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EDITED BY
Matteo Balderacchi,
Independent researcher, Piacenza, Italy

REVIEWED BY
Michelle Mothe,
Federal University of Rio de Janeiro, Brazil
Joko Pitono,
National Research and Innovation Agency (BRIN), Indonesia

*CORRESPONDENCE
Paola Sierra-Baquero
psierra@agrosavia.co
Filipa Monteiro
fmonteiro@isa.ulisboa.pt

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Insights into the cashew production system in Guinea-Bissau: implications for agroecosystem sustainability

Paola Sierra-Baquero[1,2,3]*, Sílvia Catarino[1], Gonçalo João Costa[1], Amidu Barai[1,2,4,5], Zinha Correia[5], Maria Rosa Ferreira[5], Edgar Varón-Devia[6], Maria M. Romeiras[1,2], Luís Catarino[1], Maria Cristina Duarte[1] and Filipa Monteiro[1,2]*

[1]cE3c - Centre for Ecology, Evolution and Environmental Changes, and CHANGE – Global Change and Sustainability Institute, Faculty of Sciences, University of Lisbon, Lisbon, Portugal, [2]LEAF - Linking Landscape, Environment, Agriculture and Food, Associated Laboratory TERRA, Instituto Superior de Agronomia (ISA), University of Lisbon, Lisbon, Portugal, [3]AGROSAVIA - Colombian Corporation for Agricultural Research, Agustín Codazzi, Cesar, Colombia, [4]INPA - Instituto Nacional de Pesquisa Agrária, Bissau, Guinea-Bissau, [5]DSPV - Direção de Serviço de Proteção Vegetal, Granja de Pessubé, Ministério da Agricultura da Guiné-Bissau, Bissau, Guinea-Bissau, [6]AGROSAVIA - Colombian Corporation for Agricultural Research, Espinal, Tolima, Colombia

Introduction: West Africa, particularly Guinea-Bissau, heavily relies on cashew nut (*Anacardium occidentale L.*) production, which significantly impacts the countries' economies. Cashew exhibits remarkable adaptability to impoverished and arid soils. Understanding producers' socio-economic characteristics is crucial due to their potential influence on crop productivity and household income.

Methods: This study aims to characterize the socio-economic, productive, and phytosanitary aspects of cashew production in Guinea-Bissau, through 151 interviews with producers across all administrative regions of the country.

Results: Our findings reveal that cashew producers are mainly males aged 40 to 60, they typically manage plantations under 5 ha, with the smaller plantation areas located in Gabú, Cacheu, and Bolama. The age of the older trees averaged 31 years, with the highest age found in Biombo. Tree density averaged 286 trees per hectare, with higher values in Cacheu, Bafatá, and Bolama. Cashew nut yield in 2020 averaged less than 0.5 tons per hectare, with farmer-set prices generally lower than government determined prices. Oio, Tombali, and Bolama were the regions most affected by pests, while Oio and Cacheu (North) were the most affected by diseases. Top pests included termites, branch girdler, weaver ants, African grasshopper, and stem borer; while top diseases comprised gummosis, anthracnose, and dieback.

Discussion: Characterization of cashew production system is crucial at both national and regional levels to identify region-specific limitations and strengths, aiding in the formulation of tailored strategies for sustainable production. Moreover, cashew production plays a crucial role in household incomes in Guinea-Bissau, underscoring the necessity of developing integrated management strategies.

KEYWORDS

West Africa, pests, diseases, integrated management, sustainable production, household income

1 Introduction

Cashew (*Anacardium occidentale* L.) holds a significant global agricultural importance as an export-oriented crop, boasting a world production of 3,708,384 tons of raw cashew nuts in 2021 (FAO, 2024) being one of the most marketable nuts crops, after almonds and walnuts (Otálora et al., 2024). West Africa region is one of the most important cashew producing regions, accounting for around 50% of the world production, following India and Vietnam (Monteiro et al., 2017; FAO, 2024). Notably, Guinea-Bissau, a small country in West Africa, emerged as the eighth-largest world producer and ranked third in the West Africa region, yielding 122,283 tons in 2021 (United Nations, 2016; FAO, 2021, 2024). The country relies heavily on cashew as main agriculture commodity, constituting 90% of its export portfolio thus assuming a paramount role in Guinea-Bissau's economy, both in governmental revenue and in household income involving about 30% of annual income (Monteiro et al., 2017).

Native from Brazil (South America), cashew have become a popular mainstay and is one of the most important agriculture commodity sectors in West Africa (Monteiro et al., 2015, 2017; Miassi et al., 2019; Hinnou et al., 2022; Yin et al., 2023), alongside cacao (*Theobroma cacao* L.) and yam (*Dioscorea* spp.; Ogezi, 2022). Beyond its significant value in the global nut market, the cashew tree demonstrates remarkable adaptability by thriving in impoverished and arid soils, including sandy areas (Akinpelu et al., 2021). This adaptability renders it a productive and resilient agriculture crop suitable for the prevailing conditions in the West African region. Beyond the ecological performance of cashew cultivation, understanding the socio-economic characteristics of this important agroecosystem at the smallholder farmers level becomes imperative due to its potential impact on crop productivity, as well as the importance of such crop on household income. The decisions made by farmers, influencing aspects such as land use, agricultural practices, and farm size, play a pivotal role in overall production outcomes (Assih and Nenonene, 2022; Hashmiu et al., 2024).

Considering that cashew producers in Africa are native and uphold robust cultural practices (Assih and Nenonene, 2022) and that most agriculture is based on smallholder farmers, these factors may contribute to the predominance of male cashew producers, as evidenced by numerous socio-economic studies previously conducted (Oluyole et al., 2017; Akinpelu et al., 2021; Assih and Nenonene, 2022). This is rooted in prevailing societal traditions and norms, often curtailing women's rights to inherit or own land in most African societies (Saïdou et al., 2007). The age of cashew producers in Africa, typically range between 50 and 90 years with an average of 60 years (Ibrahim, 2015; Bello et al., 2017; Oluyole et al., 2017), may significantly affect cashew productivity and resource efficiency (Akinpelu et al., 2021). Additionally, the orchard size plays a crucial role as areas smaller than 3 hectares face challenges in accessing essential productive factors like labor and capital, a common trend reported by studies indicating that 91% of cashew producers operate on small farms in Africa (Assih and Nenonene, 2022). Nigerian producers have identified other significant factors contributing to the low cashew yield, namely insect pest attacks account for 51% of productivity loss, while disease infections constitute 26.3% of the reported challenges (Agbongiarhuoyi et al., 2015).

In Guinea-Bissau, ongoing social and political shifts are driving the substitution of other crops, with cashew emerging as the primary income source for the rural population due to international demand and local policies (Temudo and Abrantes, 2014; Catarino et al., 2015; Monteiro et al., 2017; Havik et al., 2018). However, this economic reliance on a single crop poses a significant challenge to the country's food security and overall economy (Monteiro et al., 2017). Despite existing studies in Guinea-Bissau that have examined the impact of cashew on the country's economy (Monteiro et al., 2017), with limited attention to its environmental implications as a monoculture and associated phytosanitary issues, there remains a crucial need for socio-economic characterization of these important production system for smallholder farmers. Such an assessment is critical for obtaining a holistic understanding of the key factors influencing cashew productivity, practiced by smallholder farmers in managing the orchard, thus contributing to valuable insights toward the development of successful strategies aimed at improving the food security and livelihoods for cashew producers in Guinea-Bissau, leading to more resilient and prosperous farming communities.

Several socioeconomic and phytosanitary factors influence cashew crop productivity, such as the age of farmers, education level, the size of the farm, source of labor, pests, and diseases, among others (Ibrahim, 2015; Assih and Nenonene, 2022; Diaz et al., 2022). However, the limited scientific knowledge of cashew production systems in many producing countries hinders the intervention of government, institutions, and experts (Monteiro et al., 2017; Assih and Nenonene, 2022) in enhancing productivity, based on integrating the social, economic, and productive components for each country.

In Guinea-Bissau, despite favorable soil and climate conditions for cashew cultivation, several factors contribute to low productivity and inefficiencies in the cashew sector (Monteiro et al., 2015). Many farmers have limited education, and rural extension services are lacking, leading to inadequate establishment of cashew plantations in terms of selecting propagation materials and implementing proper crop management practices (Monteiro et al., 2017). Orchard maintenance and plant health management is frequently overlooked aspects of cashew cultivation in Guinea-Bissau, contributing to lower productivity and suboptimal crop quality. Furthermore, the initial harvesting and processing of cashew nuts are done manually, and a significant portion of the cashew apple remains economically underutilized (Catarino et al., 2015; Monteiro et al., 2017). In addition, most of cashew nuts are exported raw and processed in Asian countries, namely in India (Catarino et al., 2015; Havik et al., 2018).

