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Enhancing sesame production in West Africa's Sahel: a comprehensive insight into the cultivation of this untapped crop in Senegal and Mali

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Abstract

Background: West Africa's Sahel is characterized by a dry and hot climate with limited rainfall that impairs the production of several crops. Sesame is a resilient crop that is well suited to this environment. Unfortunately, there is a lack of data relative to the status of its production in West Africa. We made investigations in four major sesame-growing areas of Senegal and Mali, into the status of the crop's production, its agronomic practices, the challenges farmers face and their preferences concerning the traits that should be improved.

Results: A total of 256 sesame producers in 47 villages were interviewed using a semi-structured questionnaire. The results showed that sesame is a multi-ethnic crop and only 20% of the total fields owned by farmers were allocated to its cultivation. The yield and the seasonal production of sesame per farmer was quite weak showing that this crop is still a commodity grown on a small scale. Various cultivars were grown, and the most widely grown ones have considerable levels of oil (53–60.34%) and protein (18–21.89%) contents. In both countries, seed marketing was the main impediment the producers faced on account of a lack of reliable markets and of a considerable fluctuation in prices.

Conclusions: Overall, the sesame sector is still traditional but is progressively developing and sesame could become an important cash crop for smallholders in West Africa's Sahel. Research programs should target the release of the varieties with higher yield, a stronger resistance to drought, heat, diseases and pests, a good seed quality and improved plant architecture. This study represents the first insight into the sesame sector in West Africa's Sahel, and our findings may guide researchers and policy-makers to boost this sector for ensuring food security and the improvement of small-scale farmers' livelihood.

Keywords: Sesame, Crop production, Constraints, Food security, West Africa's Sahel

Background

In West Africa's Sahel, more agricultural areas are expected to get drier and hotter in the predicted scenario of climate change [1], resulting in unsuitable weather conditions to further the production of many crops. Nearly half the population in Sub-Saharan Africa lives on less than $1.25 a day although the potential for economic growth through agriculture is impressive [2]. Given the overwhelming importance of agriculture for rural livelihoods in West African Sahel region, it is crucial to prioritize and encourage the production of crops that are able to survive and give high yields in an increasingly harsh environment [3].

In this context, sesame (*Sesamum indicum* L.) is undoubtedly one of the resilient crops best-suited to the West African Sahel's arid climate. It is considered as one of the most ancient oilseed crops [4], and it is cultivated in marginal lands and inclement areas under frequent droughts and/or high heat [5]. Africa accounts for more than 40% of the world's sesame seed production with

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Sudan as the leading producer country on the continent [6]. Its seeds have one of the highest oil contents (~ 55%) among major oilseed crops [7]. Beyond the traditional use of direct consumption, sesame seeds have diverse applications [8]. The potentially beneficial effects of sesame on human health, because of the presence of natural antioxidants such as sesamin, sesamol and sesamolin, have recently prompted renewed interest in this ancient crop [9, 10]. While the production of many crops has declined over the last decade in West Africa's Sahel, the traded quantity of sesame has more than doubled in this area, showing growing interest in the crop [11]. Indeed, sesame is able to provide incomes in this area where the options are quite limited and thus represents an alternative cash crop for smallholders particularly women. It, therefore, plays a key role in sustaining agriculture in poorer areas. Moreover, the world's demand for sesame seeds is rapidly increasing and the West African sesame seed is particularly appreciated because it is largely produced without chemicals.

Unfortunately, sesame is an understudied crop in West Africa's Sahel [12]. There are no scientific data about the status of its production in this area, and few research programs are focused on this untapped crop [13]. Therefore, there are many knowledge gaps in the West African sesame production landscape that need to be addressed: What is the socio-economic context of sesame production in West Africa's Sahel? What are the agronomic practices of sesame cultivation and what are the market systems? What are the major constraints to its production? What are the farmer's perceptions and expectations for a better optimization of sesame production in West Africa's Sahel? How could research programs help to boost sesame productivity?

The objective of this study was both to investigate the socio-economic context of sesame production in West Africa's Sahel and to uncover the different constraints affecting its emergence. Our investigation should bring useful and relevant information for research programs and for the development of policies in view of optimizing sesame production and improving farmers' livelihoods in West Africa's Sahel.

Methods

Study area and selection of the surveyed sites

This study was conducted in two Sahelian countries, namely Senegal (14°40′N17°25′W) and Mali (12°39′N8°9′W), which are located in West Africa. In each country, two important sesame-growing regions were selected for the survey.

Mali

The Segou region (13°22′5″N5°16′24″W) covers 64,821 km^2 and is located in south-central part of Mali. It is a strategic and cosmopolitan area for the country as it constitutes the transit area between the northern part and the southern part, bordering Mauritania and Burkina Faso, respectively. The region is characterized by a semi-arid climate with two seasons: a rainy season and a dry season. The average yearly rainfall is about 513 mm. Agriculture is the most important activity in this area as Segou produces most of Mali's national food, including sedentary cattle farming [14, 15]. The major crops grown are cereals (sorghum, corn, fonio, rice), legumes and fruit (watermelon).

The Koulikoro region (13°56′41″N 7°37′28″W) covers 90,210 km^2 and is located in the Western part of Mali. It is part of the tropical area with a rainy season and a dry season. The vegetation pattern shows a decreasing northward humidity gradient as a result of the joint effects of the different climatic zones and the soils: Sahelian zone in the north (150–550 mm rainfall), the Sudanian zone in the centre (550–1150 mm rainfall) and the pre-Guinean zone in the southern part (more than 1150 mm rainfall). The population in these regions consists of diverse ethnic groups and agriculture is the most important economic activity [16]. Different crops are cultivated including cereals (sorghum, millet, maize, and rice), legumes (peanut, bean etc.) as well as cash crops (cotton, sesame etc.).

Five villages in Segou (*Boua-were*, *Tongo*, *Minankofa*, *N'gakoro* and *Kondogola*) and in Koulikoro (*Kalifabougou*, *Gouana*, *Tiendo*, *Kosa* and *Gountou*) were selected for this study (Fig. 1).

Senegal

The Sine-saloum region or the peanut basin (14°11′N16°15′W) is located in the East of Senegal encompassing 24,000 km^2 and includes the localities of Kaffrine, Kaolack and Fatick. In this region, sesame is widely cultivated mainly in the southern part. The climate is of a Sudano-Sahelian type with an annual rainfall lower than 700 mm. The "*Wolof*" ethnic group is the most predominant. Agriculture is one of the major economic activities, and millet is the prominent cereal grown in this area followed by maize.

