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Enabling effective maize seed system in low-income countries of West Africa: Insights from Benin

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Introduction: Access to high-quality seeds remains a key constraint to the intensification of crop production in low-income countries. In this study, we analyzed maize seed production and distribution systems in Benin to identify leverage points for effective seed systems, a prerequisite for improving maize production.

Methods: Semi-structured interviews were conducted with 81 seed producers selected in seven municipalities across the three phytogeographical zones of Benin. Key informant interviews were also conducted with ten public and private stakeholders involved in maize seed systems in Benin.

Results and discussion: Findings showed that the legal and institutional frameworks governing seed systems in Benin were recently reinforced with a national seed policy, the creation and operationalization of the National Committee of Plant Seeds and the existence of regulations and rules on the production, quality control, certification, trade, and packaging of seeds. In addition, enabling conditions to facilitate the involvement of the private sector have been greatly improved with the revision of modalities for obtaining approval for the production and distribution of seeds in Benin. While the seed sector is improving and both public and private stakeholders are involved in maize seed production and distribution, synergies among stakeholders need to be strengthened. Strengthening business and marketing skills of seed producers through training and promoting the comparative advantages of improved seeds in increasing yield and production among maize farmers could be a promising avenue. Connecting seed producers with maize farmers' organizations coupled with ICT-based agro-advisories could boost the development of the maize seed sector, and ultimately the maize value chain.

KEYWORDS
seed system, maize production, seed policy, seed governance, public-private partnership, Benin

Introduction

Maize (*Zea mays* L.) is one of the most cultivated cereal crops worldwide and a key staple crop in Sub-Saharan Africa, where more than 300 million people depend on it for their subsistence (Badu-Apraku and Fakorede, 2017). In West Africa, the average maize supply is estimated at 30.46 kg/capita in 2019 and the total annual maize production is estimated to be 25.98 million tons in 2020 (FAO, 2022) with Nigeria, Mali, Ghana, Burkina Faso, and Benin being the top five producers (representing 85.13% of the total production). The average West African country's production over the last decade (2011–2020) was 1,397,030.62 tons, with a maximum of 10,428,502.4 tons (Nigeria), and a minimum of 3,453.4 tons (Cabo Verde). Moreover, the average maize yield between 2011 and 2020 ranged from 0.11 (Cabo Verde) to 2.53 t ha^{-1} (Mali) with an average of 1.39 t ha^{-1} (FAO, 2022). Despite the tremendous increase in maize production (by 60% between 2011 and 2020; FAO, 2022), the observed maize yield is far below the potential yield of registered improved varieties, which ranged between 3 and 13.2 t ha^{-1} depending on the type of varieties (open-pollinated or hybrid varieties) (CEDEAO et al., 2016, 2018, 2021). Reasons of low yield in West African countries are diverse and include the use of inappropriate varieties, poor soil fertility, climate-related stresses and impacts, poor management practices, the limited use of fertilizers and other agro-inputs, pest and diseases pressure [e.g., *Striga hermonthica* (Del) Benth parasitism, maize streak virus, downy mildew, armyworms, stem borers, ear borers, and weevils] (Badu-Apraku et al., 2014a; Owusu Danquah et al., 2020). This situation is similar across low- and middle-income countries of West Africa, including Benin.

Among these constraints, the use of inappropriate varieties results from the limited-use of high yielding improved varieties (OPVs and hybrids) as about 80% of planted seeds by farmers are on-farm saved seeds (Badu-Apraku et al., 2014b). Therefore, poor quality seeds are used and access to quality seeds is particularly a key determinant of recorded low maize yield in West Africa, including Benin (Achigan-Dako et al., 2014). Access to high-quality seeds is a key factor in crop productivity improvement (McGuire and Sperling, 2016), and this is achieved through the establishment of an effective seed system. Across West African countries, maize farmers have access to seeds through mainly two systems: the formal and informal systems (Baco et al., 2010). The main difference between the two seed systems is related to the formalization of control over seed quality during development and production in the formal seed system (Akpo et al., 2012). The informal seed system provides about 60–70% seeds used by farmers while the formal one provides about 10% of all maize seeds planted (Badu-Apraku et al., 2014b). This situation results from the under-developed formal system in West Africa compared to other regions of Africa and the world, where well organized formal seed system represents an important driver for higher maize productivity (Smale and Jayne, 2003; Niangado, 2010).

According to Badu-Apraku et al. (2014b), the maize seed industry of West African countries is at different stages of development and can be categorized into three groups such as: relatively well-developed, where all the facets of modern seed programs are present (e.g., Ghana and Nigeria); intermediate, where few links in a seed program chain is lacking (e.g., Senegal and Mali) and rudimentary structures (e.g., Liberia and Benin). Factors affecting the development of maize seed sector (production, marketing, distribution and use of improved certified seeds) in West Africa include: (i) low adoption of improved varieties; (ii) lack of adequate seed policy; (iii) lack of appropriate varietal release system (lengthy of variety release process); (iv) lack of support for emerging seed enterprises; (v) lack of human and financial resources; (vi) insufficient quantities of foundation seeds for certified seed production; (vii) high cost and unavailability of other inputs (fertilizers, pesticides); and (viii) lack of awareness of the potential of improved varieties (OPVs and hybrids), among others (Badu-Apraku et al., 2014b). To overcome these constraints, several efforts are put into improving not only the maize seed sector across West Africa countries but the overall seed system (e.g., ECOWAS regional variety catalog, ECOWAS regional harmonized seed regulations). It is therefore important to assess the current situation for maize seed system after almost a decade from the latest report on maize seed systems in West Africa by Badu-Apraku et al. (2014b). In the present study, we analyze maize seed system using Benin as a case of study, where the seed industry was characterized as rudimentary by Badu-Apraku et al. (2014b).

In Benin, maize farmers source their seeds from extension services agencies, farmers organizations, community-based or individual seed producers (formal system), local markets, exchanges, gifts from friends, neighbors, and family members or previous harvests (informal system) (Tahirou et al., 2009; Baco et al., 2010; Badu-Apraku et al., 2014b). Achigan-Dako et al. (2014) showed that national policies shaped the production and distribution of maize seeds and constrained private investment in Benin. In addition, maize seed system is characterized by a weak relationship between the public and private sectors, a lack of visibility of the national seed association, poor knowledge by stakeholders regarding seed legislation, seed producers' low technical capacity, and the absence of private seed companies (Achigan-Dako et al., 2014). However, the study covered only the southern part of the country, while maize is an important crop in the central and northern parts of the country, where more than 67% of the national production occurs (MAEP, 2022). We, therefore, analyzed current maize seed production and distribution systems across all of the regions of the country and proposed avenues for effective maize seed system development. Specifically, we (i) assessed the current legal and institutional environments of maize seed system in Benin, (ii) documented the agricultural practices and constraints of certified maize seed producers across the phytogeographical zones of Benin, and (iii) proposed a number of strategies for enabling effective maize seed systems.

Materials and methods

Study area

This study was carried out in the three phytogeographical zones of Benin, namely, the Guinean zone, the Sudano-Guinean transitional zone and the Sudanian zone (Figure 1). The Guinean zone is characterized by a bimodal rainfall pattern with two rainy seasons and a total annual rainfall varying between 1,200 and 1,300 mm. The temperature varies between 24 and 30°C (Akoègninou et al., 2006). Major crops include cereals [*Z. mays* L. and *Sorghum bicolor* (L.) Moench], and legumes [*Vigna unguiculata* (L.) Walp. and *Arachis hypogea* L.]. The Sudano-Guinean zone is the largest phytogeographical zone with an annual rainfall from 1,100 to 1,300 mm and temperature between 25 and 34°C. The Sudano-Guinean zone is a transitional phytogeographical zone with a trend toward a unimodal rainfall pattern (Akoègninou et al., 2006). Farming systems in this zone are dominated by cereals (*Z. mays* and *S. bicolor*), legumes (*V. unguiculata* and *A. hypogea*) and roots and tubers (*Dioscorea* spp. and *Manihot esculenta* Crantz). The Sudanian zone of Benin is characterized by a unimodal rainfall pattern with one rainy season (Akoègninou et al., 2006). The annual rainfall ranges from 900 to 1,100 mm, while the temperature ranges from 21 to 35°C. The major crops include cereals [*Z. mays*, *S. bicolor*, *Digitaria exilis* (Kippist) Stapf.] and legumes [*V. unguiculata*, *Vigna subterranea* (L.) Verdc.].

