable under research conditions [3]. This yield gap can be attributed to biotic and abiotic constraints and socio-economic challenges. The key biotic constraints to pearl millet production are parasitic weeds (*Striga* species), bird damage, downy mildew, head miner, and the use of low-yielding landraces [4].

Drought stress and low soil fertility are among the major abiotic constraints affecting pearl millet production [4]. In Burkina Faso, pearl millet is mainly grown in the semi-arid Sahelian and Sudano-Sahelian zones that are characterized by poor soils, low and erratic rainfall, and high temperatures. The intensity and frequency of biotic and abiotic stresses intensified by climate change have increased in sub-Saharan Africa (SSA), including Burkina Faso, which has increased the need for resilient crop cultivars [5].

Striga species are notorious parasitic weeds affecting pearl millet production in the Sahel and Sudano-Sahel regions [6]. There are 13 *Striga* species reported in Burkina Faso, with *Striga hermonthica* (Del.) Bentham and *S. gesneroïdes* (Willd) Vatke being the most devastating weeds of cereal and legume crops, respectively [7]. Yield losses due to *S. hermonthica* vary between 7 and 41% in the central zones, while up to 55% losses have been reported in the eastern zones of Burkina Faso [8,9]. The parasitic weed has a wide range of hosts, including rice (*Oryza glaberrima* Steudel and *O. Sativa* L.), maize (*Zea mays L.*), sorghum (*Sorghum bicolour* [L.] Moench), pearl millet, and fonio (*Digitaria exilis* (Kippist) Stapf) [7,10]. The wide host range, the easy dispersal of *S. hermonthica* seeds by animals and wind, and the seeds' ability to stay viable in the soil for about 14 years make it difficult to control the weed [6].

Farmers employ hand weeding, crop rotation, and botanicals such as a concoction powder prepared from pods of the African locust bean (*Parkia biglobosa* (Jacq.) R. Br. ex G. Don) and almonds of the shea tree (*Vitellaria paradoxa* C.F. Gaertn.) to control *S. hermonthica* [7]. These methods reduce the amount of *S. hermonthica* seed in the soil and improve soil fertility, but they have high labour requirements that limit their implementation and use. The use of chemical herbicides is not widely reported among smallholder farmers due to their high cost, limited access, and potential environmental hazards. In addition, the use of host plant resistance against *S. hermonthica* is limited by poor access to or the unavailability of resistant varieties. A combination of effective *S. hermonthica* control methods is required to reduce *S. hermonthica* on pearl millet production in SSA.

The active participation of farmers in developing strategies to control *S. hermonthica* is important to ensure high adoption of the developed strategies. It is also imperative to understand the important traits of a pearl millet variety that the farmers require to design and breed farmer-preferred pearl millet varieties. Participatory rural appraisal (PRA) is a multi-disciplinary research tool used to gain information from farmers through their participation in the initial stages of technology development. The tool helps to understand the farmers' knowledge, experiences, perceived and encountered production constraints, preferred traits, and their agricultural needs [10,11]. It emphasizes incorporating local knowledge in developing new interventions [12], which provides opportunities for local people to define their circumstances, conduct a situational analysis, and draft suitable plans for intervention. The PRA approach has been used to identify farmers' production constraints, preferred crop varieties, understand their agricultural environment, and develop suitable intervention strategies [13,14]. DeVries and Toenniessen [15] emphasized the need for farmers' involvement in all stages of cultivar development, including prioritizing target traits, selecting early breeding generations, and varietal evaluations to accommodate and promote their input in the breeding value chain.

Omanya et al. [16] lamented the low adoption rates of "improved" cultivars of pearl millet in Senegal, which was attributed to poor information dissemination among farmers and a disregard of farmers' opinions by the plant breeders during cultivar development. Farmers in Nigeria were involved in a PRA study and identified *S. hermonthica* infestation as the most important constraint of pearl millet production, and consequently,

S. hermonthica resistance was the most preferred trait in pearl millet [17]. In Burkina Faso, PRA was employed to collect information on production constraints and farmers' preferred traits to guide pearl millet breeding programs and design new varieties that meet farmer needs and preferences [4]. However, the study area was limited to only three districts, and there were a few respondents. Therefore, the objective of the current study was to include more sites and more respondents to have a broader data set to document farmers' perceptions on the prevailing constraints affecting pearl millet production. Special emphasis was placed on their approaches to managing *S. hermonthica* to guide the future development and release of improved and locally acceptable varieties to farmers in Burkina Faso.