Located in the southern part of Senegal near the Gambia, Casamance (13°0′54″N15°19′4″W) is a big region which covers 28,350 km^2 (approximately 1/7 of total Senegal's land) and includes Sedhiou, Kolda and Ziguinchor localities. The climate is a sub-Guinean type with an ample rainfall between 800 and 1300 mm, and the area is covered by dense vegetation. The major ethnic group in Sedhiou locality is the "Mandingue" and the main crops produced are rice, maize, fonio, groundnut, cotton and sesame, whereas in Kolda locality, the ethnic group "Peulh" is the most represented and is devoted to agro-pastoralism. The main crops grown in this area are maize, sorghum, rice, cotton and sesame [17].

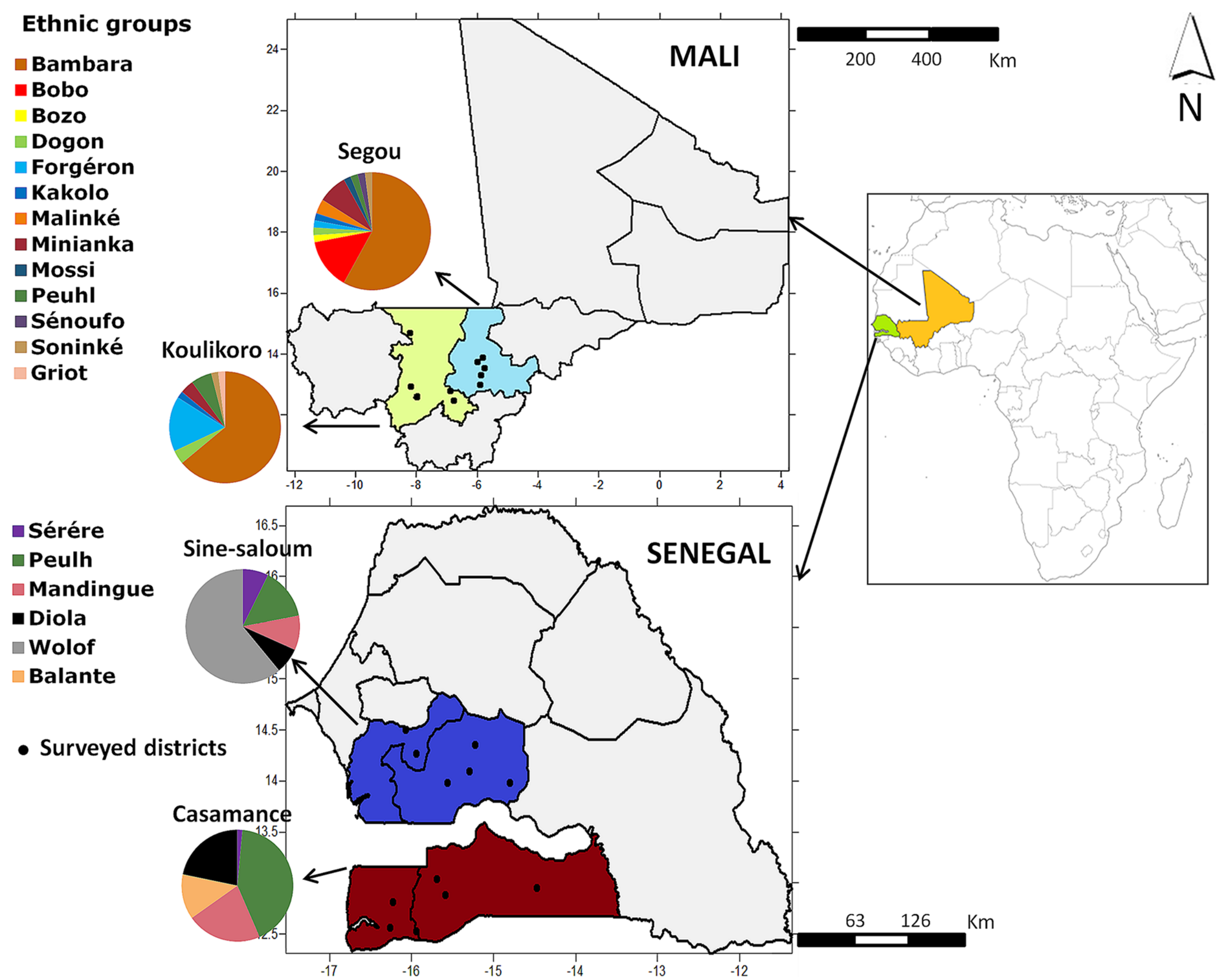

Fig. 1 Map of Senegal and Mali showing the selected regions and districts selected for the study along with the different ethnic groups encountered

Twenty-three villages in Casamance (*Thies-pakane, Tenghori, Tambacouda, Soutouyel, Saré-koutayel, Saré-hamidou, Saré-amadou-diallo, Saoundé-popodié, Safane, Medina-souané, Médina-sadio, Kounaya-mankagne, Kégnéto, Kandiadiou, Kamboua, Kabaar, Faoune, Darou-salam, Boydo-malick-counda, Boutoupa-kamara, Boutolate, Bani* and *Bambadala*) and 14 villages in Sine-saloum (*Tewrou-mbeyenne, Niambour1, Ngettou-farba, Mbelbouck, Sahm, Sagna, Immidine, Dianké-souf, Mbaye-mbaye, Pirame, Patoulou-peulh, Diam-diam, Palangué-manding* and *Kalbirom*) were selected for this study (Fig. 1).

Data collection

A preliminary survey was carried out in each region with local extension service agents during April–May 2016 to identify villages to be investigated. The villages where sesame is widely produced were selected, and the more distant ones were retained in order to cover a wide geographic area in each region.

The sampling of farmers per village was not totally random: we included 30% of women in the participants as well as young people and adults. The participants included were individuals who have a good experience in sesame cultivation and have been fully identified, thanks to village chiefs' help. The questionnaire was pre-tested in two villages (not included in this study) from each region and adjusted prior to data collection.

Data collection was conducted in May–August 2016 and in total, 146 farmers (76 in Koulikoro and 70 in Segou) were surveyed in Mali whereas in Senegal, 110 farmers (69 in Casamance and 41 in Sine-saloum) were surveyed.