Data collection

Key informant interviews were conducted with ten public and private stakeholders involved in the maize seed system in Benin (Table 1). The stakeholders were mainly from the National Agricultural Research Centers and extension services agencies and farmers' organizations. The information collected included (i) the current status of maize seed production and distribution and (ii) the organization of the maize seed sector. In addition, semi-structured interviews were conducted with 81 maize seed producers across selected municipalities (Table 1) using a questionnaire. These municipalities were selected based on their importance in terms of maize production over the last 10 years and the existence of maize seed producers. In the Guinean zone, three municipalities were selected (Lokossa, Zè, and Kétou), while two municipalities were selected in the Sudano-Guinean (Djidja and Glazoué) and the Sudanian (Bembèrèkè and Gogounou) zones (Figure 1). We considered as a maize seed producer a farmer having (i) proof of an approval of the seed quality control and certification department [*Service de la Promotion de contrôle de Qualité et du Conditionnement des produits agricoles* (SPQC)]; (ii) land (at least 1 hectare) under maize seed production; and (iii) experience in maize seed production (at least 2 years). Maize seed producers in the study area were identified using the snowball technique (Biernacki and Waldorf, 1981). The data collected included socioeconomic information (age, gender, sociolinguistic group, and level of education), cropping area under maize seed production, cultivated maize varieties, seed sourcing, agronomic practices in maize seed production, seed yield, maize seed distribution, and constraints related to the production and delivery of maize seeds.

Data analysis

Descriptive statistics were used to summarize the socioeconomic characteristics of the respondents and seed production practices and constraints. The interrelationship diagram was used to show the relationships among the different stakeholders involved in the maize seed sector in Benin. To compare maize seed cropping area and seed yield among phytogeographical zones, the Kruskal–Wallis test was performed due to normality and homoscedasticity assumptions violation. Consequently, the means of maize seed cropping area and seed yield among phytogeographical zones were separated using post hoc Dunn's test at the 0.05 probability level using the R package dunn.test (Dinno, 2017). To test whether the cultivated varieties and the farmers' constraints were independent of the phytogeographical zone, we used Fisher's exact test to account for contingency table cells with frequencies <5, which represented more than 20% of the total number of cells in the contingency table (Crawley, 2013). All statistical analyses were performed using R software version 4.1.2 (R Core Team, 2021).

Results

Legal and institutional environments for seed production and distribution in Benin

Several regulations and decrees regulate the current seed industry in Benin. In February 2015, the national seed policy was revised. The policy aims to create an adequate institutional framework with a favorable socioeconomic environment for a sustainable and efficient seed sector (MAEP, 2015). This policy was reinforced by the decree n° 2018-174 of 16 May 2018 on the creation, attributions, composition and functioning of the National Plant Seed Committee in the Republic of Benin. The National Plant Seed Committee

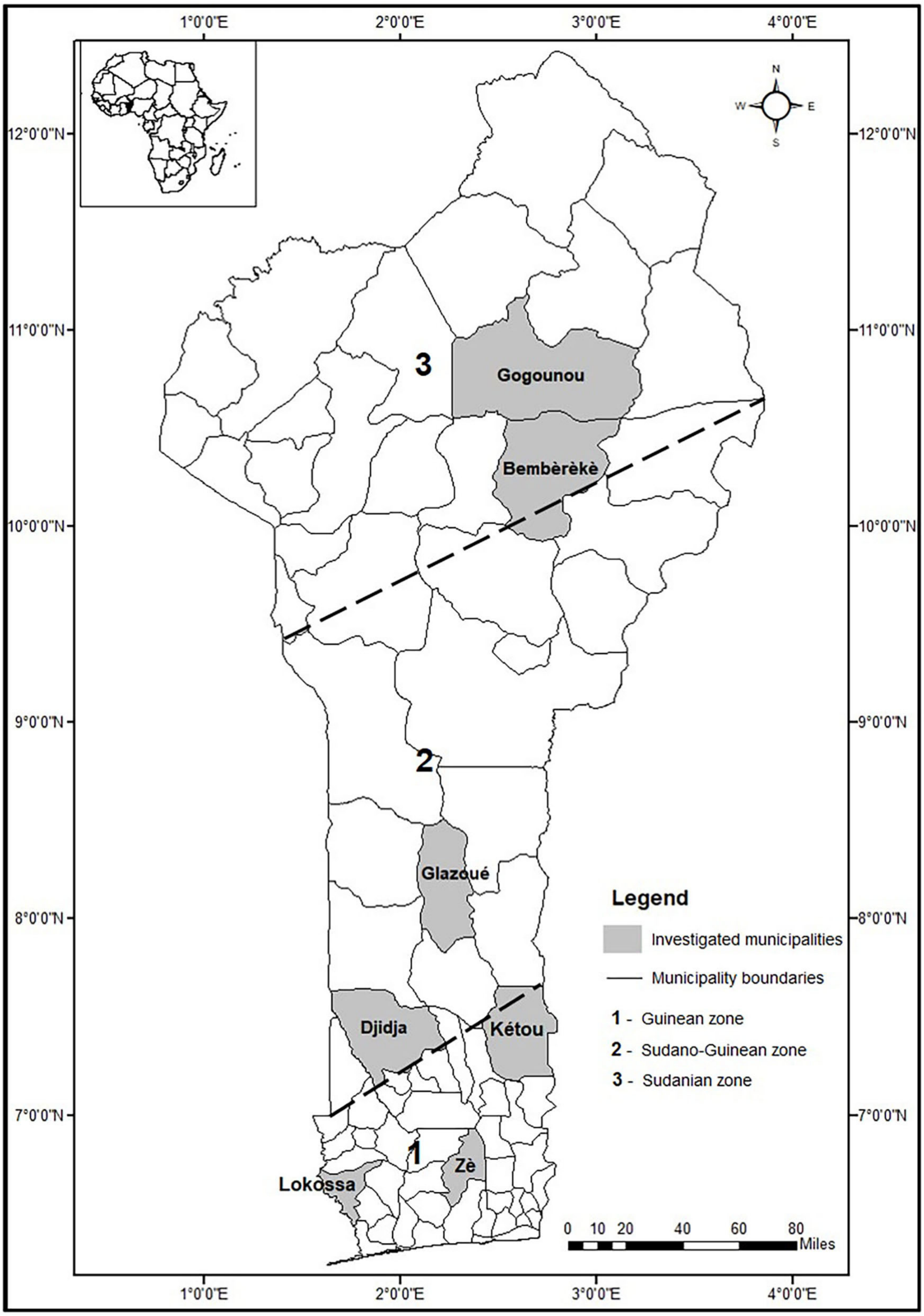

FIGURE 1
Location of the study areas.

TABLE 1 Stakeholders surveyed in each municipality per phytogeographical zone in Benin.

Phytogeographical zones	Municipalities	Number of maize seed producers surveyed	Public institutions and farmers' organizations surveyed
Guinean zone	Lokossa	02	DDAEP - Mono
	Zè	07	DDAEP - Atlantique
	Kétou	09	DDAEP - Plateau
Sudano-Guinean zone	Djidja	20	DDAEP - Zou
			UCP - Djidja
			FUPRO - Bohicon
	Glazoué	14	DDAEP - Collines
Sudanian zone	Bembèrèkè	17	DDAEP - Borgou
			Agriculture Research Center of Ina
	Gogounou	12	DDAEP - Alibori
Total		81	10

DDAEP, Direction Départementale de l'Agriculture, de l'Elevage et de la Pêche [Departmental Directorate of Agriculture, Livestock and Fisheries]; UCP, Union Communale des Producteurs [Municipal Farmers' Union]; FUPRO, Fédération des Unions des producteurs du Bénin [Federation of farmers' Unions of Benin].

oversees the enforcement of regulations and standards in terms of production, quality control, certification and trade of seeds for the development of the national seed sub-sector (https://sgg.gouv.bj/doc/decret-2018-174/). In addition, authorized varieties for seed multiplication are those registered in Benin's Catalog for Plant Species and Varieties (CaBEV) established by decree n° 2018-173 of 16 May 2018 (https://sgg.gouv.bj/doc/decret-2018-173/). Therefore, the manual on the procedures for a variety registration to the Catalog was published (MAEP, 2017). More importantly, the technical rules and regulations for the production, trade, quality control, certification and packaging of seeds and seedlings were set by the Order n°176/MAEP/DCAB/SGM/DRH/DPQC/SA of 7 June 2010 (DPQC, 2011). This order was supplemented with a specific regulation for maize through the Order n°171/MAEP/DCAB/SGM/DRH/DPQC/SA of 7 June 2010. The manual on phytosanitary certification of plant seeds in the Republic of Benin was released in 2015 (FAO, 2015). The manual on the procedures for the quality control and certification of varieties and lot of plant seeds in the Republic of Benin was published in 2019 (FAO, 2019). Obtaining approval, suspension or withdrawal of agreement for production, import and distribution of plant seeds in Republic of Benin is regulated by the recent Inter-ministerial Order 2020 N°040/MAEP/MEF/DC/SGM/DAF/DPV/CJ/SA/031SGG20 of 17 July 2020 fixing the conditions for obtaining professional agreements. It is worth mentioning that the seed sector in Benin is also regulated by the harmonized regional seed regulations and standards (REGLEMENT C/REG.4/05/2008, REGLEMENT N°03/2009/CM/UEMOA) and Regional Plant Varieties Catalog of the West African Economic and Monetary Union (WAEMU)—Economic Community of West African States (ECOWAS) and Permanent Interstate Committee for Drought Control in the Sahel (CILSS).