Guinea-Bissau, despite its modest size, occupies a climatic transition zone, resulting in a pronounced annual rainfall variability (Catarino et al., 2008; Romeiras et al., 2018). This climatic diversity, coupled with other abiotic factors (e.g., temperatures), categorizes the country into three distinct agroecological zones: North, East, and South. The northern and eastern regions experience annual rainfall ranging from 1,400 to 1,600 mm, whereas the southern region encounters a higher range, reaching up to 2,500 mm (Temudo et al., 2020). Additionally, the agroecological zones in Guinea-Bissau are, in general, characterized by ethnic groups, vegetation, soil types, farming systems, and pastoral activities (Temudo et al., 2020). Vegetation patterns are among one of the features that differentiate the agroecological zones (Catarino et al., 2000; Adeaga et al., 2022), and their influence extends to phytosanitary considerations and social practices among the population. Understanding and characterizing the different variables that influence the cashew system in Guinea-Bissau is essential for evaluating the sustainability of the agroecosystem

and major variables that would be responsible for ensuring the future production of the crop.

This study aims to characterize the socio-economic, productive, and phytosanitary aspects of cashew production in Guinea-Bissau by conducting interviews with cashew producers across all administrative regions and encompassing the three distinct agroecological zones of the country. Our specific objectives were: (i) to describe the main characteristics of cashew plantations and smallholder farmers, (ii) to analyze productivity and prices practiced in each region compared to the average values announced for the country, (iii) to understand which phytosanitary problems are affecting productivity in different regions, and (iv) to analyze the relationship between agroecological zones and the occurrence of diseases and pests, assessing their spatial distribution and which regions are most affected.

Our findings will empower agricultural experts with the knowledge needed to devise specific strategies, promoting the adoption of sustainable practices among farmers to enhance overall productivity within the cashew across the country.

2 Materials and methods

2.1 Study area

Guinea-Bissau is a country on the West Africa coast located between latitudes 10° 55′ and 12° 40' N, between 13° 40′ and 16° 45 W meridians (United Nations Development Programme, 2023). The country is situated in the warm tropics, with an annual mean temperature of 28°*C. guinea*-Bissau exhibits a monomodal regime with two distinct seasons: rainy and dry (Spark, 2023). Annual rainfall varies considerably between coastal and inland areas (Temudo et al., 2020). The research was conducted in all administrative regions of Guinea-Bissau. The study covered the eight administrative regions in the country, namely Biombo, Cacheu, and Oio located in the North agroecological zone; Bafatá and Gabú, which belong to East zone; and Tombali, Quinara, and Bolama, which belong to the South zone, the latter also includes the Bijagós archipelago (Figure 1).

2.2 Data collection

Data was collected through semi-structured surveys conducted across 151 plantations from the main cashew-producing regions of the country, with prior informed consent from all interviewees. In each region, a comparable number of plantations were randomly selected for interviews, aiming for adequate geographical distribution. However, in specific instances, targeted selection was employed, guided by the presence of local people who designated certain producers as representatives of the region. The interviews were conducted during the cashew harvest season (April–May) from 2021 to 2023, streamlining the acquisition of data associated with the harvest. The geographical coordinates of each plantation were recorded using a GPS device, as well as the total farmland area.

The characteristics of the cashew production system in Guinea-Bissau (Supplementary Table S1) were categorized in terms of geographical location (zone and administrative region), social characteristics of the producers surveyed (gender and age), and general aspects of the crop (including, cashew plantation area, cashew variety preference, age of older cashew trees, cashew apple color, preference for a type of cashew apple for further processing, and tree density). The age of older cashew trees was determined as the oldest cashews planted by the farmers, while the tree density (number of trees per hectare) was assessed by the Point Centered Quarter Method (PCQM) following Cottam and Curtis (1956). Sampling point done were spaced at least 50 m. In the PCQM, a small portion of the total area was examined in each orchard, with a total of 5 plots sampled. Each plot was divided into four 90° quadrants, and the plant closest to the point in each quadrant was identified and georeferenced with a Garmin GPSMAP 64 s unit, with 1–3-meter accuracy. The distance between the central point and the selected plant in each quadrant is measured and then averaged across the four plants to represent the distance at each sampling point. In each orchard, tree density was calculated as:

$$Absolute\ density = \underline{\lambda} = \frac{(4n)^2}{\left(\sum_{i=1}^{n}\sum_{j=1}^{4} R_{ij}\right)^2}$$

Where n is the number of sampling points in an orchard (=5); 4n is the total number of observations in the whole orchard (=25); i is a sampling point in an orchard ($i = 1, \ldots, n$); j is a quarter at a sampling point ($j = 1, \ldots, 4$); and Rij is the distance measured to the tree at the sampling point i in quarter j (Bryant et al., 2005).

Post-harvest information was also considered, which included: cashew nut yield from the year 2020, price nut in 2020, usage of the cashew apple, and trends in cashew yield and price at both the farmer and the government levels, for the years 2019–2020. The price values established by the government in 2020 were provided by the Ministério das Finanças da Guiné-Bissau (2021), which is the governmental entity that establishes yearly the recommended cashew nut price for selling purposes.Additionally, phytosanitary status regarding the occurrence of pests and diseases was recorded in the surveys done with farmers. The data on pests and diseases were compiled by the vast experience of some authors (LCatarino, FMonteiro, GCosta) gathered throughout the years through fieldwork, by an identification guide of pests and diseases in cashew from Guinea-Bissau (Monteiro et al., 2022a), and based on the literature from other West African cashew producing countries (e.g., Agboton et al., 2014).

Regarding plant species that could affect crop productivity, directly or indirectly, data was also collected from the siam weed plant, *Chromolaena odorata* (L.) R.M.King & H.Rob., and the hemi-parasitic plant, African mistletoe (*Tapinanthus bangwensis* (Engl. & K.Krause) Danser). Previous studies conducted by Catarino et al. (2019) reported *C. odorata* as an important invasive plant in several cashew orchards in Guinea-Bissau, potentially affecting the agriculture management of the orchard; while the African mistletoe (Loranthaceae family, *Tapinanthus* spp.) is among the mistletoe species recognized in West Africa (Burkill, 1985) known to affect a diverse host species. Although records on African mistletoe have been mostly reported in citrines *Citrus* sp. (Adesina et al., 2013), mango (*Mangifera indica* L.), affecting other economically important crops in West Africa (Watson et al., 2020), its impact on cashew trees and in overall orchard health has not been extensively studied.

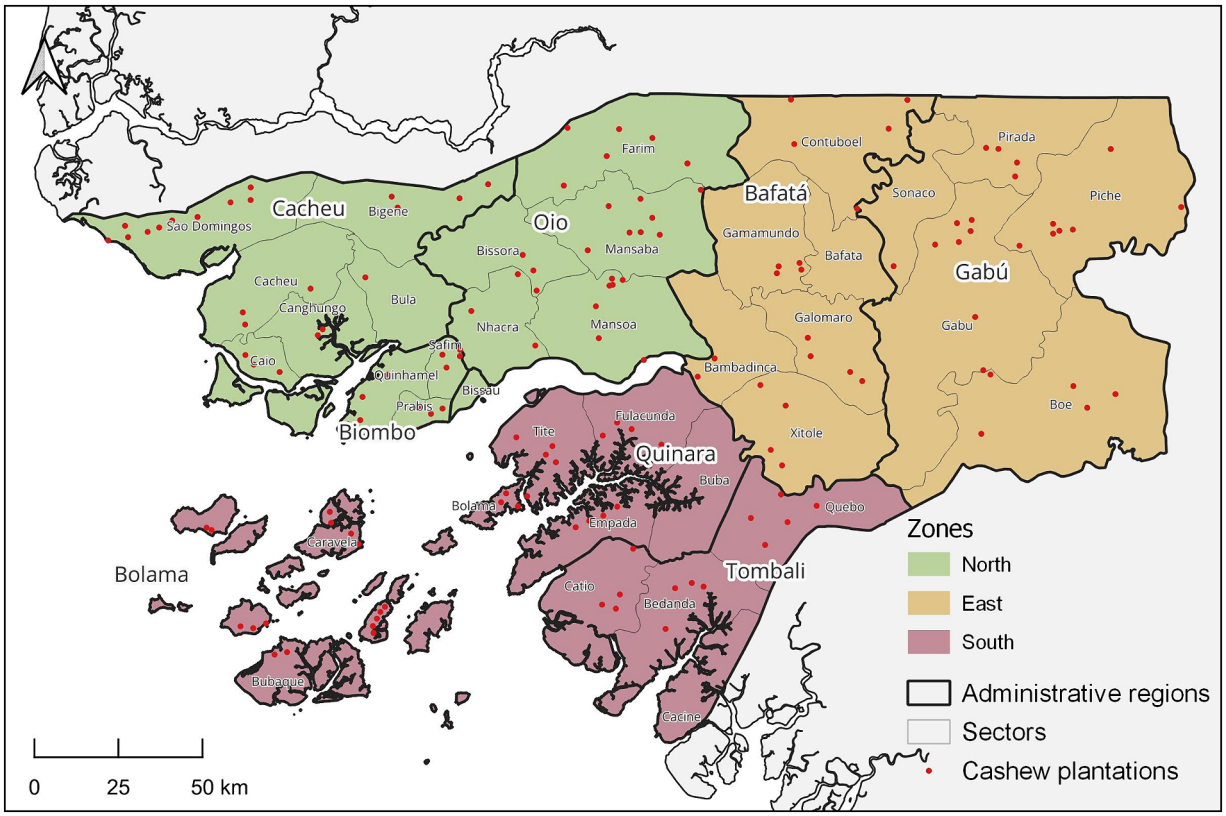

FIGURE 1
Study area with the North, South, and East zones, administrative regions of the Guinea-Bissau (Bafatá, Biombo, Bissau, Bolama including Bijagós archipelago, Cacheu, Gabú, Oio, Quinara, Tombali), and the cashew plantations surveyed (marked with red dots).