After obtaining their prior verbal informed consent, each participant was interviewed with a semi-structured questionnaire.

The questionnaire, comprising 71 items, was designed to obtain information about (1) the socio-demographic characteristics of the participants (name, age, sex, ethnic group, origin, educational attainment, contact, household size, principal and secondary activities, land owned etc.), (2) the agronomic practices (practices refer to the full range of field level management strategies, technologies and methods employed by the farmers) for sesame production (the varieties grown and their origins, agricultural practices, the type of ploughing, the use of pesticides and fertilizers, the period of harvest, the time and place of drying, conservation etc.), (3) the processing, the valorization and the market system, (4) the constraints and the farmers' preference for the most important traits in sesame to be improved. Some sesame cultivars samples were collected from the different participants for future work.

Data analysis

Statistical analysis

The survey data were doubled-checked and inputted using Excel 2007. Thereafter, we used a range of descriptive statistics to characterize and summarize the farmers' responses in each region. Categorical variables (items) were expressed as frequencies and percentages. To test whether some items varied significantly across the regions, we performed the one-way analysis of variance (ANOVA) with the Minitab® 16 software. The partitioning of the means was made with the Tukey test at a 5% probability level. To identify the most important traits in sesame to be improved and the main constraints the farmers faced during sesame production, we defined the main variables (items) based on the preliminary survey and asked the farmers to rank them. Data were analysed by adopting Garrett's ranking technique [18]. The advantage of this technique compared to simple frequency distribution is that items are arranged based on their importance from the point of view of the farmers.

Garrett's formula for converting ranks into percentage is:

$$\text{Percentile position} = \frac{100 \times (Rij - 0.5)}{Nj}$$

where R_{ij} = rank given for ith item by jth individual; N_j = number of item ranked by jth individual.

The percentile position of each rank was converted into scores referring to the table given by Garrett [18]. For each item, the scores of each respondent were added up and divided by the total number of the respondents for whom the scores were added. These mean scores for all the items were arranged in descending order; the items were ranked accordingly and the most important ones identified.

Sesame seed sample preparation and biochemical analysis

The widely cultivated sesame varieties from each of the four regions were selected for seed biochemical analyses. Dust and stones were manually removed from the seeds. All mature and well-rounded seeds were kept for the analysis. Approximately 5 g of seed samples were manually ground to fine powder with liquid nitrogen. Seed oil was estimated by the conventional Soxhlet method using petroleum ether as the extraction solvent [19]. The total protein content was determined using the Kjeldahl method according to AOAC [20]. Each sample was tested in triplicate.

Results

Socio-demographic characteristics

In total, we interviewed 256 sesame growers in four regions of Senegal and Mali. The age of the farmers surveyed varied from 22 to 76 years old, averaging 47 years old with 10% < 30 years old, 47% between 30 − 50 years old and 43% > 50 years old (Table 1). Most of farmers interviewed had basic attainments and nearly 70% of them were native to their villages. In both Senegal and Mali, diverse ethnic groups were encountered. The Bambara was the most represented ethnic group (60% of respondents) found in the two regions surveyed in Mali whereas in Senegal, the "Peulh", the "Wolof" and the "Diola" were the most represented ethnic groups surveyed (Fig. 1). Crop production was the respondents' main occupation, and animal farming, trading and craft-making among others were some of the secondary activities. More than half of the farmers surveyed in each region stated that they were members of farmer's organizations.

Comparative analysis of sesame production in the four regions

Area under sesame cultivation and characteristics of the main cultivars grown

About 20% of the total agriculture lands owned by a farmer were allocated to sesame production (Fig. 2). In the study area, very few farmers grow only sesame. Sesame fields ranged from 0.2 to 8 ha with an average of 1.4 ha per farmer. In general, most of the farmers were small-scale farmers operating on small farms. The average areas under sesame cultivation per farmer varied significantly across the regions surveyed ($p = 0.001$). The farmers from the Segou region of Mali had the largest sesame farms (1.55 ha), whereas those from Casamance had the smallest farms (0.91 ha) (Fig. 3).

Table 1 Socio-demographic characteristics of participants (*n* = 256). Values are percentage

Characteristics	Segou (*n* = 70)	Koulikoro (*n* = 76)	Casamance (*n* = 69)	Sine-saloum (*n* = 41)
Genders				
Men	70	70	68	61
Women	30	30	32	39
< 30 years	0	6	30	2
30–50 years	56	46	36	51
> 50 years	44	48	34	46
Educational attainment				
None	28	26	36	54
Basic learning	44	54	36	37
Primary school	18	14	16	7
Middle school	6	4	10	2
High school	2	2	1	0
Technical training	2	0	1	0
Origins				
Native	70	62	77	68
Immigrant	30	38	23	23

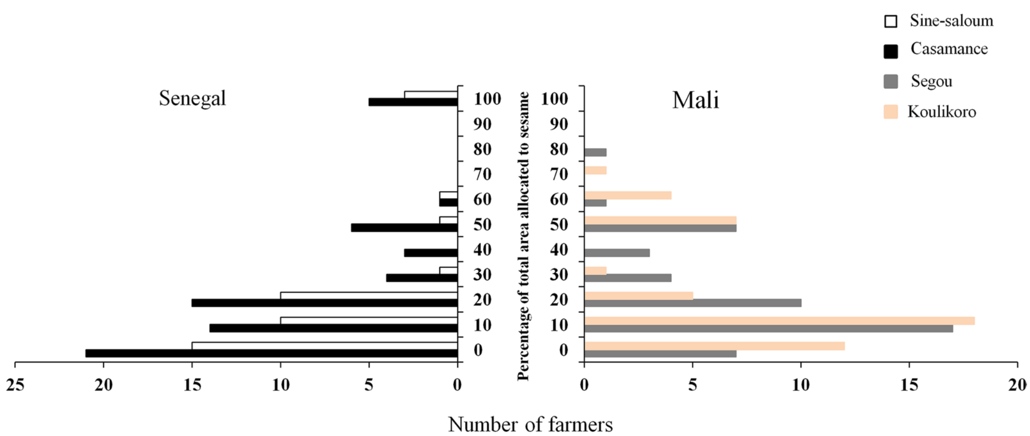

Fig. 2 Percentage of total lands allocated to sesame cultivation in the four regions