2. Materials and Methods

2.1. Description of the Study Sites

Burkina Faso has a tropical climate consisting of a long dry season (November to May) and a short rainy season (June to October). Pearl millet is cultivated in the short rainy season. The study was conducted in the Sahelian and Sudano-Sahelian agro-ecological zones of Burkina Faso, where much of the pearl millet is produced (Figure 1). The Sahelian zone receives less than 600 mm of rainfall with monthly mean temperatures between 24 and 35.3 °C during the short rainy season between 2 and 3 months. The Sudano-Sahelian zone receives rainfall between 600–900 mm over 4 to 5 months, with mean temperatures between 25 and 33.5 °C [18]. The predominant soils are deficient in nitrogen and phosphorus due to soil erosion and high temperatures experienced in these regions [19].
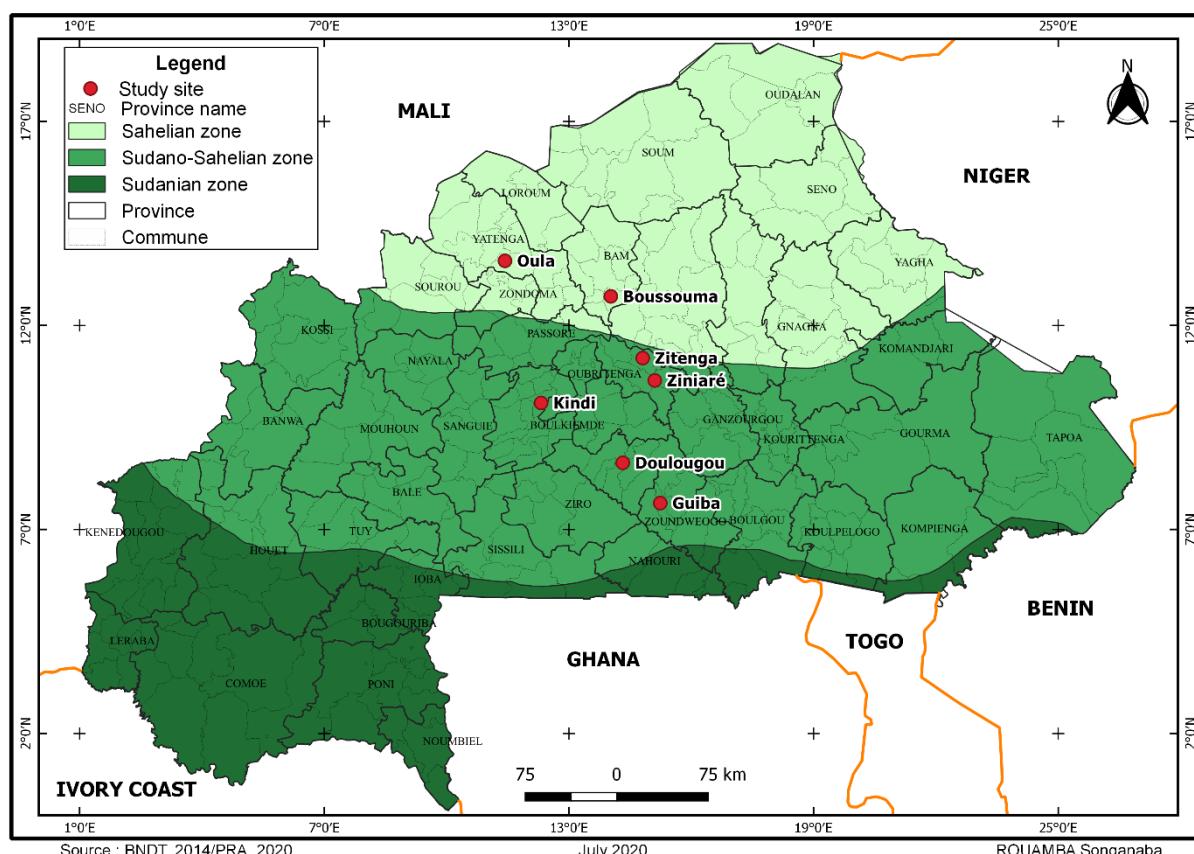

Figure 1. Map of Burkina Faso showing the common agro-ecological zones and the study sites.

2.2. Sampling Method

A hierarchical sampling method based on pearl millet production, *S. hermonthica* infestation, and the regions' administrative organisation was used to select the study sites (Figure 2). Secondary data on pearl millet production and *S. hermonthica* infestation were

obtained from the Agriculture Department [20]. Two agro-ecological zones involved in large-scale pearl millet production were selected. Subsequently, five regions were identified based on *S. hermonthica* infestation, and accessibility. Three regions, namely Central Plateau, South Central, and West Central, were identified in the Sudano-Sahelian agro-ecological zone, while two regions, namely North and North Central, were selected in the Sahelian zone. Six provinces were selected where *S. hermonthica* regularly occurs in farmers' pearl millet production fields. Additionally, the selected villages were known for their pearl millet production and *Striga* infestations. Farmers who experienced high *S. hermonthica* infestation in their fields were chosen after a preliminary survey. The sampling process was facilitated by a social scientist, breeders, key informants, and agricultural extension agents. A total of 492 respondents participated in the study. Three hundred farmers were interviewed using a structured questionnaire, and 192 farmers were part of the focus group discussion. Focus group discussions (FGD) were used to record farmers' perceptions, the main constraints in pearl millet production, and their strategies to coping with *S. hermonthica* infestations in the surveyed areas. The questionnaires were administered to farmers in the North, North Central, and South Central regions, while the FGD was conducted in Central Plateau and West Central regions in January and February 2020.
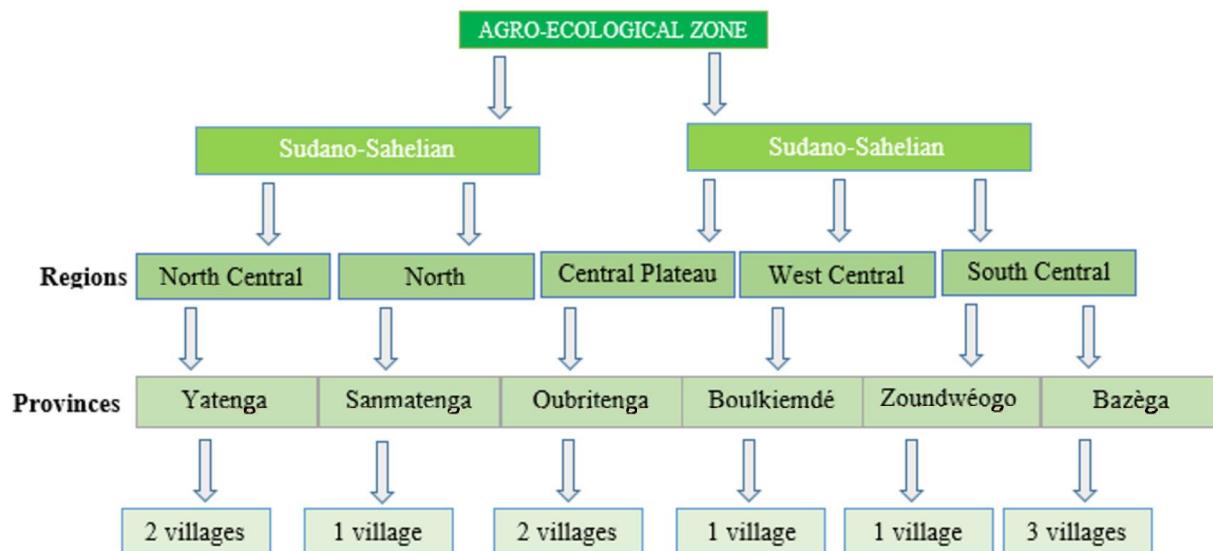
Figure 2. Sampling method cascading the selected zones, regions, provinces, and villages for the study.