Stakeholders and maize seed distribution in Benin

Public stakeholders

The National Agricultural Research Institute of Benin (INRAB), through its agricultural research centers, ensures the production and distribution of breeder and foundation seeds and maintains any variety registered in the national catalog of varieties (Figure 2). The Crop Production Directorate (*Direction de la Production Végétale*—DPV) coordinates all the activities related to the seed sector management. The directorate contributes to the dissemination of information on seed regulations as well as the capacity building of seed producers. The Seed Quality Control and Certification Department (*Service de la Promotion de contrôle de Qualité et du Conditionnement des produits agricoles*—SPQC) is involved in field inspection, control and certification processes of all generations of seeds, including breeder, foundation and certified seeds. The Territorial Agencies for Agricultural Development (*Agences Territoriales pour le Développement Agricole*—ATDA) ensure the dissemination of agricultural technologies and the promotion of the use of certified seeds of improved varieties. They also train farmers in seed production with the assistance of SPQC officers and help farmers in the distribution of produced seeds. In addition, national projects and programs [e.g., ProCAD (Programme Cadre d'Appui à la Diversification Agricole), PAPVIRE (Programme d'Amélioration de la Production Vivrière et de Renforcement), PPAAO (Projet de Productivité Agricole en Afrique de l'Ouest)] contribute to promoting certified seeds of improved varieties by purchasing seeds wholesale from seed producers and selling them to maize grain producers at a subsidized price (Figure 2).

Private stakeholders

Seed farms ensure the multiplication and distribution of foundation seeds. Maize certified seed producers multiply and ensure the dissemination of certified maize seeds to grain maize farmers. Farmer's organization (*Fédération des Unions des producteurs du Bénin*—FUPRO) defends producers' interests, provides financial and technical support to certain producers and helps seed producers in the marketing of certified seeds. This is achieved through its deconcentrated structures, such as the Regional Union of Producers (URP) and the Municipal Union of Producers (UCP). The National Seed Association of Benin (*Association Nationale des Semenciers du Bénin*—ANASEB) and the National Federation of Seed Producers of Benin (*Fédération Nationale des Producteurs de Semences du Benin*—FNPS) defend seed producers' interests, provide financial and technical support to seed producers, assist producers in the marketing of their products and work to implement an advocacy plan to convince decision-makers in regulating the sale of seeds, especially the seed prices in the country at the start of the agricultural season.

Certified maize seed production in Benin

Sociodemographic characteristics of certified maize seed producers

Men were more involved in the production of certified maize seed than women (Supplementary Table 1). Maize seed producers were on average 48.31 ± 8.03 years old, with the majority (~51%) between 36 and 50 years old. Approximately 43% of producers were illiterate; 16% attended primary school, while ~40% reached secondary school. Farmers were involved in maize seed production for an average of 9.68 ± 5.85 years, with 33 years for the most experienced producer.

Diversity of maize varieties cultivated by maize seed producers across phytogeographical zones in Benin

Maize seed producers grew different improved varieties across the phytogeographical zones (Figure 3A). Varieties cultivated by producers depended on the phytogeographical zone (Fisher exact, $p < 0.001$), but the number of varieties by producers did not significantly differ among phytogeographical zones ($Z = -0.410$, $p = 0.681$). Producers from the Guinean zone cultivated mainly three varieties EVDT 97 STR W, DMR ESR-W, and 2000 SYN EE-W (Figure 3A), which were early, early and extra-early varieties, respectively (Table 2). In the Sudano-Guinean zone, producers cultivated two early varieties (EVDT 97 STR W and DMR ESR-W). In contrast, maize seed producers of the Sudanian zone produced mainly intermediate (FAABA-QPM) and late (TZPB-SR W) varieties (Figure 3A). All the varieties were registered in the Benin Catalog of Plant Species and Varieties. Characteristics of theses varieties are summarized in Table 2.

Varietal diversity across municipalities within phytogeographical zones

Varieties cultivated by seed producers were municipality dependent (Fisher's exact test, $p < 0.001$), and the number of varieties per seed producer was not significantly different among municipalities ($Z = -0.892$, $p = 0.373$). Maize seed producers cultivated an average of one variety. Although producers could cultivate different varieties, there was a leading variety used by all the producers in each municipality of a given phytogeographical zone (Figure 3B). In the municipality of Zè, 100% of producers produced DMR ESR-W, whereas EVDT 97 STR W was cultivated by all producers in the municipalities of Lokossa, Kétou, Djidja, and Glazoué. Varieties TZPB-SR W and FAABA-QPM were leading in Bembèrèkè (94% of producers) and Gogounou (100% producers), respectively. Other varieties were cultivated based on market demand.

Farmers' practices, seed yield and seed certification

Figure 4 summarizes farmers' practices related to seed production and certification across the study area. Three steps are required for obtaining the approval to produce seeds (Figure 4). First, farmers (i) identify the production site based on soil organic matter content, drainage, depth, accessibility, land history (avoiding field previously planted with cereals crops and infested with *S. hermonthica*) and (ii) declare to the Official Control and Certification Service (*Service Officiel de Contrôle et de Certification*) through the Departmental Directorate of Agriculture, Livestock and Fisheries (*Direction Départementale de l'Agriculture, de l'Elevage et de la Pêche* - DDAEP) their intention for seed production at the beginning of the cropping season. When the declaration is accepted, seed producers go through the second step, which is the obtention of the approval and site validation certificate. This certificate is issued by the Official Control and Certification Service after visiting and assessing the selected production site against minimum conditions (field isolation standards, accessibility, landscape, and soil fertility). The third step consists of submitting an application form for agreement approval to the National Plant Seed Committee.

Our results also showed that maize seed production included activities such as soil preparation, sowing, weed