Different sesame cultivars were grown by farmers in each region, but little variability was observed across regions within the same country. In Senegal, a total of five cultivars including *Primoca*, *32–15*, *Blanche*, *Brune* and *Noire* were identified in the two areas. Among these cultivars, *Primoca* and *32–15* were the most widely grown. In Mali, we itemized nine cultivars including *Bénai-ba*, *Bénai-dièma*, *PorouII*, *Bénai-kourouni*, *Nassoubani*, *BanambaII*, *S42*, *Bénai-fin* and *Bénai-bléni*. The cultivar *S42* was the main cultivar in the Koulikoro region, whereas *Nassoubani* was the widely grown cultivar in Segou. Analysing the main cultivars' seed component revealed that the cultivars from Senegal, *Primoca* (brown seed coat colour) and *32–15* (white seed coat colour) had similar oil and protein contents (Fig. 4a). However, there was a significant difference between the two main cultivars from Mali ($p < 0.05$). *S42* (white-lighted seed coat colour) has high oil content and low protein content, while *Nassoubani* (white seed coat colour) is protein-rich with only 53% oil content (Fig. 4a).

Figure 4b presents the origin of the seeds used by the farmers per regions. Farmers from Mali principally acquired seeds from NGOs, Farmer organizations and conventional research institutes, whereas in Senegal, the farmers tend to purchase from markets or produce their own seeds.

Agronomic practices

Sesame is mainly grown in monoculture in the four regions (Table 2). Some farmers reported practicing

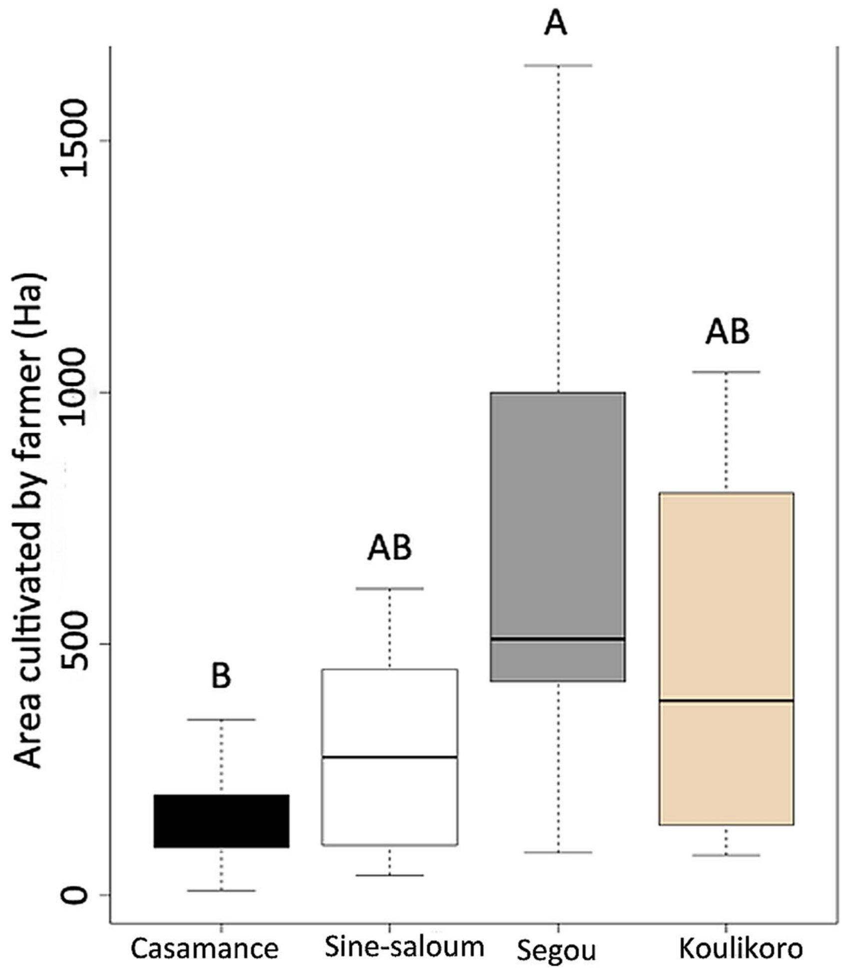

Fig. 3 Average area under sesame cultivation per farmer in the four regions. Boxes with different letters are significantly different

mixed cultivation with other crops such as sorghum and millet. Sesame was commonly grown on ridges. In contrast to Senegal where field ploughing is predominantly mechanized, 90% of the farmers from the two regions surveyed in Mali ploughed their field manually (Table 2). However, sesame is sown in rows by most of the farmers in the four regions. In addition, more than half of the farmers we interviewed stated that they used a sowing device in the 4 areas. Sesame is sown in July–August in the 2 regions of Senegal, but some farmers sow early in June or later in September. In Mali, the sowing date of sesame is mainly in July; however, some early and late sowing can be observed in June and August, respectively (Fig. 5a). There is no significant difference between the number of farmers who apply pesticides ($p = 0.792$) and those who use fertilizers ($p = 0.571$) on their fields across the regions. Indeed, sesame is produced mostly without pesticides and fertilizers. Interestingly, most use organic materials applied in the form of manure or compost to the crops to boost the yield.

Harvesting–post-harvest and conservation

In Mali, sesame is mainly harvested manually in October, whereas the harvesting period in Senegal occurs during the period of November–December (Fig. 5b). After harvesting, plants are either dried directly in the fields or taken home for drying (Table 2). Drying time varied significantly across the regions ($p = 0.001$) with approximately 29 days in Segou, 22 days in Koulikoro, 21 days in Casamance and 20 days in Sine-saloum. The seeds are principally stored in 50 kg jute bags and conserved in warehouses (Table 2).