2.3. Data Collection and Analyses

Data were collected through interviews using a structured open- and closed-ended questions and focus group discussions (Figure 3). Leaders of farmers' organisations in each village were involved in facilitating focus group discussions and administering the questionnaires. The questionnaires were pre-tested before conducting the actual data collection from farmers. The pre-test was undertaken to streamline the questionnaire and avoid ambiguous questions and improve the clarity of questions. The focus group discussions included an exhibition of photos with *S. hermonthica* and its associated damage, transect walks, and the discussions were recorded in writing and audio formats. The constraints identified in the questionnaires were further explored in more detail and ranked using a pair-wise matrix technique during the focus group discussions.
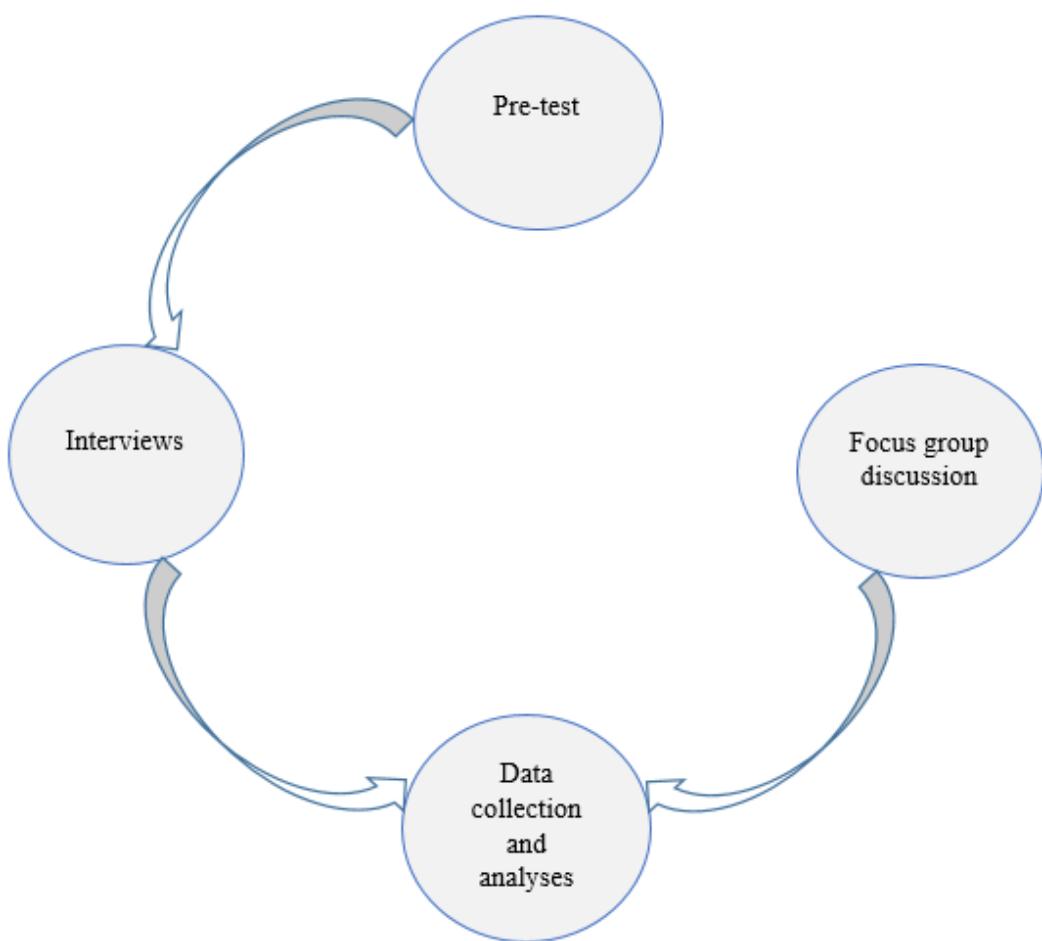
Figure 3. The interface of data collection and analysis during the study.

Qualitative data sets collected through the questionnaire were coded into district categories and subjected to statistical analyses using the 2005 version of the Statistical Package for Social Sciences software (SPSS Inc. Chicago, IL, USA). Cross-tabulations were computed, tables were constructed, and descriptive statistics were performed to summarise data from the questionnaires and FGDs. The pair-wise ranking method was used to prioritize the constraints raised during FGDs. To make statistical inferences, contingency Chi-Square tests were conducted to determine relationships among the different variables.

3. Results

3.1. Sociodemographic Description of Respondent Farmers

Three hundred smallholder farmers were interviewed individually using structured questionnaires, while 192 farmers were involved in focus group discussions. The demographic characteristics of participants are presented in Table 1. The number of male or female respondents varied significantly between the regions ($X^2 = 18.349$; $p < 0.000$) across the different zones. The North zone had the least male respondents (36%), while South Central had 65% male representation ($n = 100$ per surveyed region). About 80% of the non-disabled population are involved in the agriculture sector in Burkina Faso.

Fifty-three percent of the farmers were above 50 years old, while 34% were between 30 and 50 ($n = 300$). The low number of individuals below 30 years indicates the rural to urban migration of youths in pursuit of urban livelihoods. The distribution of farmers in the different age groups showed similarities across the different zones. The majority (51%) of households had a family size of 1 to 10 individuals, while close to 40% had up to 20 individuals ($n = 300$) suggesting the high population growth rate in addition to the practice of polygamy in the rural areas. The trend was similar across the zones. Relatively few of

the respondents (8.3%) had attended primary school, secondary school (1.3%), and college (0.4%) and were able to read and write. The remaining 90% did not attend formal schools and experienced difficulties in reading and writing ($n = 300$).

Table 1. Social and demographic information of respondent farmers during the study in three regions in Burkina Faso (%; $n = 300$).

Variable	Class	Regions			Mean	df	Chi-Square	*p*-Value
		North Central	South Central	North				
Gender	Male	43	65	36	48	2	18.349	0.000
	Female	57	35	64	52			
Family size	1–10	49	62	43	51.3	4	65.370	0.183
	11–20	45	32	42	39.7			
	>20	6	6	15	9			
Age (years)	<30	16	10	12	12.7	4	136.094	0.060
	30–50	43	61	55	53			
	>50	41	29	33	34.3			
Marital status	Married	97	85	94	92	4	11.048	0.026
	Single	0	3	1	1.3			
	Widowed	3	12	5	6.7			
Education level	Literate	96	88	86	90	6	11.242	0.081
	Primary school	3	11	11	8.3			
	Secondary school	1	0	3	1.3			
	Graduate	0	1	0	0.4			

df, degrees of freedom.