2.3 Data analysis

The collected data were recorded on paper sheets and then databased in Microsoft Excel (Supplementary Table S1). Based on the information collected, a descriptive analysis was initially performed. The relationship between the administrative region, orchard area, farmers age, and the age of the older trees is presented To analyze significant differences among the various administrative regions regarding farm area, age of the oldest tree, farmers age, yield in 2020, and tree density we conducted a Kruskal-Wallis test (p-value $\leq$0.05; Kruskal and Wallis, 1952). The test and the representative boxplots were performed in R v.4.2.3 (R Core Team, 2023) using the packages *tidyverse* (Wickham et al., 2019) and *agricolae* (Mendiburu and Yaseen, 2020). Additionally, the difference between the government-set cashew nut price and the price nut by cashew farmers, we conducted a Kruskal-Wallis test (p-value $\leq$0.05) and representative and represented graphically using a bar chart.

Heatmaps presenting the intensity of pests and diseases occurring in the eight administrative regions of Guinea-Bissau were generated in R v.4.2.3 (R Core Team, 2023) with the *gplots* package (Warnes et al., 2016) and the *heatmap.2* function. The distance matrix was calculated based on the mean values per region, using the Spearman correlation method, and clustering was executed using the complete linkage method. Additionally, a correlation matrix presenting the relationship between the characteristics of the cashew production systems and the occurrence of pests, diseases, and hemi-parasitic plant was performed. This analysis used the *corrplot* package (Lê et al., 2008) employing the Spearman correlation method in R v.4.2.3 (R Core Team, 2023). Only statistically significant values (p-value $\leq$0.05) are presented.

3 Results

3.1 Main characteristics of cashew plantations in Guinea-Bissau: socio-economic features

A total of 151 surveys were documented across Guinea-Bissau, distributed as follows: in the north zone about 62 orchards, in the east zone, 44 orchards and in the south zone, 45 cashew fields (Supplementary Table S2). In the cashew system in Guinea-Bissau, most producers were male (96%), with a mean age of 55 years, ranging from 20 to 87 years (Supplementary Table S2). Bafatá presented the lowest mean age of farmers at 48 years, while Tombali and Gabú had the highest mean ages, at 60 and 61 years, respectively. The areas of cashew plantations were typically less than 5 ha (62%; Figure 2A; Supplementary Table S3). The larger cashew plantations (> 25 ha) were predominantly located in the Northern regions and seemed to be associated with older farmers (> 40 years, Figures 2B,C; Supplementary Table S4). Bolama had the lowest mean area of 2.8 ha, while Biombo and Tombali had the highest mean areas, at

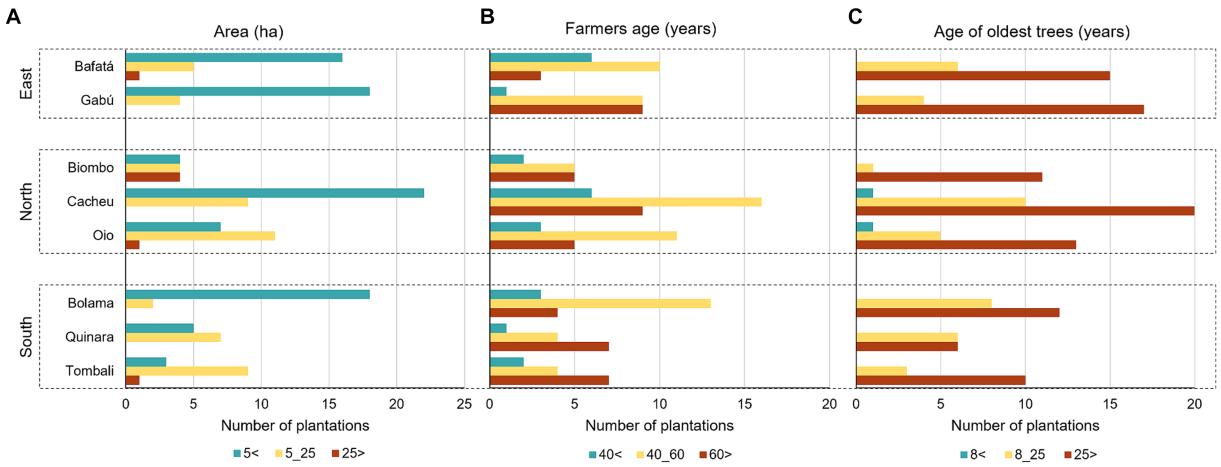

FIGURE 2
Characterization of the cashew production system in Guinea-Bissau, considering agroecological zones (North, East, and South), administrative regions (Tombali, Quinara, Bolama, Oio, Cacheu, Biombo, Bafatá, Gabú), and the distribution of **(A)** cashew plantation areas (ha, hectares), **(B)** age of the producers (years), and **(C)** age of the older trees (years).

17.4 ha and 12.3 ha, respectively. The largest single plantation was found in Bafatá (149 ha), which belonged to a private company (Capé), despite the average in this region was only 10.6 ha (Supplementary Table S2). A statistical analysis conducted using the Kruskal-Wallis test revealed significant differences ($p < 0.05$) between Biombo, Tombali, Quinara, and Oio, which included the larger areas, and Gabú, Cacheu, and Bolama which had smaller areas (Figure 3A).

In the studied plantations, the global mean age of older trees was 31 years, ranging from 7 to 80 years. Only two farmers (1.3%) reported that the oldest trees were less than 8 years old, and both farmers were over 40 years old (Figure 2). Biombo exhibited the highest mean with 42 years, while Quinara and Cacheu presented the lowest (29 years). Significant differences ($p < 0.05$) were found only between Biombo and Cacheu (Figure 3B). Regarding general aspects of the cashew plantations, tree density exhibited an average of 286 trees per ha in Guinea-Bissau, ranging from a minimum of 69 (Oio) to a maximum 890 (Cacheu) trees per ha. Cacheu showed the highest mean tree density at 351 trees per ha, while Quinara registered the lowest mean at 188 trees per ha. Significant differences ($p < 0.05$) were found between Quinara, which presented the lower density, and Cacheu, Bafatá, and Bolama, which exhibited higher tree densities (Figure 3C).

Farmers predominantly reported the presence of cashew apples with both colors (yellow and red; 66.2%) and exhibited a notable preference for the native cashew red apple referred to as "di terra" ("from land"; 76.8%; Supplementary Table S3). However, throughout our field surveys, a great diversity of apple colors and shapes were observed across the different regions screened (Supplementary Figure S1). Moreover, a cashew apple with orange color was observed in several coastal regions (Cacheu, Bolama and Tombali), though not reported by farmers with apple usage. Post-harvest phase was mainly characterized by the non-utilization of cashew apples (54.3%). All administrative regions of the east, Bafatá, and Gabú, as well as Quinara in the south, exhibited over 70% non-utilization of cashew apples. In contrast, Biombo and Bolama showed a higher percentage of utilization (91.6 and 85%, respectively). The collection of cashew fruit was predominantly carried out by family members (60.3%; Supplementary Table S3).

Our study recorded that in the year 2020, the mean cashew nut production was 0.5 tons per ha in the country, ranging from 0.03 to 5.6 tons per ha. Bafatá and Cacheu presented the highest mean production values (0.8 and 0.6 tons per ha, respectively), while Oio had the lowest mean production (0.2 tons per ha). However, no significant differences were found across regions (Figure 3D). Farmers (37.7%) reported an increasing trend in cashew nut yield between 2019 and 2020 (Supplementary Table S3). However, there was a decreasing trend in cashew nut prices over the same period, both as practiced by farmers (37.7%) and the value set by the government (68.9%; Supplementary Table S3). In Guinea-Bissau, the mean price of cashew nuts per kilo set by farmers was 358 West Africa CFA franc (XOF), the currency shared by eight West African nations including Guinea-Bissau (corresponding to 0.58$ in May 2020). In most administrative regions, the price of cashew nuts per kilo set by farmers was lower than that set by the government at 375 XOF (0.62$) in 2020 (Figure 4). However, in the North zone, specifically in Cacheu and Oio, as well as in the South zone in Quinara, the prices set by farmers were higher than those set by the government with XOF means at 387 (0.64$), 376 (0.62$) and 379 (0.62$), respectively. Contrary, Bafatá showed the lowest price of cashew nuts set by farmers with a mean at 311 XOF (0.51$). A statistical analysis using the Kruskal-Wallis test revealed significant differences ($p < 0.05$) only between Bafatá, which had the lowest mean price, and Cacheu, with the highest mean price.