Sesame production and seed yield

The total production of sesame per farmer seasonally ranged from 3 to 3162 kg with an average production of

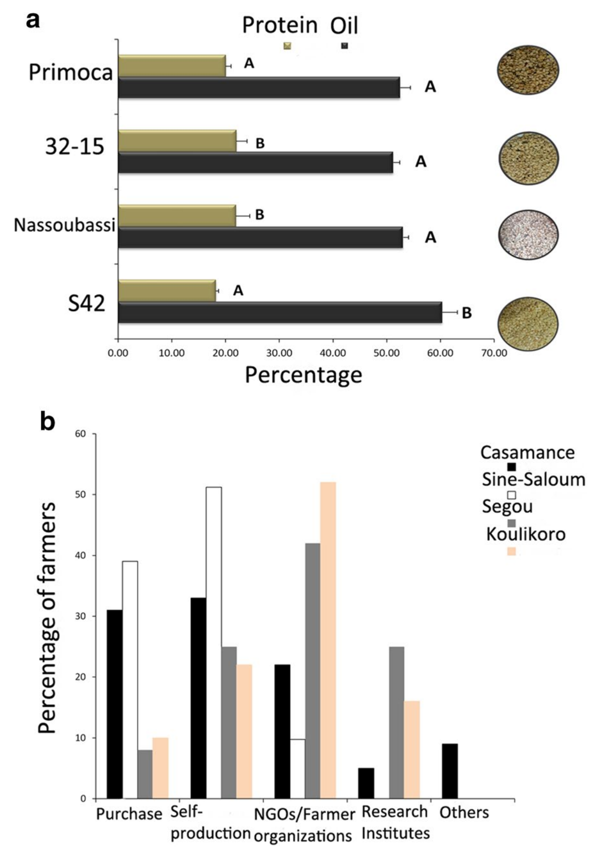

Fig. 4 Cultivars grown and their characteristics. **a** Oil and protein contents of the four major cultivars grown in all the regions. **b** Origin of the seeds used by farmers. Bars for oil content and protein contents according to the cultivars with different letters are significantly different

448 kg. There was a significant difference of sesame production per farmer across the four regions ($p = 0.001$). The farmers in Segou had the highest sesame production (765.8 kg), while farmers from Casamance exhibited the lowest production level (193 kg) (Fig. 6a). Concerning the seed yield, it also varied significantly across the surveyed regions ($p = 0.001$) and ranged from 50 to 1500 kg/ha with an average yield of 298 kg/ha. The Segou region presented the highest seed yield (417.3 kg/ha), whereas the lowest seed yield was observed in Sine-saloum (249.5 kg/ha) (Fig. 6b). In general, sesame seed yield in Senegal (258.4 kg/ha) was lower than in Mali (378.4 kg/ha) ($p = 0001$).

Valorization, marketing and market systems

Sesame is essentially a cash crop as most of the respondents reported that they grow sesame for commercial purposes (Table 2). The crop is cultivated for its seed, which is the main product that is subsequently sold.

Table 2 Summary of variables used in this study

Variables	Koulikoro	Segou	Casamance	Sine-saloum
Cultural practice				
Monoculture	94	64	97	95
Mixed cultivation	6	36	3	5
Field ploughing type				
Ridge plough	96	96	95	67
Flat plough	4	4	5	33
Means of Ploughing				
Manual	90	90	33	7
Mechanized	10	10	67	93
Sowing period				
June	10	18	3	48
July	24	80	15	52
August	65	2	67	
September	1		15	
Means of sowing				
Mechanized	56	76	54	84
Manual	44	24	46	16
Use of fertilizers				
Yes	14	22	15	13
No	86	78	85	87
Use of pesticides				
Yes	7	9	8	22
No	93	91	92	78
Harvest period				
September	5	20		18
October	95	80	13	22
November			37	45
December			42	15
Janvier			8	
Seed drying area				
Home	20	30	19	
Field	80	70	81	93
Other				7
Means of conservation				
Jute bag	98	98	100	98
Large basin	2	2		2
Place of storage				
Room	22	34	84	63
Warehouse	78	66	16	37
Purpose of sesame production				
For sale	100	90	92	85
Consumption		10	8	15
Selling channels				
Field brokers	56	40	85	36
Village traders	44	60	15	64
Mode of selling				
Individual	100	72	71	93
Group		28	29	7

Values are percentage

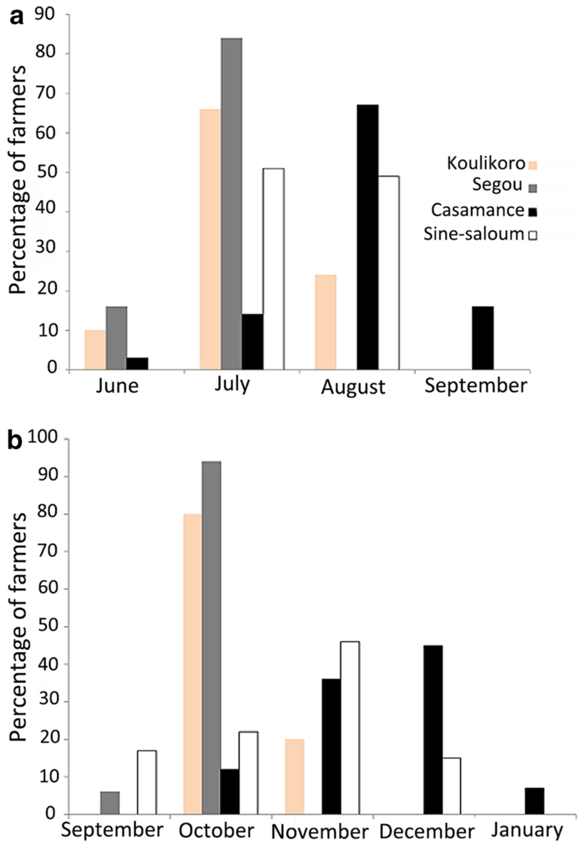

Fig. 5 Sowing and harvest periods of sesame in the four regions. **a** Sowing period. **b** Harvest period