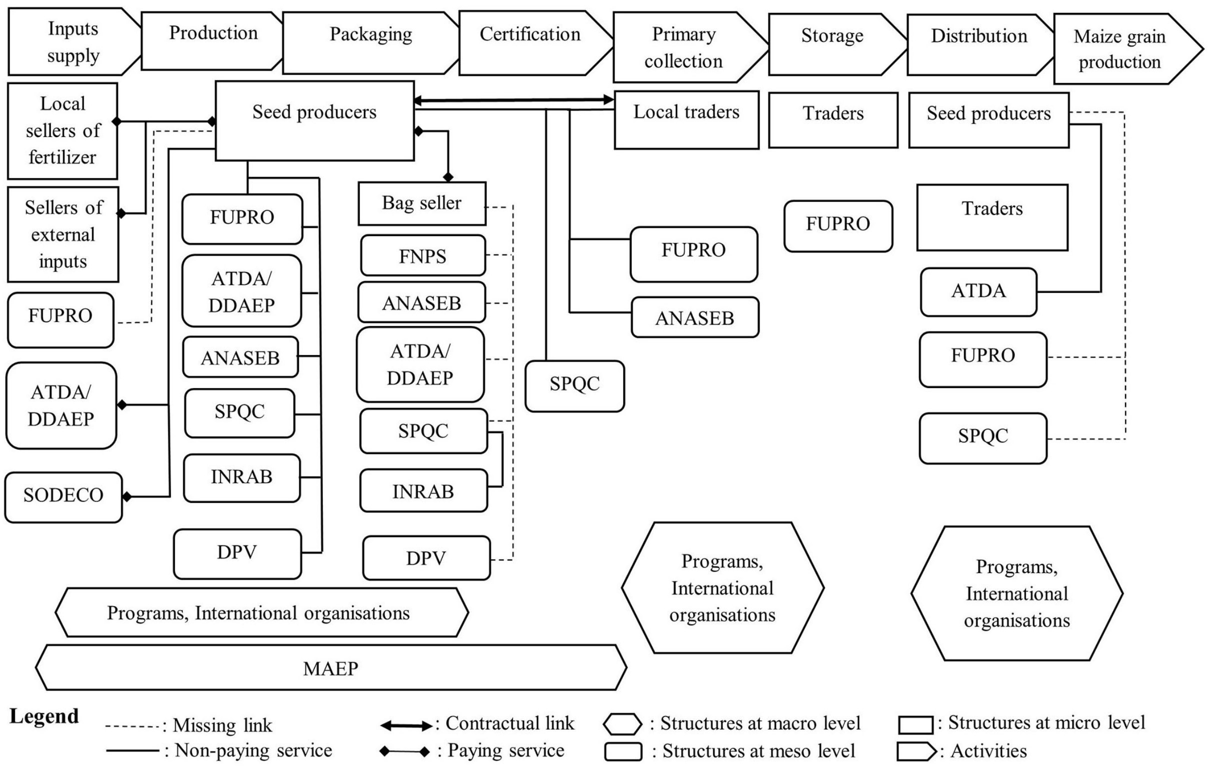

FIGURE 2
Maize seeds distribution chain [adapted from Achigan-Dako et al. (2014)].

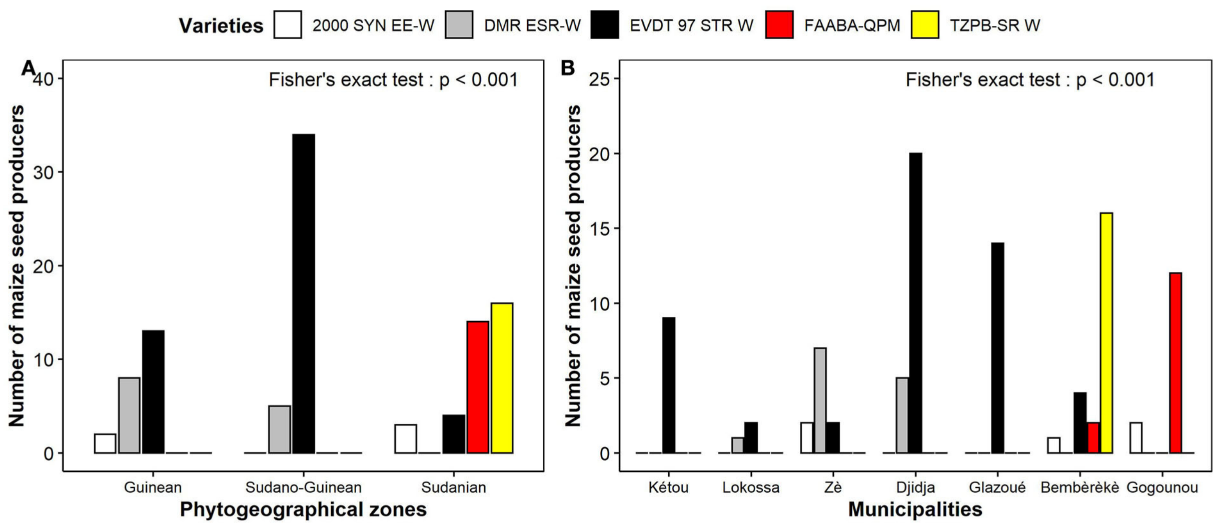

FIGURE 3
Number of maize seed producers growing given maize seed varieties across phytogeographical zones **(A)** and municipalities **(B)**.

control, fertilization, pest control, harvesting, seed processing and certification. For soil preparation, ridging (41% of seed producers) or flat plowing with the tractor (59% of seed producers) are practiced and depend on the phytogeographical zone (Fisher's exact, $p < 0.001$, Figure 5A). Cropping area under maize seed production varied significantly according

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TABLE 2 Key characteristics of improved varieties cultivated by certified maize seed producers in Benin (MAEP, 2016).

Variety	Local name	Tip cover	Grain color	Cycle (days)	Yield ($t\ ha^{-1}$)	Resistance to field pest	Resistance to lodging	Resistance to drought	Processing aptitude	Other characteristics
TZPB-SR W	Saki faba	Good	White	120	4	High	Very high	Medium	Easy	Resistant to maize streak disease
FAABA-QPM	Obatampa	Very good	White	105	3.5	High	High	Medium	Easy	Rich in amino acids (lysine and tryptophan)
EVDT 97 STR W	Mougnangui	Very good	White	90	3	High	High	High	Easy	Resistant to *S. hermonthica* (Delile) Benth
DMR ESR-W	Ouyé	Very good	White	90	3	High	High	Low	Easy	Resistant to mildiou and maize streak disease
2000 SYN EE-W	Ku Gnaayi	Very good	White	80	2.5	High	High	Medium	Easy	–

to phytogeographical zones (Kruskal–Wallis test, $p < 0.001$; Figure 5B). Seed producers in the Guinean zone produced maize seeds on a small area (2.67 ± 1.49 ha), while in Sudanian zone seed producers cultivated on a large area (10.03 ± 6.76 ha). Sowing was performed at a density of 62,500 plants/hectare with 2 seeds per hole (0.80 × 0.40 m), and foundation seeds were supplied by INRAB's research centers (40.74% of producers), ATDA (28.39% of producers) or seed farms (12.34% of producers). For soil fertilization, two types of fertilizers were used: NPKSB (14–23–14–5–1) or NPK (10–20–20), applied before sowing or after sowing (15 days after sowing) at a rate of 200 kg ha^{-1}, and urea (46% N), applied at a dose of 100 kg ha^{-1} between 30 and 45 days after sowing depending on the varieties. Seed producers used insecticides such as pacha (acetamipride + lambda cyhalothrin) or emacot (emamectin benzoate) to control mainly fall armyworm (*Spodoptera frugiperda* Smith) since its appearance in 2016. The dose of insecticide varied according to the attack severity and ranged from 1 to 2 l ha^{-1} for Pacha and 200 to 250 g ha^{-1} for Emacot. At maturity, seed producers harvest seeds and proceed with the postharvest activities.

Post-harvest activities implemented by producers included drying, sorting, ginning, winnowing, grading, and packing of seeds. The sorting consisted of eliminating ears poorly filled and attacked by insects or rodents. Then, the good ears are ginned and calibrated. The good grains are manually sorted from the bad ones (broken, infested, too small, badly formed, grains of another color, etc.) and treated with Sofagrain (deltamethrin + pirymiphosmethyl). Finally, the seeds are packaged in 50 kg bags and stored in a suitable storeroom to avoid contact with soil and humidity. The postharvest activities resulted in two types of products: maize seeds for certification and maize grains for sale (grains that failed to pass the calibration). The maize seed yield varied according to phytogeographical zones (Kruskal–Wallis test, $p < 0.001$) (Figure 6). The average certified maize seed yield in the Guinean zone was lower (1.76 t ha^{-1}) than that in the Sudano-Guinean zone (1.85 t ha^{-1}), while the highest yield was obtained in the Sudanian zone (3.07 t ha^{-1}).

During maize seed production, at least four inspections were performed by the quality control officers (Figure 4) to ensure that the seed production standards and regulations were met: (i) before planting, to validate the choice of the site; (ii) before flowering, for varietal purity and field cleanliness checking; (iii) after flowering, to check varietal purity; and (iv) before harvesting, to check physiological maturity and firmness of the seed and to schedule the harvest. At the end of the postharvest activities, a sample of seeds (5 kg) is collected by the Official Control and Certification Service officers for quality control at the laboratory. The quality control parameters assessed included moisture content, germination, varietal purity, specific purity, seed health and 1,000-seeds weight. The moisture content was determined using either a