3.2 Phytosanitary status across the Guinea-Bissau regions

Concerning the phytosanitary status, the surveys identified 14 pests and 8 diseases according to cashew producers (Table 1). Cashew pests cause damage such as trunk or large branches boring, mining or feeding on leaves, and superficial fruit damage. Cashew diseases resulted in symptoms including leaf spots, superficial walnut spots,

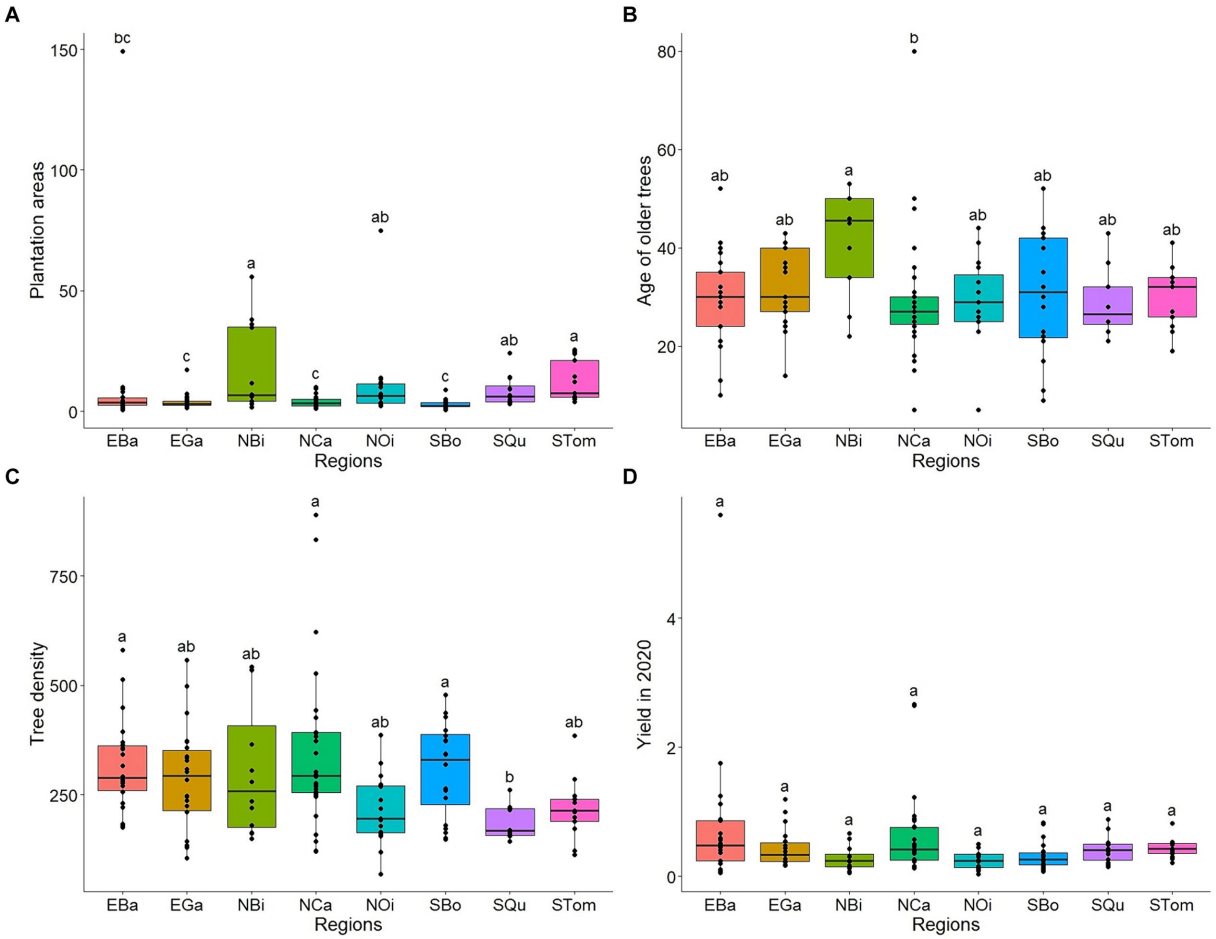

FIGURE 3
Boxplot of **(A)** cashew plantation areas (hectares), **(B)** age of older trees (years), **(C)** tree density (trees per hectare), and **(D)** yield in 2020 (tons per hectare) across administrative regions for characterization of the cashew production system in Guinea-Bissau. Administrative regions: East; EBa - Bafatá, East; EGa - Gabú, East; North: NBi - Biombo, North; NCa - Cacheu, North; NOi - Oio, North; South: SBo - Bolama, South; SQu, Quinara, South; STom, Tombali, South. Different letters indicate significant statistical differences ($p \leq 0.05$) by the Kruskal-Wallis test.

cankers, and dieback on trunks and branches. The surveyed farmers reported an average in Guinea-Bissau of 6 pests occurring in their cashew plantations. However, in Cacheu, Oio, Tombali, and Bolama, the mean numbers reported were higher than 6, contrary to Quinara, Gabú, Biombo, and Bafatá which were lower than 5. The average number of identified diseases by cashew orchards in Guinea-Bissau was 4. Higher means were found in Oio (6 diseases) and Cacheu (5 diseases). The lower mean values were reported in Quinara (only one disease), Gabú, and Biombo (two diseases each; Supplementary Table S2). The occurrence of the African mistletoe and the siam weed was reported in 27.2 and 12.6% of the farms, respectively (Supplementary Table S3).

The correlation between the characteristics of cashew production systems and the occurrence of pests showed a significant positive relation (p-value ≤ 0.05) between the area of the plantation and the presence of twig borer ($r = 0.02$; $p = 0.0399$), thrips ($r = 0.07$; $p = 0.0251$), and African mistletoe ($r = 0.19$; $p = 0.00612$; Figure 5). The age of the older trees also presented a positive correlation with the African mistletoe ($r = 0.17$; $p = 0.0073$). Tree density does not have a significant correlation with the presence of pests and diseases. Conversely, termites ($r = -0.15$; $p = 0.0396$), black rot of the stem ($r = -0.18$; $p = 0.0474$), and African mistletoe ($r = -0.25$; $p = 0.0224$) had a significant negative correlation with the yield in 2020. Pests and diseases occurrences according to farmers displayed a very uneven distribution in the different regions of Guinea-Bissau. Figure 6A illustrates the occurrence of pests by region, providing an intuitive visualization of their distribution. Oio, Tombali, and Bolama were the administrative regions most affected by pests, with Oio showing a high occurrence of trunk xylophage, African grasshopper, stem borer, and thrips, while Tombali exhibited higher occurrences of twig borer and stink grasshopper. Bolama showed elevated values for the occurrence of caterpillar and leaf miners. Gabú presented the lowest occurrences of pests (number of pests).

Regarding diseases (Figure 6B), Oio and Cacheu showed high occurrences for a greater number of diseases, with Oio primarily associated with the occurrence of pestalotia leaf spot, black leaf spot, anthracnose, and dieback. Bolama stood out for the highest occurrence of algae, but septoria leaf spot and xanthonomas spot also had a high occurrence. Gabú and Quinara appeared to be the regions with the lower occurrence of diseases.

The top five pests, referring to those most frequently found in cashew plantations, were termites (occurring in 123 plantations),

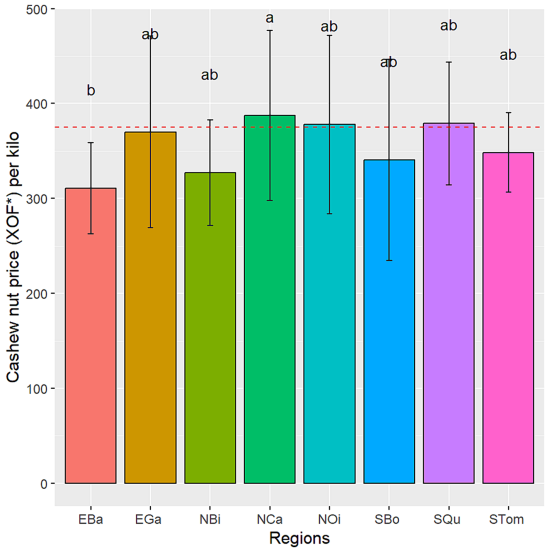

FIGURE 4
Mean prices of cashew nuts reported by farmers in 2020 (XOF – West Africa Franc) across administrative regions of Guinea-Bissau. The price reported by the government in 2020 is shown by the red dashed line. Different letters indicate significant statistical differences ($p \leq 0.05$) by the Kruskal-Wallis test. *607 XOF = 1 $ US in May 2020, according to Exchange Rate (2024).

branch girdler (94), weaver ants (84), African grasshopper (70), and stem borer (67). Quinara and Biombo were the regions where these pests were more prevalent, representing 82.4 and 76.7% of the total pests reported by farmers, respectively (Figure 7A). In Tombali (53.3%), Oio (52.1%), Cacheu (50.2%), Gabú (49.2%), and Bafatá (49.0%) these five pests together accounted for about half of the total. In Bolama, they exhibited a lower representation, at about 41.1%.

Regarding the top five diseases observed in cashew plantations, gummosis (occurring in 131 plantations), anthracnose (82), dieback (79), septoria leaf spot (73), and black leaf spot (63) were the most prevalent. These diseases were especially representative in Biombo and Quinara regions, accounting for 96.3 and 86.7%, respectively (Figure 7B). At Oio (74.6%), Gabú (74.4%), Tombali (72.7%), and Cacheu (72.4%), the proportion of these diseases exceeded 70%. Bafatá (69.3%) and Bolama (68.3%) exhibited relatively lower prevalence rates.