3.2. Main Socio-Economic Activities in the Study Provinces
Income Sources

Crop production was the single most common source of income among the respondent farmers, with 36.7% affirming that they derived income from crop production (Table 2). The second most important income source was a combination of crop and livestock production, as indicated by 21.0% of the farmers. In comparison, about 18.0% of the respondents earned income from either livestock production alone or businesses such as in small shops ($n = 300$). Most of the respondents derived their livelihood from agriculture in one form or the other. Farmers practice mixed farming—a combination of livestock rearing and crop production to pursue food security and livelihoods.

3.3. Pearl Millet Varieties Grown in the Study Areas

Several different crops were grown in the study area, as confirmed by the respondent farmers and observation made during transect walks (Table 3). The majority of the farmers used local varieties of pearl millet, while 32% adopted improved varieties. However, there were significant variations among the different regions. For instance, almost all of the farmers (93%) in the North Central region cultivated improved pearl millet varieties owing to the support given by the local non-governmental organisations NGOs. In contrast, in the South Central and North regions, 80 and 97% of respondents, respectively, cultivated local varieties. This is due to the limited research support to pearl millet when compared with other major crops such as maize and rice ($n = 100$ in each region).

Table 2. Income source according to the regions (%; *n* = 300).

Income Source	Regions			Mean	df	Chi-Square	*p*-Value
	North Central	South Central	North				
Crop production	43	7	60	36.7			
Livestock production	4	41	11	18.7			
Crop and livestock production	49	0	14	21.0			
Tuckshop	3	45	5	17.7	16	2.326	0.000
Crop production and tuckshop	0	0	8	2.7			
Craftmanship	0	3	1	1.3			
Gardening	0	3	1	1.3			
Livestock production and tuckshop	0	1	0	0.3			
Processing of crop products	1	0	0	0.3			

df, degrees of freedom.

Table 3. Proportion of farmers using different crop varieties in the study area (%; *n* = 300).

Crop	Varieties	Regions			Mean	df	Chi-Square	*p*-Value
		North Central	South Central	North				
Pearl millet	Local	6	80	97	61	2	2876	0.000
	Improved	93	0	3	32			
Sorghum	Local	14	79	43	45.3	2	106.840	0.000
	Improved	25	0	3	9.3			
Cowpea	Local	5	56	40	33.7	2	169.769	0.000
	Improved	81	12	6	33			
Maize	Local	0	50	23	24.3	2	166.425	0.000
	Improved	1	37	6	14.7			
Groundnut	Local	4	30	44	26	2	101.267	0.000
	Improved	34	0	0	11.3			
Sesame	Local	0	2	6	2.7	2	13.090	0.011
	Improved	3	0	0	1			
Bambara nut	Local	4	1	4	3	2	72.177	0.000
	Improved	31	0	0	10.3			
Rice	Local	0	5	0	16.7	2	18.557	0.001
	Improved	0	4	0	1.3			

df, degrees of freedom.

3.4. Status of Pearl Millet Production

Table 4 represents the mean area allocated to pearl millet production in the study sites between 2015 and 2019. About 23% of the interviewed farmers allocated less than one hectare (ha) of land to pearl millet production, while 62.6% have less than two hectares (*n* = 300). Ancestral or family land ownership was confirmed by 87% of the respondents (*n* = 300). The mean yield produced and reported is presented in Table 5. Most of the respondents (61.4%) harvest grain yields less than 1 ton ha^{-1}, while the mean yield achieved in *S. hermonthica*-free pearl millet fields was between 0.5 and 2.0 ton ha^{-1} (*n* = 300). Globally, pearl millet production is estimated with a mean yield of 0.89 ton ha^{-1} [21]. The trend of pearl millet production area during the last five years is the same across the study area. This is mainly attributed to a lack of agricultural lands leading to monoculture systems and lowering soil fertility and enhancing *Striga* infestation and development. In Burkina Faso a blanket recommendation of 100 kg nitrogen, phosphorus, and potassium (NPK) and 50 kg of urea fertilizers and 5 kg crop seed per hectare are used for pearl millet production.

Table 4. Trends of pearl millet production area in the study areas from 2015–2019.

Year	Regions	Production Areas (ha) and Number of Respondents							df	Chi-Square	*p*-Value
		[0–1]	[1–2]	[2–3]	[3–4]	[4–5]	[5–6]	[6–7]			
2015	South Central	26	10	0	0	0	0	0			
	North	15	43	25	8	1	1	0	12	119.895	0.000
	North Central	10	27	24	19	3	0	1			
Total		51	80	49	27	4	1	1			
2016	South Central	23	13	1	0	0	0	0			
	North	14	42	26	8	1	1	0	12	102.140	0.000
	North Central	11	27	25	20	2	0	1			
Total		48	82	52	28	3	1	1			
2017	South Central	27	25	4	1	0	0	0			
	North	16	44	28	8	1	1	0	12	91.024	0.000
	North Central	11	28	29	19	3	0	1			
Total		54	97	61	28	4	1	1			
2018	South Central	31	29	3	1	0	0	0			
	North	16	46	28	8	1	1	0	12	101.618	0.000
	North Central	12	30	29	21	2	0	1			
Total		59	105	60	30	3	1	1			
2019	South Central	49	26	4	1	0	0	0			
	North	14	48	26	8	1	1	0	12	113.365	0.000
	North Central	14	31	31	20	2	1	1			
Total		77	105	61	29	3	2	1			

df, degrees of freedom.

3.5. Constraints to Pearl Millet Production in Burkina Faso

Farmers mentioned that bird damage, drought, downy mildew, *Psalydolytta* spp, *S. hermonthica*, a lack of access to improved varieties, lack of fertilisers, labour unavailability, shortage of cash, lack of farm equipment, and poor soil fertility were the major challenges affecting pearl millet production (Table 6). Forty percent of the respondents ranked *S. hermonthica* infestation as the most important challenge of pearl millet production (*n* = 300). *S. hermonthica* infestation is estimated to cause up to 80% yield losses in pearl millet production according to the respondents during FGDs. Yield loss accompanied by *Striga* damage that lead to poor seed germination, leaf chlorosis, stunted pearl millet growth and development and plant death under heavy infestation. A lack of access to fertilisers was ranked by 34.7% of the farmers as the most important constraint due to the high costs of inorganic fertilizers, which are prohibitive for most small farmers (*n* = 300).