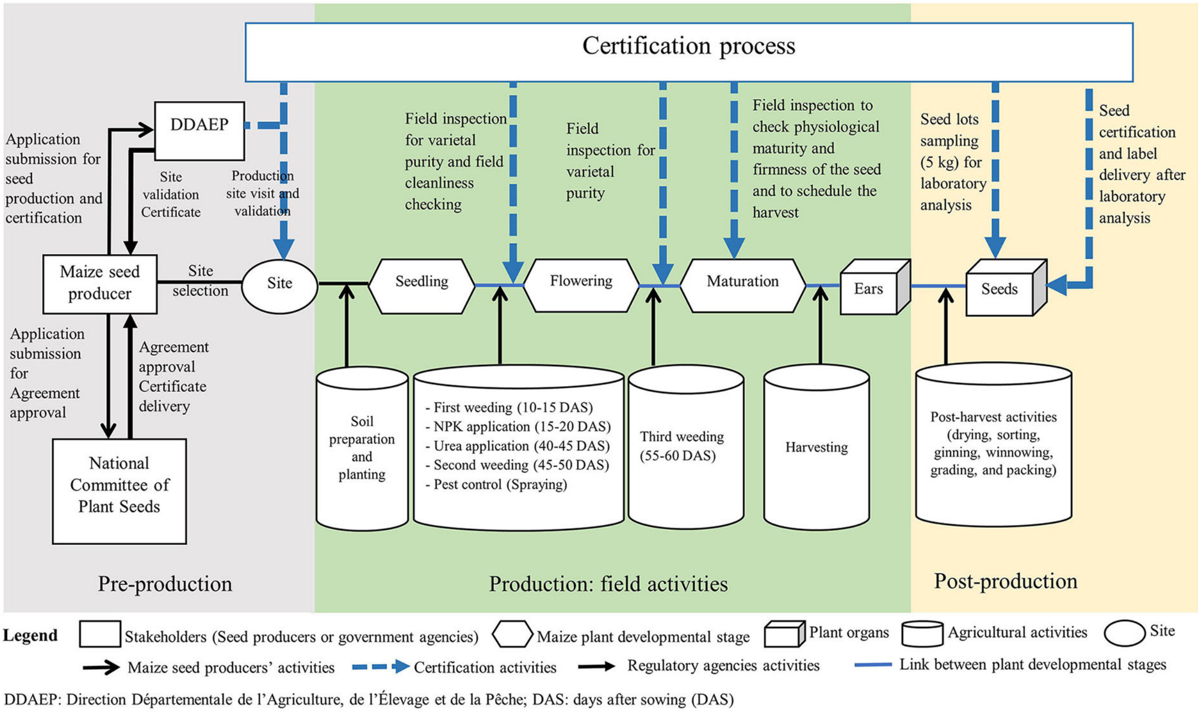

FIGURE 4
Maize seed production practices and certification process in Benin.

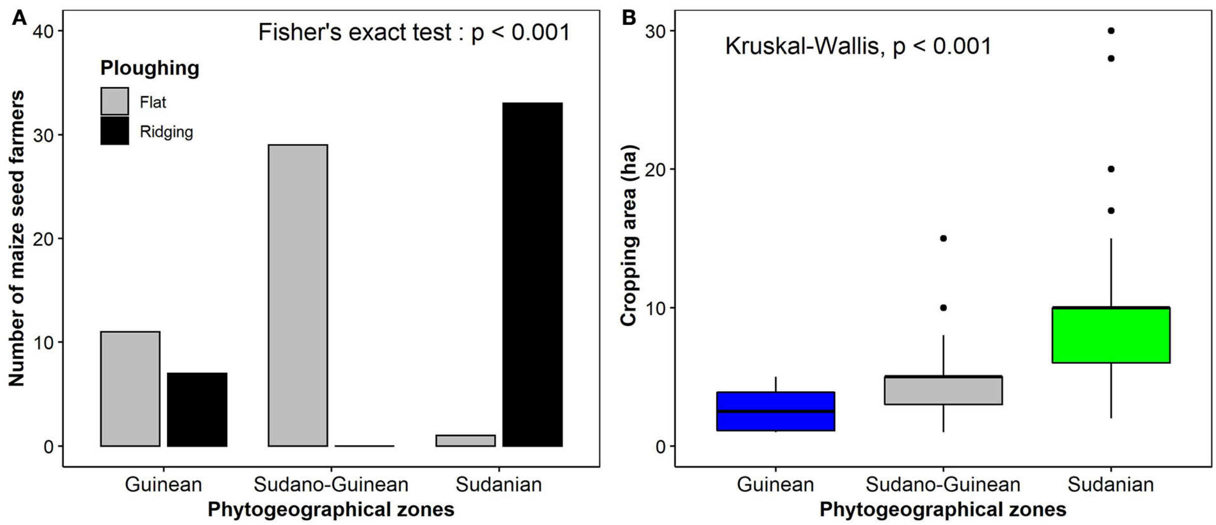

FIGURE 5
Type of plowing **(A)** and cropping area **(B)** used by maize seed producers in each phytogeographical zone.

moisture meter or the oven method of the International Seed Testing Association (ISTA). For specific purity, a sample of 900 g seeds was assessed through visual inspection for determining the proportion of pure seeds, inert matter (plant debris, broken seeds, sclerotia, stones, nematode galls, and smut balls, etc.), and seeds of weeds or other cultivated species. Furthermore, pure seeds were assessed (i) visually for the presence of any other grain color, shape and (ii) by measuring seed traits such

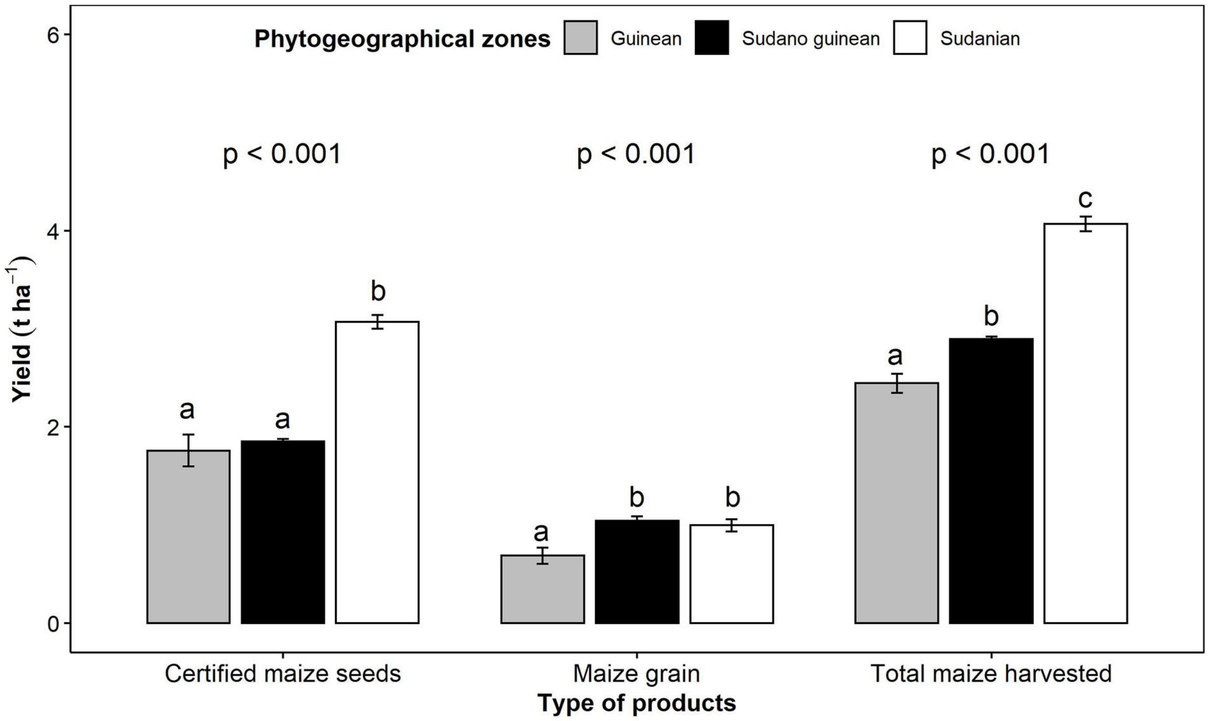

FIGURE 6
Maize certified seed yields across the phytogeographical zones of Benin. Values followed by the same letter are statistically identical according to Dunn's post-hoc test at the 0.05 probability level.

as seed length, seed width, and seed thickness, using a vernier caliper to determine the varietal purity. Three replicates of 1,000 randomly selected seeds were weighted, and the average was calculated and compared with the reference value in the Catalog. For the germination test, four samples of 100 seeds were randomly selected and planted in the sand. Four and seven days after planting, the number of normal, and abnormal seedlings, fresh seeds, and dead seeds was counted and used to determine the germination capacity and seedling vigor. With regard to seed health assessment, mainly visual inspection of seeds is used to assess the presence of: (i) insect pests such as *Sitophilus zeamays* Motschulsky, *Sitophilus oryzae* L., etc.; and (ii) any pathogen symptoms on the seed surface (mold, sclerotia, discolorization, shrunken seeds, and necrosis). The required minimum standards for the parameters assessed included 12% moisture content, 90% germination capacity, 99.7% varietal purity, 98% specific purity, and absence of insects or pathogen symptoms on the seed surface. The laboratory test results are indicated on a seed analysis bulletin issued by the National Laboratory of Analysis and Certification of Seeds and Plants. When all these requirements are met, the blue color labels are delivered to the producers, and the certified seeds are ready for sale.