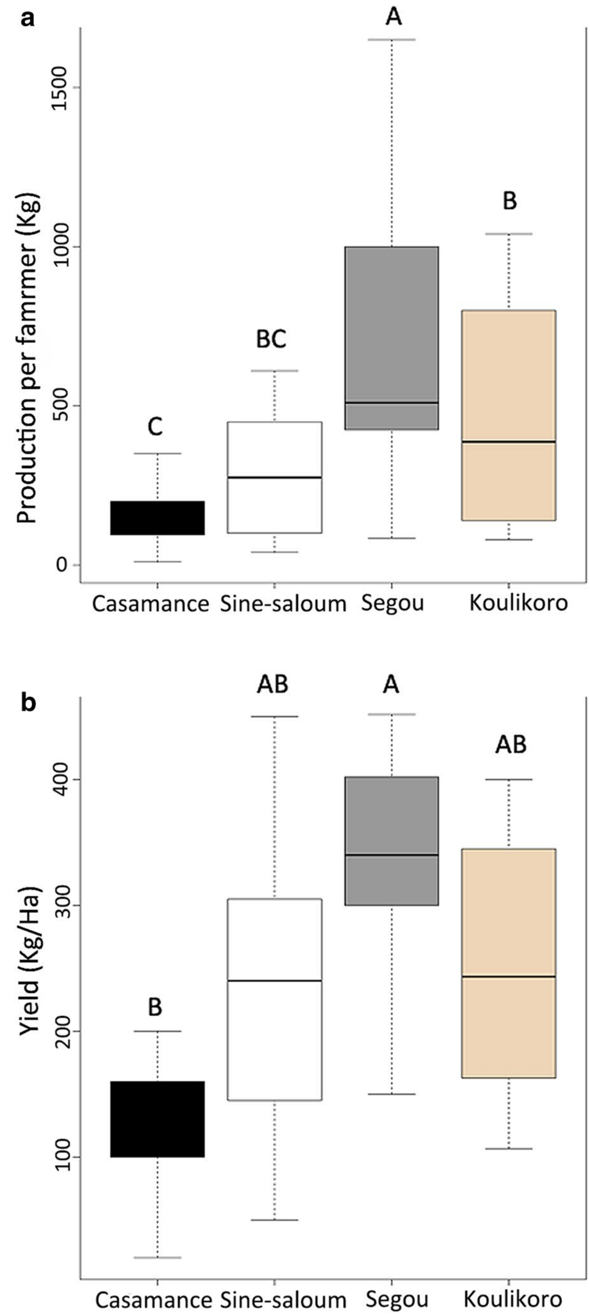

Fig. 6 Sesame production and seed yield in the four regions. **a** Sesame production. **b** Sesame seed yield. Boxes with different letters are significantly different

Local processing of sesame seeds into oil is rudimentary and limited. Some farmers reported that they also used other parts of the plant such as the dry matter for cattle feeding. The dry matter is also used for soap production, as compost manures and for the production of potash which is a cooking ingredient widely used in West Africa by women (Fig. 7).

To sell their sesame seed stocks, the farmers may choose to liaise directly with the field brokers or take their products to the village traders in the local markets. In general, farmers tended to sell their stocks to field brokers (Table 2). Furthermore, they predominantly market their seed stocks individually and not through farmer groups or organizations. Sesame market prices (mainly farm gate prices) varied significantly across the regions surveyed ($p = 0.001$). The highest price was observed in Sine-saloum (0.79$/kg, considering 1$ equals 500FCFA), whereas sesame was sold at its lowest price in Koulikoro (0.58$/kg) (Fig. 8a). Similarly, seasonal incomes earned by the farmers from sesame production varied significantly among the regions surveyed ($p = 0.001$). The highest income from sesame production was observed in Segou (496$/ha), whereas the lowest was estimated to have been earned by some farmers in Casamance (116$/ha) (Fig. 8b). Globally, comparing the two countries, we found that the farmers from Mali earned significantly higher incomes from sesame production (more than double) than their counterparts from Senegal ($p = 0.001$).

Fig. 7 Sesame plant by-products valorization. **a** Dry matter of sesame used as cattle feed. **b** Sesame-produced potash. **c** Sesame-made soap. **d**, **e** Different cakes made from sesame seeds

Constraints faced by sesame producers in each region

During the survey, the farmers in the four areas listed 13 major constraints. Using the Garrett's ranking technique, we identified the most important ones in each region (Table 3). Sesame seed marketing was reported as the most pressing constraint in all the regions. Marketing problems included the low market price and its fluctuations, the difficulty to find buyers, and other factors. Beyond this main constraint, the remaining impediments faced by the sesame producers varied from one region to another. In Segou for instance, the decline in soil fertility, the problem of access to the land and drought constituted some other important constraints. In Koulikoro, the sesame producers also have to cope with decline in soil fertility and access to land problems, but they further complained about the free-roaming livestock destroying

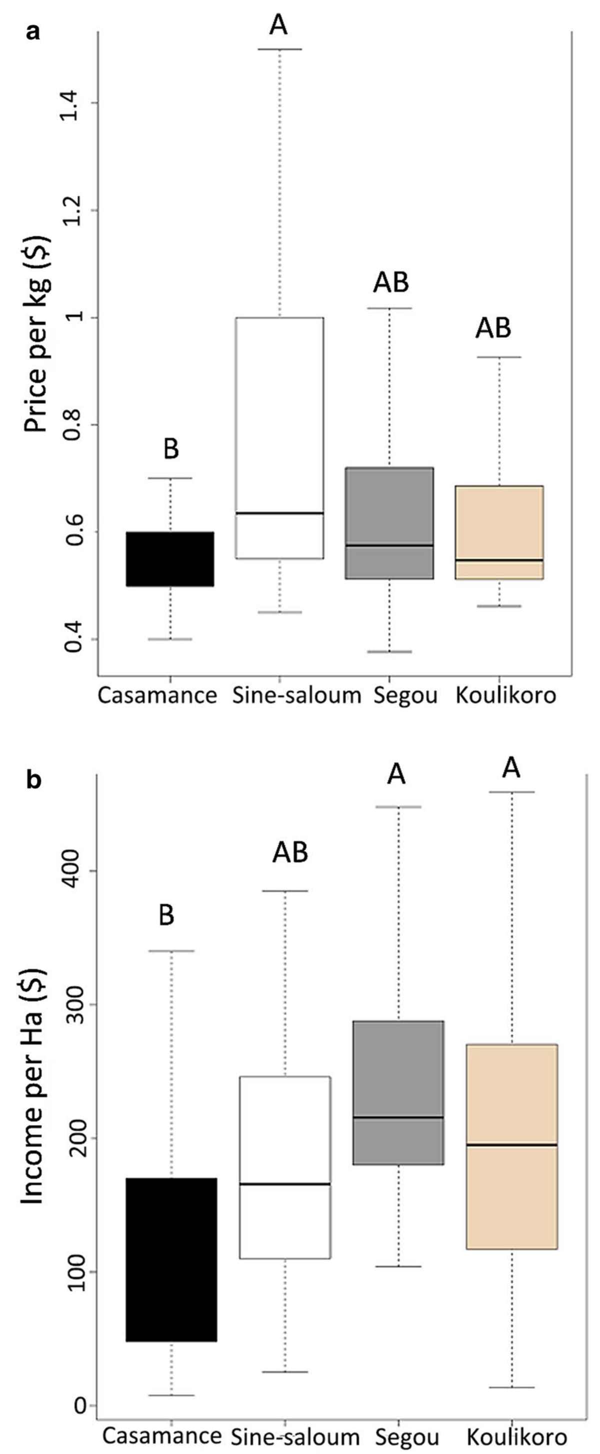

Fig. 8 Sesame marketing. **a** Sesame average market prices ($/kg) in the four regions. **b** Average seasonal incomes per farmer per Ha in the four regions. Boxes with different letters are significantly different

crops. In Senegal, sesame producers are mainly faced with insufficient agricultural implements, a lack of technical assistance and insufficient agricultural inputs.