Table 5. Mean grain yield of pearl millet in the study areas (%; *n* = 300).

Yield (kg/ha)	Regions			Mean	df	Chi-Square	*p*-Value
	North Central	South Central	North				
[0–500]	8	69	15	30.7			
[500–1000]	51	5	36	30.7			
[1000–1500]	14	0	17	10.3			
[1500–2000]	8	0	22	6.7			
[2000–2500]	5	0	6	3.7			
[2500–3000]	8	0	2	3.3	20	3.199	0.000
[3000–3500]	2	0	2	1.3			
[3500–4000]	0	0	0	0			
[4000–4500]	0	0	0	0			
[4500–5000]	2	0	0	0.7			
[5000–5500]	1	0	0	0.3			

df, degrees of freedom.

Table 6. Number of participant farmers who ranked the constraints to pearl millet production in three regions of Burkina Faso (%; *n* = 300).

Constraints	Rank	Regions			Mean	df	Chi-Square	*p*-Value
		North Central	South Central	North				
Striga hermonthica	1rst	26	64	30	40	6	43.524	0.000
	2nd	48	17	7	24			
	3rd	24	15	4	14.3			
	4th	2	1	0	1			
Lack of fertilisers	1rst	47	16	41	34.7	6	41.471	0.000
	2nd	47	36	32	38.3			
	3rd	4	15	6	8.3			
	4th	0	8	0	2.7			
Lack of cash	1rst	25	3	16	14.7	6	37.008	0.000
	2nd	3	4	22	9.7			
	3rd	21	5	15	13.7			
	4th	26	12	5	14.3			
Drought	1rst	2	10	5	5.7	6	64.906	0.000
	2nd	2	33	8	14.3			
	3rd	26	9	10	15			
	4th	22	2	1	8.3			
Lack of improved varieties	1rst	0	3	1	1.3	6	8.876	0.181
	2nd	0	4	3	2.3			
	3rd	2	23	4	9.7			
	4th	3	24	1	9.3			
Shortage of labour	1rst	0	0	3	1	6	23.185	0.001
	2nd	0	1	12	4.3			
	3rd	4	18	5	9			
	4th	0	1	1	0.7			

df, degrees of freedom.

3.6. S. Hermonthica Infestation and Control Strategies

Almost all of the farmers (99%) recognized the negative impact of *S. hermonthica* on pearl millet growth and yield (*n* = 300). They understood the need for weed management for yield improvement. Hand-weeding of *S. hermonthica* plant and fertilizer application was the main *S. hermonthica* control measures reported by 90% of the respondents (Table 7) (*n* = 300). These methods are believed to reduce the *S. hermonthica* seed bank in the soil. Hand weeding was practiced by 34.7% of the farmers, while a combination of weeding by

hand and hoe was the next most common method used by 31.0% of the farmers. Very few farmers used crop rotation and herbicides due to the lack of arable land ($n = 300$).

Table 7. *S. hermonthica* control measures used by farmers (%, $n = 300$).

S. hermonthica Control Measures	Regions			Mean	df	Chi-Square	*p*-Value
	North Central	South Central	North				
Hand weeding	57	47	0	34.7			
Hand weeding and hoeing	0	21	72	31.0			
Crop rotation, intercropping, and hand weeding	26	0	0	8.7			
Use of organic manure and hoeing	0	8	0	2.7			
Intercropping with cowpea and hand weeding	5	0	0	1.7			
Intercropping, hand weeding	5	0	0	1.7	26	3.063	0.000
Hoeing	0	0	4	1.3			
Crop rotation and hand weeding	3	0	0	1.0			
Crop rotation and intercropping	2	0	0	0.7			
Micro plots, crop rotation, hand weeding	1	0	0	0.3			
Crop rotation and hand weeding	1	1	0	0.7			
Hand weeding and use of herbicides	0	0	1	0.3			
Hand weeding and use of inorganic fertilisers	0	1	0	0.3			
Use of inorganic Fertilisers	0	1	0	0.3			

df, degrees of freedom.

The farmers used various soil moisture conservation methods (Figure 4, Table 8), as a tool to control *S. hermonthica*. Terraces, mulching, the use of micro plots or planting holes (locally referred to as *zaï*), ridges, and grass strips were some of the techniques used for moisture conservation and to suppress the impact of *S. hermonthica* (Figure 4, Table 8) ($n = 300$). Terraces, mulching, ridges, and grass strips are used to reduce ran off during the raining season, allowing water to be conserved and infiltrate into the soil. Micro plots or planting holes is a traditional technique used to conserve moisture and increase soil fertility to favour pearl millet production.

Table 8. Percentages of participant farmers who reported the use of moisture conservation methods in the study areas ($n = 300$).

Moisture Conservation Method	Regions			Mean	df	Chi-Square	*p*-Value
	North Central	South Central	North				
Terraces	99	77	89	88.3			
Mulches	0	13	0	4.3			
Ridges	0	5	0	1.7	8	42.885	0.000
Micro plots/planting holes	0	2	3	1.7			
Grass stripes	0	1	0	0.3			

df, degrees of freedom.