Constraints related to certified maize seed production and distribution

Certified maize seed producers in Benin encountered several constraints (Figure 7). The major constraint reported by maize seed producers was the lack of a market for certified maize seeds (82.71% of producers). Indeed, until 2015, the government through SONAPRA (*Société Nationale pour la Promotion Agricole*) was involved in the purchasing of certified seeds from seed producers and selling them to maize grain farmers at a subsidized price XOF 90 (US$ 0.16) per kg instead of the current price XOF 350 (US$ 0.63) per kg. Since the government was no longer involved in seed distribution, seed producers had difficulty selling the certified seeds as maize grain farmers perceived the price of certified seeds to be high. The non-sold seeds were converted into maize for consumption and sold on the market at XOF 150 (US$ 0.27) per kg, which did not benefit producers of certified maize seeds. Other important constraints hindering maize seed production included *Spodoptera frugiperda* infestation (41.97% of producers), the lack of adequate agricultural tools for production and post-harvest activities (39.50% of producers), high cost and unavailability of labor (38.27% of producers), erratic rainfall patterns (35.80% of producers)

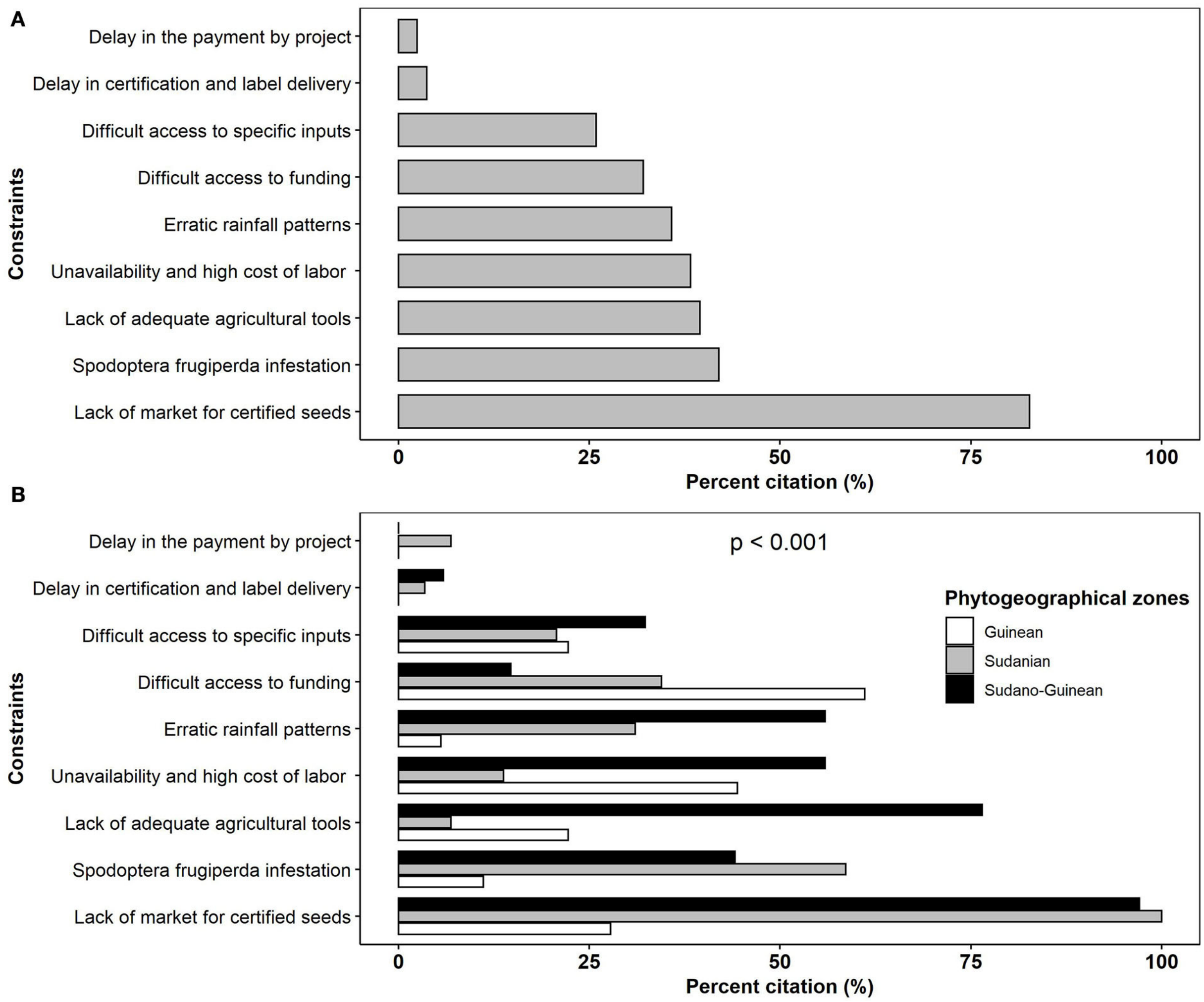

FIGURE 7
Constraints in maize certified seed production and distribution across **(A)** and per **(B)** phytogeographical zones of Benin.

(Figure 7A). The importance of the constraints differs across phytogeographical zones (Figure 7B, Fisher's exact $p < 0.001$). The difficult access to funding, unavailability and high cost of labor, and unavailability of specific inputs (fertilizers and pesticides) for production were mostly cited by producers in the Guinean zone. Producers from Sudano-Guinean zones highlighted the lack of adequate agricultural tools for production and post-harvest activities, high cost and unavailability of labor, erratic rainfall patterns and *S. frugiperda* attacks. Sudanian zone farmers identified *S. frugiperda* infestation as the major constraint, followed by difficult access to funding for production and erratic rainfall patterns.

Discussion

Socio-institutional barriers to maize seed production and distribution in Benin

Since 2016, seed producers are in charge of the seed delivery. Lack of a market for certified maize seeds represent a major constraint for seed producers, as the government is no longer involved in the certified maize seed distribution. In fact, the SONAPRA which was the public actor in charge of certified maize seed delivery (Achigan-Dako et al., 2014) was dissolved in 2016. However, some seed producers (mainly Sudanian zone farmers) had the opportunity to sign contracts with some projects that helped them in the delivery of the seeds. Previous studies in developing countries have reported that producers abandon seed production activity when inputs and support provided by projects end (Almekinders and Thiele, 2003; Okry et al., 2011; Ayenan et al., 2017). Such situation could also happen at the end of projects supporting seed delivery. Our findings also revealed that seed producers offer seeds at a price that smallholder farmers cannot afford because of the high seed production costs that affect the final seed prices (Ndjeunga, 2002; Almekinders et al., 2007; Okry et al., 2011). Consequently, maize seed producers might abandon the production of certified seeds if actions are not taken to overcome the issue of seed delivery. The risk of abandonment of production by maize seed producers may weaken the maize seed sector development and affect the national production and exports to neighboring countries. In Burkina-Faso, the high cost of seed production activities was reported to potentially weaken their seed system with reduction in seed suppliers (Bougma et al., 2018). In Ghana, Quarshie et al. (2021) highlighted the limited capacity of public institutions to supply needed seeds and low capacity of emerging private sector to be equipped with adequate seed production technologies as institutional challenges for maize seed system. Similar situation was also reported in Burkina-Faso (Bougma et al., 2018).