The African mistletoe (*T. bangwensis*) was identified in 41 cashew plantations, predominantly in Biombo (12 occurrences) and Oio (8 occurrences; Supplementary Figure S2). The siam weed plant was observed in only 19 plantations, especially in Biombo (4) and Bolama (4). Interestingly, this species was absent from the Cacheu cashew plantations visited.

4 Discussion

4.1 Socio-economic characteristics portraying cashew plantations

In Africa, men predominantly oversee cashew production due to societal traditions and customary rules limiting women's rights to land or inheritance, also restricting women's land access (Saïdou et al., 2007). Our study highlights that 96% of surveyed farmers are male, which is consistent with other West African cashew-producing countries, namely Togo (96.5%, Assih and Nenonene, 2022), Nigeria (62.50–81.88%, Oluyole et al., 2017; Akinpelu et al., 2021), Benin (83.3%, Bello et al., 2017), and Ghana (61.4%, Wongnaa, 2013), contrariwise to Tanzania, where the majority of farmers were females (70.5%; Mallya, 2013). Gender disparities in agriculture, including cashew production, often stem from deeply ingrained societal norms and cultural practices that limit women's access to land, resources, and decision-making power. These restrictions not only affect women's economic opportunities but also perpetuate cycles of poverty and inequality. In Guinea-Bissau specifically, patriarchal structures and customary laws often prioritize men's rights to land and inheritance, leaving women with limited opportunities to engage in cashew production or benefit from its economic returns. As a result, women's participation in the cashew value chain, from farming to processing and marketing, tends to be lower compared to men (Ingram et al., 2015).

In our study, about 47.7% of cashew producers were between 40 and 60 years old, which is consistent with findings from other studies conducted in African countries (Mallya, 2013; Oluyole et al., 2017; Akinpelu et al., 2021). Previous studies have also reported even higher ages ranging from 50 to 90 years (e.g., an average of 59.81 years in Benin; Bello et al., 2017). Several factors contribute to this age distribution, namely cashew farming often requires significant experience and knowledge of agricultural practices, which older individuals may have accumulated over years of working in the sector. The interplay between inheritance practices, land access, and generational preferences significantly influences the age demographics of cashew producers (Oluyole et al., 2017; Hashmiu et al., 2024). Older farmers often have inherited land or established their cashew farms earlier, which can limit opportunities for younger farmers to access land and engage in cashew farming (Bello et al., 2017). Limited access to land due to inheritance practices, as well as preferences for alternative livelihoods in urban areas, contribute to the challenges younger individuals encounter when considering cashew farming as a viable option. This can lead to a skewed age distribution within the sector, with fewer younger individuals participating observed in our study.

Regarding the size of the cashew plantations, most orchards were typically less than 5 ha (61.6%) throughout the country, which is common in most African countries where smallholder farming is a significant component of the continent's agricultural landscape and plays a crucial role in food security, rural livelihoods, and economic development (Larson et al., 2016). Smallholder farmers are typically characterized by their relatively small land holdings, often less than 5 hectares, and their reliance on family labor and traditional farming practices, which can vary across the continents (Eastwood et al., 2010). Thus, land size is a fundamental component for defining and characterizing smallholder farms. In this work, we consider that smallholder farms based on land size and the use of <5 ha limit alone provide an adequate picture of the nature of smallholder farmers in Guinea-Bissau, in accordance with other West African cashew producing countries where most orchards were usually less than 5 ha (Benin, Miassi et al., 2019; Hinnou et al., 2022; Nigeria, Oluyole et al., 2017), or even less than 3 ha (Togo, Assih and Nenonene, 2022; Benin, Bello et al., 2017). Most farmers lack physical capital (buildings, machinery, and technical equipment), relying on the use

TABLE 1 Socio-economic and phytosanitary variables were analyzed to characterize the cashew system across 151 plantations of Guinea-Bissau.

Socio-economic variables		Code
Age of the surveyed farmers (years)		Farmer_age
Cashew plantation areas (hectares)		Area_farm
The age of older cashew trees (years)		Age_older_trees
Tree density (trees per hectare)		Tree_density
The nuts yield in 2020 (Tons per hectare)		Yield_20
Total pests (number of different pests)		Tpest
Total diseases (number of different diseases)		Tdise
Zone		Zone
Administrative region		Region
Pests common name	**Order: Family (genus or species)**	**Code**
Branch girdler	Coleoptera: Cerambycidae (*Diastocera trifasciata* Frabicius)	Bgi
Trunk xylophage	Coleoptera: Cerambycidae (*Plocaederus ferrugineus* L.)	Xtr
Stem borer	Coleoptera: Bostrichidae (*Apate terebrans* Pallas)	Sbo
Termite	Blatodea: Termitidae	Term
Twig borer	Coleoptera: Curculionidae (*Hypothenemus* sp.)	Btw
African grasshopper	Orthoptera: Pyrgomorphidae (*Phymateus* sp.)	AfrGaf
Stinky grasshopper	Orthoptera: Pyrgomorphidae (*Zonocerus variegatus* L.)	StiGaf
Leaf miner	Lepidoptera: Gracillariidae (*Eteorcyctis* sp.)	Lmi
Caterpillar	Lepidoptera: Saturniidae	Cat
Thrips	Thysanoptera: Thripidae	Thr
Cottony mealybug	Hemiptera: Pseudococcidae	Mco
Protected mealybug	Hemiptera: Coccidae	Mpr
Weaver ants	Hymenoptera: Formicidae (*Oecophylla longinoda* Latreile)	Want
Aphid	Hemiptera: Aphididae	Aphid
Diseases common name	**Order: Family (genus or species)**	**Code**
Gummosis	*Lasiodiplodia* spp.	Gumm
Dieback	*Neofusicoccum batangarum* Begoude, Jol.Roux & Slippers	Dieba
Anthracnose	*Colletotrichum* spp.	Anth
Black leaf spot	*Pilgeriella anacardii* Bat., J.L.Bezerra, Castr. & Matta. Arx & E.Müll.	Sbl
Septoria leaf spot	*Septoria anacardii* Freire	Sept
Pestalotia leaf spot	*Pestalotiopsis guepinnii* (Desm.) Steyaert.	Pesta
Xanthomonas spot	*Xanthomonas* spp.	Xanth
Algae	*Cephaleuros virescens* Kunze	Algae
Plants common name	**Scientific name**	**Code**
African mistletoe (hemi-parasitic plant)	*Tapinanthus bangwensis* Engler & K.Krause	Mistle
Siam weed plant	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Weed

of low-tech equipment or local tools such as hoes and machetes, which is also a contributing factor to African farmers not practicing good agriculture management techniques even in small fields (Ibrahim, 2015; Kamara et al., 2019). As part of the cashew orchard characterization, tree density was calculated to determine if plant density could be a determining factor influencing the yield performances of cashews. In production practice, optimal yield is achieved in high-density plantations with a planting density between 100 and 180 cashew trees/ha. In our study, most cashew producers adopted tree densities exceeding 100 plants per hectare (average: 286 trees/ha; Figure 8A), much higher than the average 192 plants per hectare reported in Togo (Assih and Nenonene, 2022), and from the recommended 180 trees/ha. While many producers associate high density with enhanced yields, this is generally accurate for young trees, due to low canopy density. However, as the tree matures without adequate pruning and thinning practices, yields decline due to heightened competition for light or nutrients (Nayak et al., 2020).

Guinea-Bissau's cashew plantations have an average age of 31 years, cashew trees start bearing fruit after a 2 to 4 years of planting and continue to produce for 25–30 years (Chemonics International

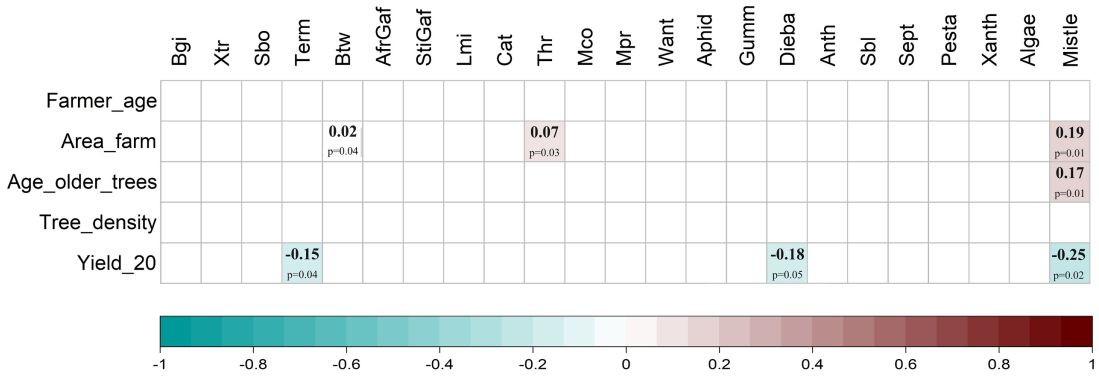

FIGURE 5
Correlation matrix of the characteristics of the cashew production system in Guinea-Bissau and pests, diseases, and mistletoe occurrence. On the color scale, red represents positive correlations while blue represents negative correlations; darker color tones represent larger correlation coefficients. Phytosanitary problems: Bgi, Branch girdler; Xtr, Trunk xylophage; Sbo, Stem borer; Term, Termite; Btw, Twig borer; AfrGaf, African grasshopper; StiGaf, Stinky grasshopper; Lmi, Leaf miner; Cat, Caterpillar; Thr, Thrips; Mco, Cottony mealybug; Mpr, Protected mealybug; Want, Weaver ants; Aphid, Aphi; Gumm, Gummosis; Dieba, Dieback; Anth, Anthracnose; Sbl, Black leaf spot; Sept, Septoria leaf spot; Pesta, Pestalotia leaf spot; Xanth, Xanthomonas spot; Algae, Algae; Mistle, African mistletoe. Only statistically significant coefficients (p-value ≤0.05, by the Kruskal-Wallis test) and the respective p-values are presented.