(**A**)

(**B**)

(**C**)

(**D**)

(**E**)
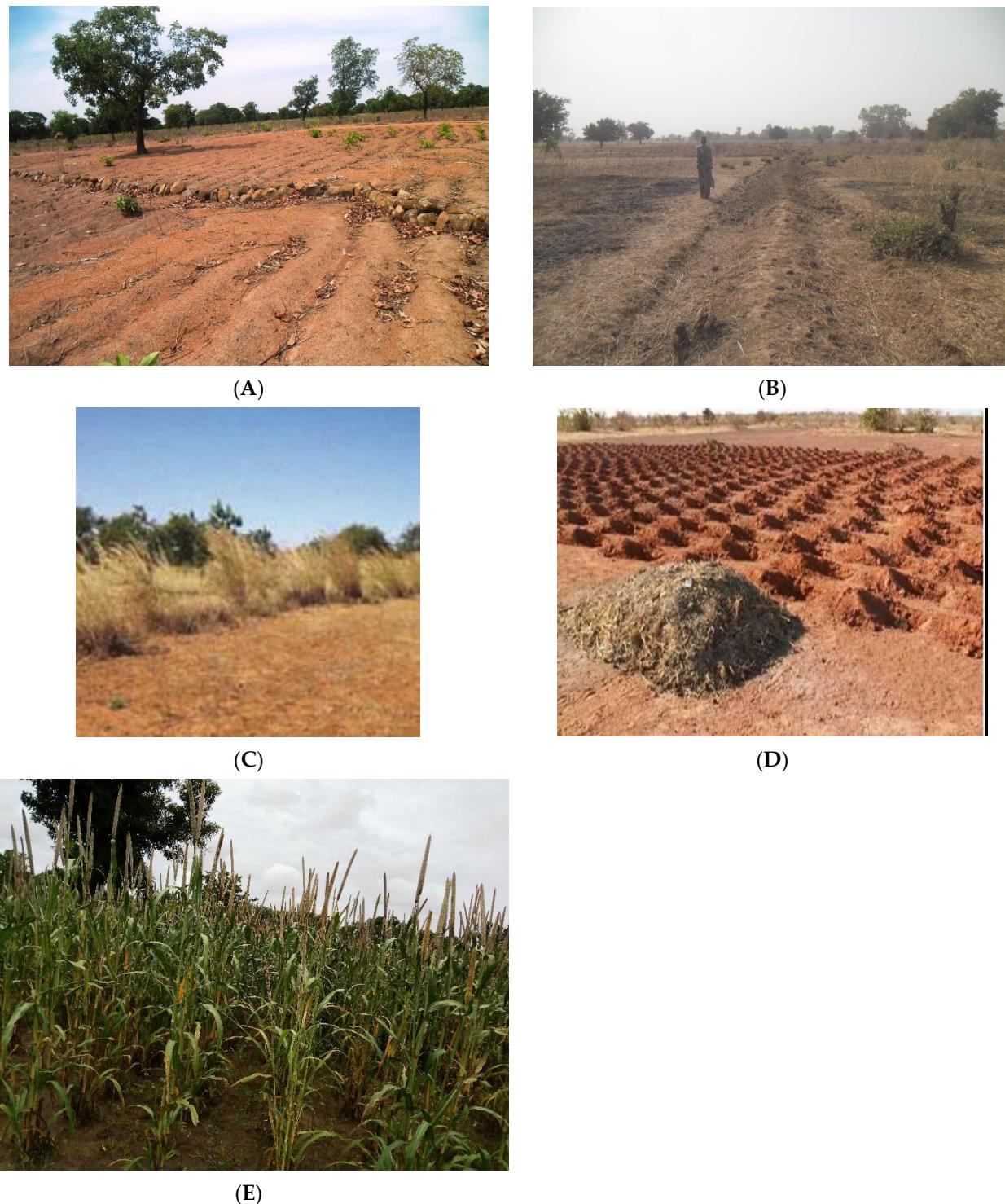
Figure 4. The common soil moisture conservation methods in pearl millet production fields in Burkina Faso to suppress *S. hermonthica* infestation. Note: (**A**) = terrace, (**B**) = ridge, (**C**) = grass strips, (**D**) = micro plots or planting holes (zaï), and (**E**): field/crop of pearl millet (Photo by Rouamba 2020 (**A**,**B**,**E**); Botoni et Reij, 2001 (**D**), GIZ 2012 (**C**).

4. Discussion

4.1. Social and Demographical Description of Respondent Farmers

The study found an almost equal representation of female (52%) and male (48%) respondent farmers involved in pearl millet cultivation in the study areas (Table 1). The active participation of women pearl millet farmers is critical in pursuing food security in

the country. Women play important roles in crop production and strengthening social networks [22]. The participation of women in this study was important to facilitate discussions and capture women farmers' perspectives because they are often underrepresented in agricultural interventions. It is also important because the lessons will cascade down to family and households, given women's multiple roles in providing household welfare. Previously, more female farmers were reported to be involved in producing crops such as Bambara groundnut in Ghana and improved agricultural technologies and practices in sub-Saharan Africa compared to male farmers [23,24].

Most participants were between 30 and 50 years of age and married (Table 1), an appropriate and active demographic group for decision-making, farm operations, and participation in the local economy. In African tradition, age and marital status are highly influential traits for making decisions such as the type of crop and variety to cultivate and land allocation that an individual can make in a household, directly impacting pearl millet production. Thus, having the majority of the participants in this demographic group was important to obtain relevant information, since most respondents were experienced in pearl millet production and encountered the constraints they perceived to be important, know some management options, and influence decisions made in the household. For instance, youths and widowed female farmers are usually at the bottom of the decision-making pyramid as they usually take directives from an older and male household head. In addition, household dynamics are also determined by family size, especially for farming operations. Most subsistence farming operations are carried out by family members [25]. Households with many family members can carry out diverse farming operations, particularly during the harvesting and processing season when labour is scarce [26]. This gives such households with large families the advantage of being able to farm on larger areas. There were no significant differences among the different zones in terms of family sizes because, in Burkina Faso, families are large, often with over eight people per household, due to the extended family system prevalent across the country [27]. Despite the large families, the farmers owned small landholdings, which negatively impacted their ability to expand their production, leading to inefficient labour practices. The small landholdings are traditionally owned along ancestral lineage and controlled by the most senior male of the family [28].

Most farmers had no formal education (Table 1), which will complicate communication processes, such as extension services, adoption of improved technologies, and access to information. Farmers with limited formal education are often unwilling to adopt new technologies and have shown a strong tendency to rely on traditional knowledge and experience. Therefore, intervention strategies that include a change in farmer behavior will likely be well-received as the level of education increases among the farmers. Literate farmers usually take the initiative and participate in developmental projects to improve agricultural practices. In contrast, farmers with little or no education are usually passive, depend on receiving information and are not proactive in participatory approaches to find solutions [29]. The low literacy rate among farmers found in this study corroborated earlier findings reported by PNDES [30]. The education level among farmers has strong implications for devising intervention strategies to improve agricultural productivity in developing countries. Farmers with strong educational backgrounds could be useful as agents to gather information regarding new interventions and play important roles as leaders in technology adoption [26].