Biotic and abiotic constraints to maize seed production

The fall armyworm (*S. frugiperda*) infestation and the erratic rainfall patterns represented key biotic and abiotic constraints hindering the production of certified maize seeds. Therefore, providing seed producers with resistant varieties and effective management practices is crucial. For instance, resistant genotypes to fall armyworm were identified (Kasoma et al., 2020) and could represent a good source for improving resistance of cultivated varieties. On the other hand, effective management practices could include the use of predatory insects like ants (Dassou et al., 2021) and botanical pesticides (Houngbo et al., 2020) made from vernonia leaves (*Vernonia amygdalina* Del.), neem leaves or seeds (*Azadirachta indica* A. Juss), pepper (*Capsicum annuum* L.), and ashes. The fall armyworm is not the only pest associated with maize production in Benin. Other pests associated with maize production in Benin included maize stem borers (*Busseola fusca* Fuller, *Eldana saccharina* Walker, and *Sesamia calamistis* Hampson), ear borer (*Mussidiani grivenella Ragonot*), maize webworm (*Marasmia trapezalis* Guen.), corn leaf aphid (*Rhopalosiphum maidis* Fitch), southern corn leaf blight fungus (*Bipolaris maydis* [Nisikado and Miyake] Shoemaker), southern corn rust fungus (*Puccinia polysora Underw*), maize *Curvularia* leaf spot fungus (*Curvularia lunata* [Wakker] Boed.), gray leaf spot fungus (*Cercospora zeae-maydis* Tehon et Daniels), maize streak virus (MSV) and the parasitic witchweed (*S. hermonthica*) (Sikirou et al., 2020). Fortunately, most of the improved varieties used by seed producers were selected for resistance to these major pests and diseases as described in the national and regional plant varieties catalogs (MAEP, 2016; CEDEAO et al., 2018, 2021). This might explain why seed producers did not list them as major pests. In contrast, fall armyworm was a new pest, first appearance in 2016 (Goergen et al., 2016), with significant damage to maize production and most available varieties showed low resistance to it. The new outbreak of fall armyworm in the West African region might further explain its listing as a major pest associated with maize production during the present study.

Diversity of maize varieties and implications for maize genetic resources conservation and utilization

Our findings indicated that only five improved maize varieties out of the twenty registered in the National Catalog of Plant Species and Varieties were multiplied and disseminated by certified seed producers. Moreover, the disseminated varieties depend on the phytogeographical zone and the municipality. Indeed, maize seed producers from the Guinean zone representing the municipalities of Lokossa, Kétou and Zè produced mainly the variety EVDT 97 STR W followed by DMR ESR W, produced primarily in Zè. This is in line with Achigan-Dako et al. (2014) who reported the low diversity of maize seed varieties produced by seed producers in southern Benin. However, the varieties DMR ESR W/QPM, QPM, and AK 94 DMR ESR Y previously identified during their study were no longer multiplied by seed producers in southern Benin. The abandonment of these varieties could be associated with the reduced market demand (Loko et al., 2021). This implies that farmers might also abandon the current leading varieties, and breeding efforts must be sustained to develop new varieties taking into account the consumers' and farmers' preferences. In the Sudano-Guinean zone, the leading variety is EVDT 97 STR W, as produced by most of the seed producers because of its precocity (90-day cycle) and its adaptation to the climatic conditions of the zone, which is a transition zone between the Guinean and Sudanian zones. For the Sudanian zone, late varieties were used by seed producers because of the long rainfall pattern. The seed producers in this zone mainly cultivate the varieties TZPB SR W (mainly in Bembèrèkè) and FAABA QPM (mainly in Gogounou). These results are consistent with Mahoussi et al. (2017), who identified the varieties DMR ESR-W, EVDT 97 STR W, TZPB-SR, and Faaba QPM as the improved varieties most adopted by maize farmers in Benin. Breeding efforts and seed system development should also thoroughly take into account factors that drive the choice of farmers.

According to Almekinders et al. (2021), in West Kenya, factors that guide the use of local but also improved maize varieties in farmers' fields include for instance rainfall, the availability of cash, the promise of a good yield, the presence of projects and programs, and the culture of seed. By taking into account the socioeconomic and cultural context together with the agro-climatic conditions, the need to use on-farm and *ex-situ* genetic resource of maize become obvious. In Benin, several other varieties are available at the Agricultural Research Center and registered in the national catalog that have not yet been adopted by seed producers, offering an opportunity for seed producers to expand their diversity in the current changing climate. The experience from Burkina Faso through the on-farm testing of *ex-situ* collections of sorghum is very illustrative of how farmers can expand their genetic diversity to cope with agro-climatic conditions when access to genetic resources is given to them (Vom Brocke et al., 2014). Also, efforts are needed to ensure the conservation of both local and improved varieties under genetic erosion for future use in breeding program toward the development of higher yielding and biotic and abiotic resistant cultivars.

Alternative scheme for effective maize seed system development in Benin

Institutional and legal environments for seed production in Benin have greatly improved with the national seed policy, the creation and operationalization of the National Committee of Plant Seeds and the existence of regulations and rules on the production, quality control, certification, trade, and packaging of maize seeds. In contrast to Achigan-Dako et al. (2014) who highlighted that the national policy and institutional contexts were not conducive enough for private investment in the maize seed system, our findings show that the current seed policy gives a central place to the involvement of private sector. Consequently, an explosion of private stakeholders (enterprises) is foreseeable in the coming years. This could lead to: (i) the competitiveness of the formal maize seed sector with an increased availability of high-quality seeds at affordable price; (ii) the increased diversity of maize varieties; and (iii) the increased demand and adoption of improved varieties. Consequently, maize yield could improve with an increase of maize production in Benin. This is supported by the findings of Badu-Apraku et al. (2014b), who highlighted that promoting the emergence of sustainable seed companies to deliver high quality seed of improved varieties will contribute to increase the maize yield in low/middle income countries of West Africa.

To enable an effective maize seed system development, the existing organizational, and institutional framework must be strengthened. Figure 8 provides an alternative scheme for an effective seed system development. In this new scheme, the link between certified maize seed producers and maize grain farmers must be reinforced. An inclusive demand-led maize variety development is a strong option to consider. This can be done through farmers' organizations. As Seboka and Deressa (1999) recommended, extension services can play a key role in improving seed supplies by organizing farmers and promoting institutional linkages. Seed producers should work toward becoming seed enterprises that will be independent and can manage the marketing of the market-driven seeds in a competitive environment. Thus, they could develop, in collaboration with extension services technological packages to accompany farmers (with focus on the smallholder farmers) to fully exploit the potential of certified seeds. This will include, for example, small packages of seeds and fertilizers as well as periodic training supports. In addition, seed producers should develop the required skills and knowledge, such as gauging farmers' seed demands, determining farmers' preferences for varieties, and developing mechanisms of price formation and strategies of advertisement to properly market seeds (Okry et al., 2011). These skills are essential as poor forecasting ability of farmer's seeds demands and inadequate marketing and business strategies by seed producers were also reported in Ghana and Burkina-Faso (Bougma et al., 2018; Quarshie et al., 2021). Seed producers organizations and enterprises may also develop a pre-ordering system using information and communication technology (ICT) to assure seed availability to farmers and secure a market for seeds (Ayenan et al., 2017). This pre-ordering system as part of coordinated seed production could be extended to pre-paid or booked seeds to boost seed availability and market. More importantly, maize seed producers and enterprises could target regional market as all varieties are registered in the regional variety catalog (CEDEAO et al., 2021), a sine qua non condition for certified seed commercialization in the region.

The government could also review the strategy to be put in place to strengthen seed producers' skills in marketing and commercialization and increase adoption of certified maize seeds by maize grain farmers. Thus, research institutions and extension services should create and strengthen collaboration with private stakeholders involved in business and advertisement skills to raise maize grain farmers' awareness of the use of certified seeds (Ayenan et al., 2017). Training should also be given to maize grain farmers to use certified seeds, and credits could be provided by agricultural public or private financial organizations. This could motivate farmers who are willing to buy these seeds and incite others to do so, therefore, contribute to strengthening the seed system and improving smallholders' welfare. It has been observed that smallholder maize grain farmers' access to improved and certified seeds positively impacted the yield, income and poverty reduction (Houeninvo et al., 2020). A similar trend was observed for the adoption of improved groundnut varieties in Nigeria, Ghana, and Mali, with 3.6% poverty reduction and more than 25%