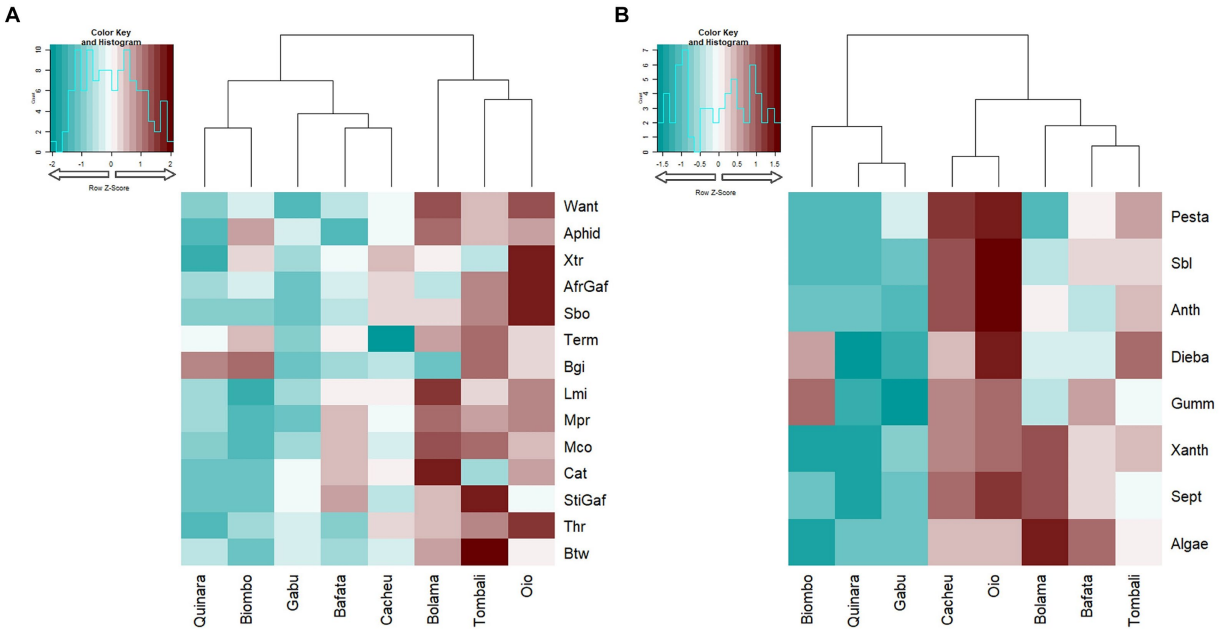

FIGURE 6
Heatmap presenting the clustering of **(A)** pest and **(B)** disease distributions across administrative regions in Guinea-Bissau. Darker red and darker blue boxes indicate high positive and negative values, respectively. Color key/histogram indicates the number of coefficient values (Z-scores) within each color bar. Pests: Want, Weaver ants; Aphid, Aphi; Xtr, Trunk xylophage; AfrGaf, African grasshopper; Sbo, Stem borer; Term, Termite; Bgi, Branch girdler; Lmi, Leaf miner; Mpr, Protected mealybug; Mco, Cottony mealybug; Cat, Caterpillar; StiGaf, Stinky grasshopper; Thr, Thrips; Btw, Twig borer. Diseases: Pesta, Pestalotia leaf spot; Sbl, Black leaf spot; Anth, Anthracnose; Dieba, Dieback; Gumm, Gummosis; Xanth, Xanthomonas spot; Sept, Septoria leaf spot; Algae, Algae.

Inc, 2002). In other West African countries like Togo and Benin, most cashew trees were over 10 years old (Bello et al., 2017; Assih and Nenonene, 2022). However, in Guinea-Bissau, most of the oldest cashew trees surpass the considered highly productive age of cashew (less than 25 years; Figure 8B). In the country, there is a limited renewal of cashew plantations which contributes to the old age of cashew trees, and together with the high tree density, these features pose determining factors for decreasing yield performances. Additionally, a considerable proportion of cashew producers in West Africa maintain the belief that the age of cashew trees does not significantly affect yield (e.g., 67% of cashew producers in Nigeria, Akinpelu et al., 2021). However, it is important to note that the economic lifespan of cashew trees is generally considered to be 20 to 25 years, after which yields tend to decline (Amanoudo et al., 2022).

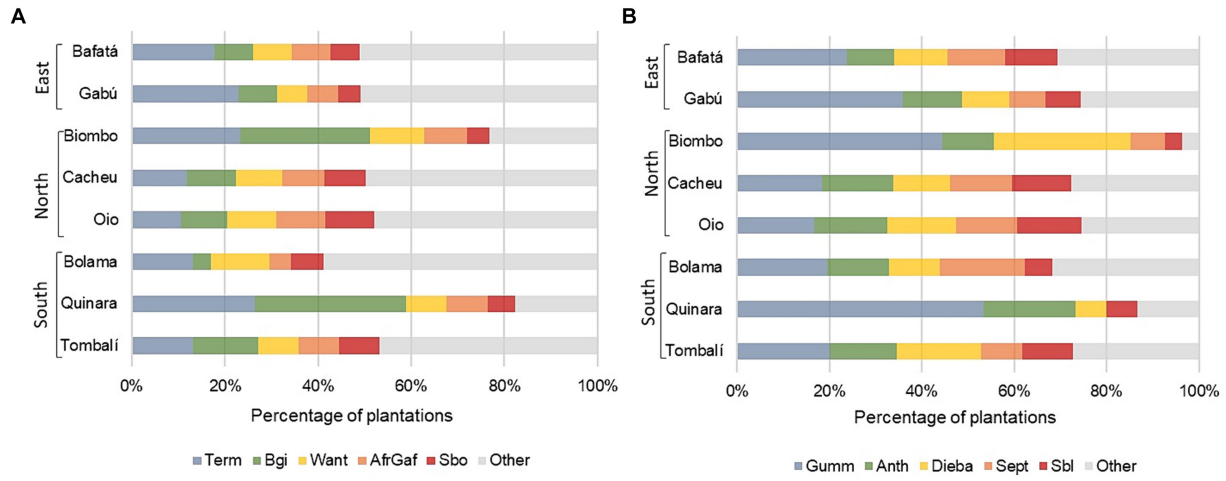

FIGURE 7
The top five pests **(A)** and diseases **(B)** identified in Guinea-Bissau, with their prevalence in cashew plantations across each administrative region. Pests: Term, Termite; Bgi, Branch girdler; Want, Weaver ants; AfrGaf, African grasshopper; Sbo, Stem borer; Others: Leaf miner; Protected mealybug; Cottony mealybug; Caterpillar; Stinky grasshopper; Thrips; – Twig borer, Trunk xylophage, and Aphid. Diseases: Gumm, Gummosis; Anth, Anthracnose; Dieba, Dieback; Sept, Septoria leaf spot; Sbl, Black leaf spot; Others: Pestalotia leaf spot; Xanthomonas spot, and Algae.

FIGURE 8
(A) Orchards with high-density trees (plants per hectare) from Biombo, are common in cashew plantations in Guinea-Bissau. **(B)** Cashew tree with more than 25 years. **(C)** African mistletoe (*Tapinanthus bangwensis*), a hemi-parasitic plant in a cashew tree. Photos by Filipa Monteiro **(A,B)** and Luís Catarino **(C)**.

In our study, cashew harvest relied mostly on family labor, a pattern consistent with findings from other cashew-producing countries where 62.5% of the workforce is predominantly familiar (Ibrahim, 2015), also pointing out that family size plays a determinant role in production levels and household income. In Guinea-Bissau, cashew harvest involves a manual separation of cashew nuts from the apple, with nuts being dried in the sun for 2–3 days to reduce the moisture from 25% to 8–9%, before selling. Most cashew producers abstained from utilizing cashew apples, consistent with findings from Tanzania and Ghana, where 90% of cashew apples went unused. Reasons contributing to this include limited knowledge of cashew apples health benefits, inadequate processing and harvesting equipment, and high perishability (Dimoso et al., 2020; Akyereko et al., 2022). Furthermore, in Guinea-Bissau, certain religious constraints play a key role in the non-utilization of cashew apples, particularly in the administrative regions within the East zone, where over 70% of cashew apples remain unused. Due to the prevalence of Muslim beliefs among the local population in Guinea-Bissau, which discourage the consumption of alcoholic beverages, cashew apples in the region are primarily used for making juices, which due to high temperature during harvest season, can easily turn into wine

due to alcoholic fermentation (Catarino et al., 2015). This fact contributes to the phenomenon of abstaining from utilizing cashew apples also for other purposes (Abdrakhmanova and Moghavvemi, 2022; Sarfo et al., 2023).