Farmers' preference for the sesame traits that need to be improved

Based on the farmer's preference for a sesame variety ideotype, we identified 8 main traits in all the regions (Table 4). High seed yield is by far the most important trait that farmers in all the 4 surveyed areas concurred to. In the two regions of Mali, sesame producers also preferred short cycle time, good seed quality (high oil content, high seed weight, big size, and white seed coat colour), and drought resistance as their main criteria for the sesame variety ideotype. In Senegal, farmers preferred the shorter cycle time, good architecture (multi-branching type, high height), drought resistance and good seed quality. For the farmers, flooding affecting the seed germination which sometimes occurred after sowing as a result of heavy rains was not an overwhelming issue. In addition, sesame plants also suffer from diseases and pest attacks, but they think that the crop is quite a hardy and robust plant which can adequately bear all such constraints.

Discussion

Status of sesame production in West Africa Sahel

This study investigated the status of sesame production in four regions in Mali and Senegal, two important producing countries in West Africa's Sahel. Our aim was to get insight into this sector and reveal both the constraints and the farmers' expectations so as to boost cultivation of this crop. We discovered that sesame is a multi-ethnic crop. Nearly all the encountered ethnic groups including the major and minor ones in the surveyed regions were involved in sesame production. This suggests that sesame may have been an ancient crop in this area of Africa and is widely adopted by all classes in the local population. We found that women were actively involved in sesame production, but they owned smaller farms as compared to men [21]. The first reason for sesame adoption is its relatively simple cultivation owing to the fact that it can grow in different soils, does not need irrigation, is capable of withstanding high temperatures, is a subsistence plant, is not labour intensive, and fits in well with crop rotation schemes [5, 22]. Moreover, it is a very rewarding crop because of low production cost and high price, which makes it tailored to the small-scale poor farmers of West Africa's Sahel.

Only 20% of farmers' total fields were allocated to sesame production. This suggests that sesame is still behind other important crops that are used as staple foods such as sorghum, maize, rice, millet etc. Indeed, sesame is completely export-oriented and is rivalling cotton production as it could be an environmental-friendly and cost-effective alternative crop. In contrast to cotton, sesame has the advantage of being paid for upon collection,

Table 3 Constraints faced by sesame producers ranked using Garrett's ranking technique

Constraints	Segou ($n = 70$)			Koulikoro ($n = 76$)			Casamance ($n = 69$)			Sine-saloum ($n = 41$)		
	Total score	Mean score	Rank	Total score	Mean score	Rank	Total score	Mean score	Rank	Total score	Mean score	Rank
Decline in soil fertility	1632	23	III	1896	25	II	69	1	XIII	83	2	IX
Access to land	1746	25	II	1273	17	IV	92	1	XII	100	2	VII
Capsule dehiscence	152	2	IX	116	2	XI	100	1	XI	50	1	X
Oil extraction	156	2	VIII	91	1	XII	101	1	X	218	5	V
Free-roaming livestock	1208	17	V	1593	21	III	104	2	IX	45	1	XI
Drought	1566	22	IV	785	10	V	106	2	VIII	37	1	XII
Diseases	1085	16	VI	560	7	VI	178	3	VII	91	2	VIII
Floods	460	7	VII	283	4	VII	309	4	VI	23	1	XIII
Problem of seed storage	49	1	XIII	56	1	XIII	314	5	V	124	3	VI
Insufficient agricultural inputs	88	1	XII	180	2	VIII	533	8	IV	1010	25	II
Lack of technical assistance	121	2	X	150	2	IX	693	10	III	564	14	IV
Marketing problems	2249	32	I	2201	29	I	1660	24	II	1267	31	I
Insufficient agricultural implements	111	2	XI	120	2	X	2273	33	I	946	23	III

Table 4 Farmers' preference for the sesame traits that need to be improved

Traits	Segou ($n = 70$)			Koulikoro ($n = 76$)			Casamance ($n = 69$)			Sine-saloum ($n = 41$)		
	Total score	Mean score	Rank	Total score	Mean score	Rank	Total score	Mean score	Rank	Total score	Mean score	Rank
Short cycle time	2249	32	II	2537	33	II	1955	28	II	644	16	III
High yield	2991	43	I	3015	40	I	3524	51	I	2099	51	I
Good seed quality	1250	18	III	891	12	III	250	4	V	199	5	IV
Drought resistance	630	9	IV	445	6	IV	680	10	IV	86	2	V
Disease and pest resistance	124	2	VI	160	2	VI	200	3	VI	23	1	VII
Flood resistance	111	2	VII	140	2	VII	69	1	VII	69	2	VI
Good architecture	500	8	V	315	4	V	1117	16	III	1142	28	II

which is extremely important in improving the poorer farmers' livelihoods [23]. The local market is still rudimentary and virtually dominated by women in processing the end-products.

Several cultivars are grown locally by the farmers and may hold important genetic diversity [12]. Biochemical analyses of the seed components in the most important cultivars grown in each region showed that sesame from West Africa has valuable levels of oil and protein. Cultivar *S42* grown in Mali is by far the best genotype in terms of seed quality and is also widely grown in other countries like Burkina Faso, Niger and Chad. More information is needed on the West African sesame germplasm seed quality as this can provide guidelines for obtaining high-quality nutritional breeds and adding marketing value to the crop.

Sesame cultivation is gradually becoming modernized. Once grown in association with other crops, sesame is nowadays grown in monoculture and is planted in rows with a sowing device. This facilitates crop husbandry practices such as weeding and thinning that are essential for yield optimization. However, the use of external inputs is still very modest in sesame cultivation in West Africa's Sahel and there is still a lot of room for intensification. For example, using high-quality seeds is essential for sesame productivity's improvement as it guarantees a good germination rate and a higher yield potential. Therefore, such conventional centres as NGOs, Research Institutes or commercial seed multipliers must further work in connection with the local farmers especially in Senegal to supply good quality seeds. In addition, pesticides and fertilizers are rarely used by the farmers for sesame production. According to Ojikpong et al. [24], an incremental application of NPK fertilizer up to 150 kg/ha significantly increases the average sesame seed yield. So far, there is no compound fertilizer that has been tailored for sesame production in West Africa's Sahel; thus, further research for the formulation of a compound fertilizer optimized for sesame production in this area is required.