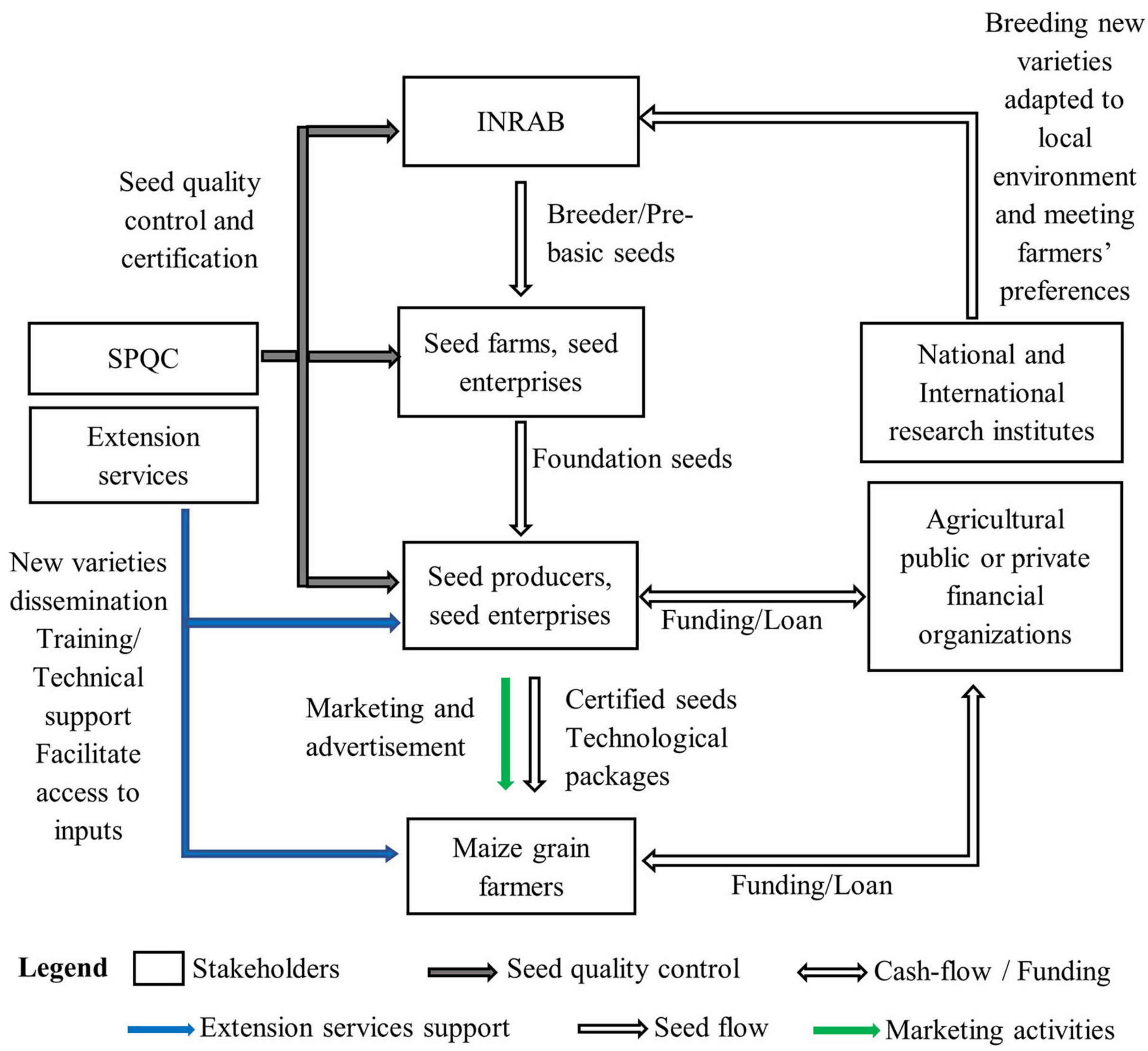

FIGURE 8
Alternative scheme for an effective formal maize seed system in Benin.

increase of gross margin (Lokossou et al., 2022). This means that the formal system should be strengthened and involve smallholder farmers, who mainly sourced their seeds through the informal seed system. Previous researchers pointed out that smallholder farmers source seeds through the informal channel (seeds from previous seasons) but also through the formal channel (certified seeds of improved varieties) (Akpo et al., 2012; McGuire and Sperling, 2016; Ayenan et al., 2017; Kilwinger et al., 2020). Future research should explore specifically the informal seed sector through diagnostic studies (Kpéra et al., 2017) to understand its functioning and organization in Benin and West African countries.

It is of paramount importance to highlight that, research activities regarding new variety creation should involve more maize farmers and clearly identify farmers' preferences, which will be the basis of new cultivar development. Given the importance of seeds for increased productivity, it would be essential to develop and make available to producers' new varieties with high yield and resistance to biotic and abiotic stresses. Moreover, the current varieties cultivated by farmers are open-pollinated varieties, which aligned with the previous reports on the absence of hybrid varieties cultivation in Benin (Tahirou et al., 2009; Abate et al., 2017). Similarly, maize production in most West African countries is dominated by OPVs with few hybrids in contrast with Eastern and Southern African countries where hybrid varieties were preponderant (Abate et al., 2017). In this context, the development of hybrid maize varieties is an option for breeding programs in

West African countries. Hybrid varieties have the potential to outperform open-pollinated varieties (OPVs) for yield, tolerance to biotic and abiotic stresses and nutritional values, as they better exploit heterosis (Ndoli et al., 2019; Labroo et al., 2021). The adoption of maize hybrid varieties has increased maize yield and production in Eastern and Southern African countries (Smale and Mason, 2014; Abate et al., 2017). For instance, the use of hybrid cultivars in Ethiopia and Zambia has led to an increase of maize yield over the last two decades by 143.32 and 84.33%, respectively (FAO, 2022). Most importantly, hybrid maize cultivars adoption was strongly and positively associated with higher incomes and assets as well as improved livelihoods and welfare of smallholder farmers in Zambia (Smale and Mason, 2014), Kenya (Mathenge et al., 2014), and Ethiopia (Jaleta et al., 2018). In addition, maize hybrids adoption has positive effects on country's economy and on food security given the role of maize in the population diets (Smale et al., 2015; Jaleta et al., 2018). However, these benefits of hybrids depend on several adoption factors including availability and accessibility of high-quality seeds and other inputs (such as fertilizers, pesticides, etc.), profitability of hybrid cultivation, access to credit, consistency between reported potential yield and on farm yield (Schroeder et al., 2013; Van Asselt et al., 2018; Blekking et al., 2021). For instance, in Ghana where few farmers grown hybrid varieties, none was produced in the country and farmers are ready to adopt maize hybrid varieties but is positively constrained by high cost of production and pests and diseases (Ifie et al., 2022).

All above mentioned support the outcomes of Badu-Apraku et al. (2014b) analysis of the maize seed system in West and Central Africa, which revealed a need to strengthen the system in all the countries by (i) promoting the emergence of sustainable seed companies to deliver high quality seed of improved varieties especially hybrid varieties, (ii) improving public-private partnerships among stakeholders, and (iii) motivating farmers to buy improved varieties seeds, to increase the maize yield across low/middle income countries of West Africa.

Therefore, while the formal system is working toward a better organization, providing farmers with good quality seeds at affordable cost and ensuring a market for maize certified seeds, the informal system should also be considered and strengthened by upgrading informal seed producers to formal seed producers and later to private seed enterprises (Akpo et al., 2020). Louwaars and de Boef (2012) suggested an integrated seed sector development that better links the formal and informal systems, balances public and private sector involvement, and shapes seed programs and policies that can be more applicable to smallholder farmers and be effective in reaching food security. Therefore, the results from informal seed sector diagnosis coupled with those of this study will contribute to defining a roadmap for an effective and integrated seed system in Benin and West African countries.

Conclusion

The maize seed sector in Benin is a critical subcomponent of the agriculture sector that needs to be intensively developed to improve maize production. The analysis of the maize seed sector revealed the existence of legal and institutional framework, that has been reinforced recently with various decrees, regulations and orders. Though both public and private stakeholders were involved in the maize seed system, the new policy provides a better environment for an increased involvement of private sector in the seed industry. The main private stakeholders included individual seed producers and farmers' organizations. A weak interaction between seed producers and end users (maize grain farmers) threatened the maize seed distribution, and seed producers' skills should be strengthened on marketing and their upgrading into enterprises. Limited varieties are cultivated and this depends on the climatic zone, yet there is a wide range of varieties available. A better development of the maize seed sector requires: (i) training to strengthen the link between seed producers' organizations and farmers' ones; and (ii) the development of seed packaging technology and new varieties' resistance to emerging pests and tolerant to erratic rainfall. The observed improvement of legal and institutional framework will favor the emergence of more private stakeholders, seed enterprises, to create competition that will promote a high quality and cost-effective seed for maize grain farmers. Further research should diagnose the maize informal seed system to contribute to defining a roadmap for an effective and integrated seed system in Benin. Given the similar roles of each stakeholder group in the maize seed system and seed system in general, the proposed model can be applied to other crops in Benin to improve farmers' access to quality seeds for better crop productivity.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

RFRA, NF, and EA-D conceived and designed the study. RFRA and RPMA conducted the survey. RFRA analyzed the data and wrote the first draft. AH contributed to data analysis and revised the manuscript. NF, AS, SN'D, CA, and EA-D critically revised the manuscript. All authors read and approved the final manuscript.

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Conflict of interest

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

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.1045629/full#supplementary-material

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