Regarding this study, the presence of African mistletoe was recorded in nearly one-third of the cashew plantations (37%; see Figure 8C). According to Watson et al. (2020), the African mistletoe (*T. bangwensis*) may have a low presence in fruit trees such as cashew cultivated outside its native range. However, a high incidence of this hemi-parasitic plant was reported outside the native range, specifically in cocoa crops in Equatorial Africa (Room, 1972; Watson et al., 2020). In West Africa, in economically important crops like cashew reports documented the presence of several genera of hemi-parasitic plants from the Loranthaceae family, the same family as *T. bangwensis* (Malami et al., 2017). Mistletoes exhibits both generalist species, which are not selective of their hosts, and specialist species, which are restricted to specific hosts, particularly fruit-bearing plants. For example, *T. bangwensis* has been documented to infect 43 hosts across 18 plant families (Adesina et al., 2013). This underscores the necessity of implementing control measures (e.g., mechanical removal) to prevent its propagation on cashew plantations, particularly in coastal regions.

Some characteristics of cashew plantations can vary significantly across different administrative regions within a country and are crucial for characterizing the cashew production system. According to Bello et al. (2017), the low, medium, and high productivity of cashew in Benin was characterized primarily by the area of cashew plantations, the age of cashew trees, and tree density, which exhibited statistical differences among regions. In our study, key characteristics distinguishing administrative regions were cashew plantation area, age of older cashew trees, and tree density (Figure 3). However, Guinea-Bissau's regions showed no significant difference of yield in 2020 across the different regions. Biombo and Tombali showed relationships between larger cashew areas and older tree age, and these characteristics combined with the high occurrence of African mistletoe, may have contributed for the low yield recorded in 2020. Conversely, Cacheu and Bafatá had the highest yields in 2020, characterized by high tree density and younger trees compared to the country average. Oio region reported the lowest yield in 2020, despite having below average tree ages, likely due to high pests and diseases occurrences.

Government intervention can play a crucial role in addressing various challenges and enhancing the sector's overall performance. Thus, effective interventions can support farmers, improve infrastructure, facilitate market access, and promote sustainable development (World Bank, 2019). In Guinea-Bissau, the National Cashew Agency (ANCA-GB) is the governmental institution responsible for setting the annual cashew nut price per kilogram as a regulatory measure for producers and farmers (Ministério das Finanças da Guiné-Bissau, 2020). Additionally, taxes are applied on cashew nut exports, with the beneficiaries being governmental institutions (e.g., Ministry of Agriculture, ANCA-GB, National Confederation of Cashew Sector Stakeholders-, National Farmers' Association- ANAG, National Institute for Agrarian Research- INPA) with no direct revenues to farmers. Institution fragility and political instability in Guinea-Bissau has been detrimental to overall investment and development financing, as well as the long-term implementation of measures (Havik, 2016). Furthermore, government initiatives to promote local processing of cashew nuts are scarce, and even when implemented, farmers encounter high costs due to unstable electricity supply, lack of certification mechanisms for exports, and challenges in the export capacity at the Port of Bissau. Access roads to rural communities across most regions are a primary constraint, particularly during the rainy season, hindering truck access for transporting cashew nuts to the port of Bissau thus interrupting the supply chain. This contributes to traders taking advantage and reducing the government-set base price for cashew purchases in some communities. Additionally, traders practice high export duties as another reason for offering lower prices to cashew producers, especially outside cashew season (Havik, 2016). Among such supportive policies that would be beneficial include favorable tax regimes, subsidies for agriculture inputs and incentive for local processing, which unfortunately are not yet implemented in the country. Also, establishing quality standards of cashew nuts using KOR value would be important to enhance competitiveness in international markets.

4.2 Cashew nut yield and price: important variables impacting smallholders' livelihoods

Overall, the yield of cashew nuts per hectare can vary depending on several factors, including agricultural practices, climate, soil conditions, and the variety of cashew trees grown, as well as regional conditions (e.g., Ibouraïman et al., 2015; Sanchez et al., 2024). On average, a well-managed cashew plantation can yield between 0.5 to 2 tons of raw cashew nuts per hectare per year. Factors such as irrigation, fertilization, pest management, and the age of the trees can significantly impact the yield. The average cashew nut yield in Guinea-Bissau was below 0.5 tons per hectare in all regions (Figure 3D), which is consistent with Ibrahim (2015) findings in Tanzania, where 46.25% of respondents also reported yields ranging from 0.25–0.5 tons per hectare; as well as in Ghana (Danso-Abbeam et al., 2020), contrariwise to the high-yield values reported in Nigeria (2.28 tons/ ha, Adeigbe et al., 2015). The low yield performance in almost all regions in Guinea-Bissau could be associated with several factors, namely high planting density (i.e., > 150 trees/ha), irregular orchard maintenance, no selection of best-performing cashew trees, poor harvest, and post-harvest practices. It can be asserted that the present low productivity per hectare of cashew is mainly attributable to the use of non-selected varieties, non-adoption of recommended planting and management orchard practices, and maintenance of old orchards (Aliyu, 2005; Amanoudo et al., 2022). Thus, there is a great gap between the average yield harvested and the potential yield that cashew crop can produce under optimum growth conditions. A high value of raw cashew nut production in West Africa is attributed to an increase in plant area rather than yield (Monteiro et al., 2017; Kouakou et al., 2018), which has been linked to poor-yielding trees that make up a major part of the cashew tree population in Africa (Sika et al., 2015; Dadzie et al., 2020), resulting in highly variable tree yields in farmers' fields. In our study, we observed similar yield performance across screened regions, but distinct factors contributed to these outcomes. For instance, in Biombo (North), despite having larger farm areas, orchards feature the oldest trees in the country combined with high density. Conversely, in Bafatá (East), where yields were higher (up to 1 ton/ha), farmers leverage older trees and high-density orchards but also select superior-performing varieties based on tree vigor and nut quality.

The cashew market in Guinea-Bissau is highly open and liberalized, allowing exporters to directly engage with various supplier categories, leading to internal price fluctuations. During the market season, prices with informal traders may be higher but generally fall below the government's set floor price at the start of the season (Muder et al., 2024). Unfortunately, due to farmers' heavy reliance on cashew income and existing debts outside the cashew season, they often accept extremely low prices, such as 50 XOF ($ 0.08) per kilo. This situation raises concerns about poverty alleviation and food security in the country. The low prices also limit farmers' purchasing power to invest in agricultural practices that could improve yields. According to our study, the average price set by surveyed farmers in 2020 was 375 XOF per kilo (approximately $ 0.62), exceeding the average price of 300 XOF per kilo (approximately $ 0.50) reported by the Ministério das Finanças da Guiné-Bissau (2021), for cashew nuts in Guinea-Bissau in the same year. Mallya (2013) highlighted a positive correlation between cashew production and cashew nut prices in Tanzania. In contrast, our findings in Guinea-Bissau revealed a negative relationship between the price of cashew nuts set by farmers and cashew nuts yield in 2020 in most administrative regions (except in Cacheu). Despite an increasing yield trend from 2019 and 2020 reported by the farmers surveyed, there was a corresponding decline in prices during this period. In Guinea-Bissau, and overall, an overlooked factor in cashew nut pricing is the assessment of nut quality, particularly the Kernel Outturn Ratio (KOR), which indicates the percentage of the cashew nut's weight that consists of the kernel after processing (Bassett et al., 2018). Cashew nuts with higher KOR values are more valuable due to their better quality and processing efficiency. Understanding KOR is crucial for farmers and traders as it directly impacts the value and marketability of cashew nuts, ultimately resulting in better returns for producers in the cashew industry. The average KOR of raw cashews in Guinea-Bissau is around 52–54 lbs. (LIFFT-Cashew, 2022), which is comparable to other West African countries such as Burkina Faso (above 50 lbs., Semporé et al., 2021), Nigeria (46–48 lbs), Ghana (44–48 lbs), Tanzania (45–52 lbs), and Côte d'Ivoire (48–52 lbs; Dahiya, 2016; Bassett et al., 2018). According to joint standards set by the EEC (European Economic Community) and UN (United Nations) member states for selling cashew nuts in the international market, a good KOR should exceed 50 lbs. (Semporé et al., 2021 and references therein). The overall quality of KOR in Guinea-Bissau and most other West African cashew-producing countries is considered excellent, which explains the high purchasing of cashew nuts from this region in the international market. Therefore, this value should be recognized as a quality certificate by the government to both increase and stabilize the price of cashew nuts on an annual basis. This approach is instrumental in enhancing cashew productivity and supporting household annual income. The economic downturn in 2020, exacerbated by the COVID-19 pandemic, likely contributed to declines in the cashew sector as reported in other West African countries (e.g., Ouattara et al., 2020), as reported by the Ministério das Finanças da Guiné-Bissau (2021), with a 6.2% decrease in cashew production.