Overall, sesame is still a small-scale farmer commodity in this area with a very weak yield (298 kg/ha) as compared to other sesame-growing areas such as Northern Uganda (673 kg/ha, [23]), Vietnam (500 kg/ha, [25]) and Ethiopia (735 kg/ha, [11]). Although sesame production is profitable for the farmers at this level of yield, there are possibilities for further improvement. Yield improvement will augment their total revenues and will contribute to the sesame sector's long-term competitiveness.

Sesame sector is better organized in Mali

The farmers from Mali receive valuable support from local NGOs and research institutes in terms of technical assistance including the supply of good quality seeds, crop husbandry, the supply of inputs, training and general assistance during seed marketing. This positively impacts on the seasonal production and yield of sesame in Mali. Consequently, a farmer's total income from sesame production is higher in Mali than in Senegal. This implies that the sesame sector is better organized in Mali which should lead to the rapid development of the sector. Our results were well corroborated by the conclusions of Gildemacher et al. [21] who reported that the area dedicated to sesame production increased 2.5 times between 2000 and 2010 in Mali. It is thus crucial to firstly strengthen collaboration between the sesame sector's stakeholders, and then with the oversight bodies. In addition, the remarkable achievements in the development of the sesame sector over the last decade in Burkina Faso may be a textbook case for the remaining producer countries in West Africa's Sahel [26].

Sesame marketing, an important challenge for the sector

Many constraints were raised by the sesame producers in the surveyed area but seed marketing is by far the most important impediment. The problem is basically the lack of reliable markets for their stock. Indeed, sesame producers have become more price takers than price makers. Since sesame is mainly sold directly and fragmentally to field brokers who operate individually, their product is always under their control. There are no institutional arrangements to fix the market price, as it fluctuates considerably and farmers have no option but to let go of their product more often at low prices. There is therefore an urgent necessity to strengthen sesame value chains and provide reliable market information to facilitate smallholder's market participation. Furthermore, organized group marketing could be a strategy to avoid considerable price fluctuation. Collective action would help coordinate production and marketing functions. Unfortunately, our study was conducted during a period when it was impossible to have complete insight into the value chain. Therefore, additional socio-economic surveys from December to February (the active period for sesame marketing) will help understand sesame marketing systems better and propose genuine solution schemes for this issue.

What can be the contributions of research programs in West Africa's Sahel?

Sesame is an under-rated crop in West Africa's Sahel [27]. Few research programs are focusing on this untapped crop, and little is known about the potential of the sesame cultivars grown locally. The farmers have identified the high seed yield as the most important trait in sesame to be improved. High yield varieties or commercial lines are not yet available for the farmers in this area. Similarly as for most cultivated crops, the main objective for growing sesame is for high seed yield and quality [28]. Sesame yields in West Africa's Sahel are very low, and this results from a combination of factors including abiotic stress such as drought and heat, inappropriate crop husbandry, low seed quality, pest and diseases as well as socio-cultural and socio-economic factors. Sesame seed yield per plant is considered to be composed of three components, i.e., the number of capsules per plant, the number of seed per capsule and 1000 seed weight. Some other factors, including plant height, length of capsules and axis height of the first capsule, were found to be strongly associated with sesame' grain yield [29, 30]. Some candidate genes, QTLs and associated molecular markers for yield-related traits, have been described previously and could contribute to efficiently improve the West African sesame seed yield through molecular breeding [1, 10, 31, 32].

The remaining traits listed by the sesame producers (short cycle duration, good seed quality, drought resistance, disease and pest resistance, resistance to flooding, good architecture), all contribute to high yields. For instance, sesame's short cycle time is important for avoiding pest attacks, soil moisture depletion and weathering on the open capsules, hence enabling farmers to harvest as soon as possible without incurring significant yield penalty [33, 34]. Moreover, improving drought tolerance and thermotolerance in sesame genotypes should be one of the major objectives of sesame breeding programs mainly in drought-prone areas like West Africa's Sahel [10, 35–37]. Sesame biotic constraints have been widely neglected in this area, but observations show that, with the increasing of the crop acreage, diseases and pest attacks are becoming very serious. Therefore, future studies should focus on this major issue in order to reduce the risks and damages on sesame productivity. Seed quality traits, according to farmers, include high oil yield and seed components, white seed coat colour and big seed size. There are no data about the seed quality of the sesame cultivars grown in West Africa's Sahel, although growing higher oil yielding and nutritional sesame varieties could bring outright premium prices in the market system. Hence, it is essential to assess the seed quality traits' variability in locally grown cultivars. Many genes and QTLs related to oil yield and seed quality were published and could valuably serve in breeding high-oil-yielding sesame varieties in West Africa's Sahel [1, 38–40].

In summary, research efforts in West Africa's Sahel should focus on:

- collecting cultivars grown in different areas of West Africa's Sahel and other growing areas in West Africa with the aim of constituting the first sesame gene bank for this area.
- understanding what is the ideal sesame phenotype for the West Africa's Sahel environment and exploiting the diversity available in sesame germplasm for its improvement towards high yield, short cycle duration, good seed quality, drought resistance, thermotolerance, good architecture through breeding, genetics and biotechnological approaches.
- identifying the major diseases and insects affecting sesame production and develop integrated management practices.
- defining in connection with the local farmers the best crop husbandry practices including cropping practices, optimum planting density, planting date, sowing techniques, tailored fertilizer application and pesticide, and seed drying techniques, for the yield optimization.
- analysing the value chain and market systems for finding appropriate solutions so as to improve the value chain organization and solve the seed marketing problem for a better competitiveness of the sesame sector in West Africa's Sahel.

Authors' contributions

KD, MN and NC conceived and designed the experiments. KD, YD and MK performed the experiments. KD, YD and MK analysed the data. KD, MN and NC contributed reagents/materials/analysis tools. KD wrote the paper. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests

Availability of data and materials

The datasets supporting the conclusions of this article are included within the article.

Consent for publication

Not applicable.

Ethical approval and consent to participate

This study did not require any ethical approval. All participants in this study provided their consent.

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