4.2. Main Socio-Economic Activities in the Study Provinces

Income Sources

Many of the respondents derived their livelihood from agriculture in one form or the other (Table 2), as is typical in most developing countries. Sorgho [31] estimated that agriculture accounted for 76.3% of Burkina Faso's economy, showing that it was integral to sustaining livelihoods. However, agriculture faces several challenges, including low mechanization levels for intensifying production, poor sustainability, and a lack of

agricultural credit access that impede agricultural expansion [30]. These challenges limit agricultural productivity and make farming communities vulnerable to natural disasters such as severe droughts. The farmers in the study sites are highly vulnerable because they have no alternative sources of food or money if there is a crop failure or their livestock dies. It is crucial to build a resilience in their systems against unexpected stresses notably from climate change. One method might be to increase the participation of the local farmers in value addition on their agricultural products. Some of the respondents (17.7%) generated some income by selling household wares such as groceries and toiletries in small shops. Still, they alluded to the fact that the viability and profitability of such enterprises were dependent on a good harvest in the area, which creates disposable income for the region (Table 2). During drought years, leading to crop failure and livestock deaths, other enterprises suffer significantly because most clients are farmers who depend on crop sales for disposable income to spend on household goods [32].

4.3. Pearl Millet Varieties Grown in the Study Areas

The farmers were cultivating a range of crops dominated by local varieties, common among subsistence farmers who often lack resources to buy seeds of improved varieties (Table 3). However, there were significant differences between the zones in terms of the pearl millet varieties cultivated. Varietal choices can vary due to localized challenges or opportunities. Farmers who have access to extension services, agricultural inputs, and novel information usually cultivate more improved cultivars than farmers who live in inaccessible areas, farther away from agro-dealers. The majority of farmers in the North Central zone cultivated improved cultivars (Table 3). The widespread adoption of improved cultivars in North Central could be attributed to several agricultural and livelihood projects established with the support of various non-governmental organisations (NGOs) working with farmers and more active extension services in this region than in the other regions.

Many farmers used local varieties by retaining seeds for the next cycle of planting. For example, superior panicles of local pearl millet varieties would be selected and conserved for seed for the next season at harvest time. The use of retained seed is common among smallholder farmers in Africa, as reported in Uganda, where 92% of farmers used local varieties [33], and in Nigeria, where 80% of farmers used farm-retained seed [17]. However, the cultivation of local varieties is one factor contributing to the low yields attained by most farmers in the study areas (Table 5).

Local varieties are often highly adapted to their agroecology, perform relatively well in marginal environments, with minimal inputs, and have been selected for cooking qualities appropriate for preparing traditional foods [34]. However, many have low yield potential and lack uniformity compared to improved cultivars bred for yield. The adoption of improved varieties is limited by seed costs and a lack of access to seed by the local farmers. In addition, the improved varieties often do not meet cooking quality criteria [16].

In Burkina Faso, the commercial seed industry for traditional crops such as sorghum and pearl millet is not well developed. This limits seed distribution to distant communities in rural areas. Low adoption rates of improved cultivars may also be related to skepticism among the farmers for varieties that they are not familiar with, and sometimes the susceptibility to pest/disease of some improved varieties, which do not have essential farmer preferred traits [22]. Local pearl millet varieties were mainly used in the North, South Central, West Central, and Central Plateau regions. The predominance of local varieties in these regions is due to a poorly developed seed system, especially for neglected crops such as pearl millet, and a poor extension service in these regions. Farmers in these regions have little access to information, extension services, and seed supply, which leaves them entirely dependent upon farm-saved seeds of local varieties.

Improved varieties such as IKMP 5 and MISARI, which are medium maturing and have a high yield potential of above 2.00 tons ha^{-1}, were widely cultivated in the North Central region, where access to seed and to extension services was better established. The farmer-preferred traits in pearl millet in Burkina Faso have been documented by

Drabo et al. [4]. They include large-sized panicles that are compact and non-bristled, large grain size, medium plant height, early maturity, medium panicle length, and wide panicle diameter. In any breeding program, it would be vital to integrate these traits during cultivar development to ensure a high adoption rate for newly improved varieties of pearl millet in the study areas. It has been noted that involving farmers and other stakeholders during variety design and development increases adoption rates of improved cultivars [33]. A PRA provides an opportunity to bridge the gap between farmers' expectations and breeders' objectives for cultivar development. Previously plant breeders were more focused on developing modern varieties with high productivity in optimal and intensively managed environments. In reality, most farmers operate in sub-optimal environments and select varieties specifically adapted for production under marginal growing environments, with particular quality traits [22]. Breeders must understand farmers' conditions and expectations to breed suitable cultivars with high adoption rates.

4.4. Pearl Millet Production

This study showed that farmers allocated between one and three hectares of land for pearl millet production (Table 4), which is common for subsistence farmers who have small landholdings passed on from a previous generation under the traditional ownership system of inheritance. The land tenure system is a major challenge for agricultural development in smallholder communities. The landholdings are too small for substantial production, and there is no formal security of tenure, limiting the incentives for capital investments. In Africa, small farms of less than 2 ha represent 80% of all farms [35], contributing to non-commercialization and little or no mechanization of farm operations.

The farmers continue to use traditional and often inefficient agricultural practices because there is no incentive to improve methods because yields are often too low to offset investment costs on smallholdings (Table 5). The majority of farmers (87%) use ancestral land, while the female farmers were cultivating land belonging to their marital family. The lack of land ownership rights among women is also a challenge for agricultural development. Single or widowed female farmers are the most disadvantaged in land ownership because they cannot own land and may be removed from the lands that they are farming if the husband/male figure dies [28]. This takes away their decision-making powers in terms of cropping practices and contribution to agricultural development. In terms of variety design and development, female farmers' preferences are often overridden by the dominant male farmers, who are the landowners. This also affects cultivar adoption because cultivars that male farmers prefer are adopted to a larger extent than those cultivars that incorporate traits preferred by female farmers. For instance, the adoption of improved maize varieties in Malawi by females was about 12% lower than their male counterparts [36], showing that women are often sidelined in varietal adoption.

4.5. Constraints to Pearl Millet Production

The farmers mentioned that damage from birds, drought stress, downy mildew disease, cantharid beetles, *S. hermonthica*, lack of improved varieties, lack of fertilisers, a shortage of labour at critical stages, a shortage of cash, a lack of equipment, and soil infertility were the most important challenges affecting pearl millet production in their environments. *S. hermonthica* infestation was ranked as the most important challenge to pearl millet production (Table 6). Almost all the farmers mentioned that they experience *S. hermonthica* infestation in their fields. A transact walk across the farms showed that *S. hermonthica* infestation was widespread. The lack of resources for *S. hermonthica* control, poor soil fertility, and drought contributed to the proliferation of the weed in this area. The abundance of *S. hermonthica* is attributed to its ability to produce many seeds that remain viable for many years, even under harsh conditions [37]. The *S. hermonthica* weed is prevalent in most semi-arid regions of sub-Saharan Africa, north of central Tanzania.

Ouedraogo et al. [38] found that *S. hermonthica* was a devastating weed in sorghum, while Dawud et al. [17] also reported that *S. hermonthica* was the main constraint affecting

pearl millet production in Nigeria. According to the respondents, *S. hermonthica* infestation can cause up to 80% yield loss in pearl millet, making it the most important constraint of pearl millet production. In some places, farmers ended up abandoning *S. hermonthica*-infested pearl millet fields or replaced the pearl millet with sorghum, which is more tolerant to *S. hermonthica* [4,33]. The other important constraint to pearl millet production is that most farmers have limited access to fertilizers. The soils in the study area are sandy with low fertility levels, which increase *S. hermonthica* infestation and result in poor crop yields. The Sahel and Sudano-Sahel regions account for some of the most degraded and infertile soils in sub-Sahara Africa [7,9]. As a result, most soils require supplemental fertilizers to increase plant-available nutrients. Although pearl millet is relatively resilient and has a dense root system, the highly degraded nature of the soils provides minimal nutrients to support proper plant growth, which significantly reduces achievable yields.

The lack of access to financial resources, land tenure policies, and high fertilizer costs exacerbate the shortage and lack of fertilizer inputs. Suboptimal fertilizer use among farmers in marginal environments has also been reported across Africa [33]. Land shortages, a lack of access to extension services, a lack of land tenure resulting in a lack of access to financial credit, and high labour costs have been reported previously as constraints to pearl millet production [17,33]. These challenges will affect even improved cultivars of pearl millet. Therefore, it is essential to develop the agricultural support system parallel to cultivar design and development. It will be futile to deploy improved cultivars into a poorly developed agriculture system where farmers lack ancillary support to boost their agricultural potential. For instance, the lack of adoption of improved cultivars has been attributed partially to the non-performance of some improved cultivars [39]. However, the inadequate support systems could be partly responsible for the poor performance of the improved cultivars. Thus, it is essential to improve the agricultural environment concurrently with variety design and development for the highest impact on crop productivity, food security, and rural farmer development.

4.6. S. hermonthica Infestation and Control Strategies

The farmers recognized that *S. hermonthica* was detrimental to plant growth and reduced yield potential. Therefore, they employed various measures to control the weed. The control measures included hand-weeding of *S. hermonthica* plant, weeding, and fertiliser application (Tables 7 and 8), which had varying success rates, depending on the extent of infestation and time of intervention. To a large extent, these methods helped reduce the *S. hermonthica* seed bank in the soil and conserve soil moisture, which increased yield potential. The methods were readily available to the farmers since they depend on family labour for these operations. Most farmers lack resources such as equipment or financial means to acquire pesticides, which leaves them with minimal options but to use hand weeding and hoeing. Crop rotations are not feasible due to limitations in the size of their landholdings and given the long life of *S. hermonthica* seeds. Most farmers own less than 3 ha of land, which is too small to allow effective crop rotation in controlling *S. hermonthica*. Previously, in Nigeria, 79% of farmers confirmed using hand weeding in *S. hermonthica* management, while only the remainder used hoeing and inorganic fertiliser application [17]. Inorganic fertilisers enhances pearl millet growth and development and its competitive ability against *Striga* infestation. Although these methods have been encouraged for many years, crop losses are still high due to a wide host range for *S. hermonthica* and the persistence of its seed in the soil for long periods [40]. Furthermore, these methods have many limitations, including being labour intensive and not managing underground *S. hermonthica* infestation of pearl millet roots before the parasitic plants emerge. Therefore, integrating breeding for *S. hermonthica* host resistance with other control measures, such as biological control, may offer a more viable solution to control *S. hermonthica* infestation [40].

5. Conclusions

Pearl millet is an important cereal crop adapted to arid and semi-arid environments. In Burkina Faso, pearl millet production is primarily constrained by *S. hermonthica* infestation, which is estimated to cause up to 80% yield losses. Many respondent farmers (68%) used local varieties with low yield potential, which are also highly susceptible to *S. hermonthica* infestation. Hand weeding and hoeing were the most commonly used methods to control *S. hermonthica,* although they are not very effective. The farmers lack resources such as labour, inorganic fertilizer, and finance to implement more effective strategies against S. hermonthica and boost agricultural productivity. Therefore, an integrated management approach, which would involve breeding for *S. hermonthica* host resistance combined with other control measures, may offer a better option for managing *S. hermonthica* infestation in Burkina Faso. It is also recommended that variety design and development for *S. hermonthica* resistance be coupled with agricultural development such as improved extension services, increased access to information, access to micro-finance, and developing functional agro-input systems. The provision of an enabling environment would draw maximum benefits from improved varieties of pearl millet. Local farmers perceived that landrace varieties have good eating quality and adaptation to adverse effects.

Author Contributions: A.R.: Methodology, data analysis, and Writing of the manuscript draft. H.S.: Recourses, Supervision, writing conceptualization, review, and editing. M.L.: Review and editing. I.D.: Coordinated data collection, review and editing. P.G.: Review and editing. I.M.: Writing, review and editing. E.M.: Writing, review and editing. A.I.T.S.: Review and editing. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest. The authors declare that they have no competing interests.

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