Seasonal income (only during cashew harvest season), market fluctuations of cashew prices, poor infrastructure with limited access to markets, poor storage facilities, and transport (International Monetary Fund, 2020), contribute not only to create debt but also to difficulties in repaying existing debts. Also, many farmers are not equipped with knowledge to manage finances effectively, leading to poor debt management and increased vulnerability to predatory loan practices, inconsistent or inadequate governmental support and policies impact farmers' ability to manage and repay debts effectively. During the months of October to December (the period after the cashew harvest and before the harvest of crops such as rice, peanuts, and other crops), producers take loans of rice and some essential products from traders (Havik et al., 2018), which they repay during the cashew harvest season with a 50% interest rate. Formal credit options in the country are scarce, and when available, they require insurances that small-scale farmers cannot provide, thus limiting their ability to manage and refinance existing debts (World Bank, 2019). Moreover, community expectations and social obligations often lead farmers to prioritize immediate needs over long-term debt repayment, leading to a positive feedback loop of long-term debt maintenance and aggravation. The government, through its economic partners, implemented agricultural credit systems to support producers, but such initiatives have not achieved the expected success, primarily due to the lack of farmers' awareness of the benefits and access conditions (e.g., credit bank for the agricultural sector in Guinea-Bissau in 2011; Welle, 2011) with only one loan, the first agricultural credit Bank launched in 2023 by the government in partnership with the Canadian group "Jd Euroway," (Fédération Atlantique des Agences de Presse Africaines, 2023) and to the continuous cycle of initiating and terminating initiatives (e.g., agricultural credit system at Orabank, in partnership with the government of Guinea-Bissau). The government has recently established an investment and development plan (Câmara de Comércio Indústria Portugal Guiné-Bissau CCIPGB, 2023) to cope with social constraints affecting farmers and rural communities namely at the establishment of roads and rural tracks to improve access to market facilities, growth of the cashew value chain as well as the diversification and enhancement of other food crops to reduce reliance on cashew cultivation revenues alone, and guaranteeing an establishment of a rice production system (mangrove rice), ensuring the main staple crop all year around, reducing food insecurity outside cashew market season. These multifaceted factors including improving access to affordable credit tailored to the needs of cashew farmers, such as low-interest loans and microfinance options; providing financial education and developing infrastructure and market access are important means to ensure the profitability of cashew farming, affecting the farmers' ability to repay debts (World Bank, 2019).

4.3 Relationship between socioeconomic factors and the occurrence of diseases and pests

Pests and diseases severely limit cashew production in West Africa, resulting in diminished yields and nut quality (Babatunde et al., 2023). In our study, the occurrences of pests, specifically termites and dieback, negatively affected yield in 2020, while diseases had no significant impact. These findings are in accordance with observations from Nigerian cashew plantations, where pest attacks including branch girdler, stem borer, termites, and grasshopper were strongly associated with yield reduction. Notably, 57% of Nigerian cashew producers considered pest attacks a severe problem, identifying them as a primary factor contributing to low yields (Agbongiarhuoyi et al., 2015). This study also found that the age of older cashew trees did not correlate with pest occurrence. In contrast, in Côte d'Ivoire, older

cashew orchards presented a progressive increase in termite attacks, while the grasshopper (*Zograohus regalis* Browning, 1776) attacks decreased (Diabaté et al., 2021).

The perception of cashew diseases by farmers is an important aspect of agricultural management and production. Farmers' ability to identify and recognize cashew diseases is essential for early detection and effective management (Malekela and Kitali, 2021). They often rely on visual symptoms such as leaf discoloration, spots, lesions, or abnormal growth patterns to diagnose potential diseases in their cashew orchards, which depend on extension services for informed identification and control measures, agricultural advisors, and local agricultural organizations. Access to accurate and timely information about cashew diseases is crucial for effective disease management. There is a general understanding of the detrimental impact that cashew diseases can have on yield and income, which can lead to reduced nut production, poor nut quality, and an overall decline in orchard health, which directly affects farmers' livelihoods. Cashew diseases in Nigeria exhibited no significant relationship with cashew nut yield, with only 26% of producers regarded the diseases as highly impactful on yield (Agbongiarhuoyi et al., 2015).

Our findings revealed a positive correlation between farm areas and the age of older trees, while a negative correlation of farm areas or age of older trees was observed with yield in 2020. The presence of older trees combined with inadequate management practices, such as the absence of sanitary pruning, is a significant factor contributing to the spread of pests and diseases and subsequent yield reduction in cashew orchards. Additionally, in older orchards with high planting density, particularly in coastal regions and the Bijagós archipelago (Bolama region), there is a notable prevalence of African mistletoe that negatively impacts cashew plants, often resulting in dieback and plant mortality. The most effective method for managing mistletoe in horticultural plantations is mechanical removal through pruning infected branches (Watson et al., 2020). However, this approach is labor-intensive, presenting challenges for implementation in large areas or with older, taller trees. Overall, the farmers' inability to identify current phytosanitary issues in cashew orchards, largely due to the absence of agricultural extension services, perpetuates the maintenance of unhealthy trees. Many of these trees are already yielding poorly and are old, which creates a false sense of productivity despite farmers being aware of an overall declining trend in productivity.

4.4 Phytosanitary constraints across Guinea-Bissau: cashew orchards at risk?

The varying occurrence of cashew pests and diseases observed across administrative regions in Guinea-Bissau may also stem agricultural practices. In Tanzania, regional differences in cashew pest incidences were linked to pesticide malpractice and intercropped with annual crops like pigeon peas, beans, and cowpeas, which act as alternative host pests (Assenga et al., 2020). Notably, in Guinea-Bissau, pest and disease occurrences were highest in Oio (North) and lowest in Gabú (East), despite the occurrence of several diseases and pests also across the remaining regions in the country. Malekela (2021) suggests that the prevalence of cashew pests and diseases varies between diverse geographical locations, primarily due to fluctuations in weather patterns. Both Oio and Gabú are among the warmest regions in Guinea-Bissau, being also affected, during the dry season (~November to April), by the Harmattan regime, a yearly trade wind that blows from the Sahara toward the Gulf of Guinea, with transports of Saharan dust (Bergametti et al., 2022). This climatic event co-occurs with the flowering time of cashew (January–March) and several farmers reported the drying of the inflorescences after Hartmann winds, which compromise the overall yield. Furthermore, assessment of pests and diseases according to cashew production stages is important, as reports showed the flowering and leaf-shading stages had a high effect on cashew pests and diseases, while the fruiting stage exhibited a moderate effect (Malekela, 2021). Therefore, since our data were collected during the harvest season, we cannot directly attribute which pests or diseases are impacting specific production stages in cashew production stages.

Concerning cashew pests, in both our study (Figures 9A–G) and in Tanzania, as reported by Assenga et al. (2020), branch girdler was noted among the top 5 reported cashew pests (though it was referred to by the former name *Analeptes trifasciata*; Figure 9C). Notably, the weaver ants (*Oecophylla longinoda*), documented as a predator in Tanzania (Assenga et al., 2020), was reported as a pest by farmers surveyed in our study. Malekela (2021), observed different dominant cashew pests in Tanzania, such as aphids and cashew mosquito bugs, contrary to our study, cashew farmers reported aphids as non-limiting pests and although mosquito bug specimens were observed during fieldwork surveys, no associated damage was recorded, and thus were not considered as pests. Interestingly, most of the top five pests reported in our study (excluding weaver ants) were reported as major pests in Nigeria, contributing to decreased cashew yields (Agbongiarhuoyi et al., 2015).

The top five cashew diseases reported by surveyed farmers in this study (gummosis, anthracnose, dieback, septoria leaf spot, and black leaf spot; Figures 9H–L) were identified as significant contributors to reduced cashew productivity, as reported earlier (Monteiro et al., 2022b) as the main worldwide cashew diseases affecting its productivity. While gummosis is the most prevalent cashew disease worldwide (Monteiro et al., 2022b) and observed in all Guinea-Bissau surveyed regions (Figure 9H), anthracnose mainly affects cashew during the fruiting stage (inflorescences and fruits; Monteiro et al., 2022a; Figure 9I), being mostly prevalent in coastal regions with high humidity. Additionally, *Septoria* sp. (septoria leaf spot; Figure 9K) and *Pilgeriella* sp. (black leaf spot; Figure 9L) represent emerging local cashew diseases (Monteiro et al., 2022b), and our data highlights the emerging potential of the Septoria disease which is prevalent in all territory. Although initially considered negligible, Septoria can significantly impact cashew productivity by affecting mature leaves and promoting chlorotic lesions that impair photosynthetic performance (Freire et al., 2002). While the individual impact of Septoria on each leaf may seem minor at first, a cashew tree with multiple leaves experiencing reduced photosynthetic ability due to *Septoria* sp. can become highly stressed. This stress, especially when combined with suboptimal conditions such as older plant age or co-occurrence with other pests and diseases, ultimately limits the productivity potential of the cashew plant. One important finding was the inexistence of powdery mildew disease, a major cashew nut disease in East African countries where cashew is cultivated (Monteiro et al., 2022b). For instance, in Tanzania cashew plantations, powdery mildew was identified as the predominant disease, causing between 70 to 100% yield losses (Malekela, 2021). Based on our comprehensive

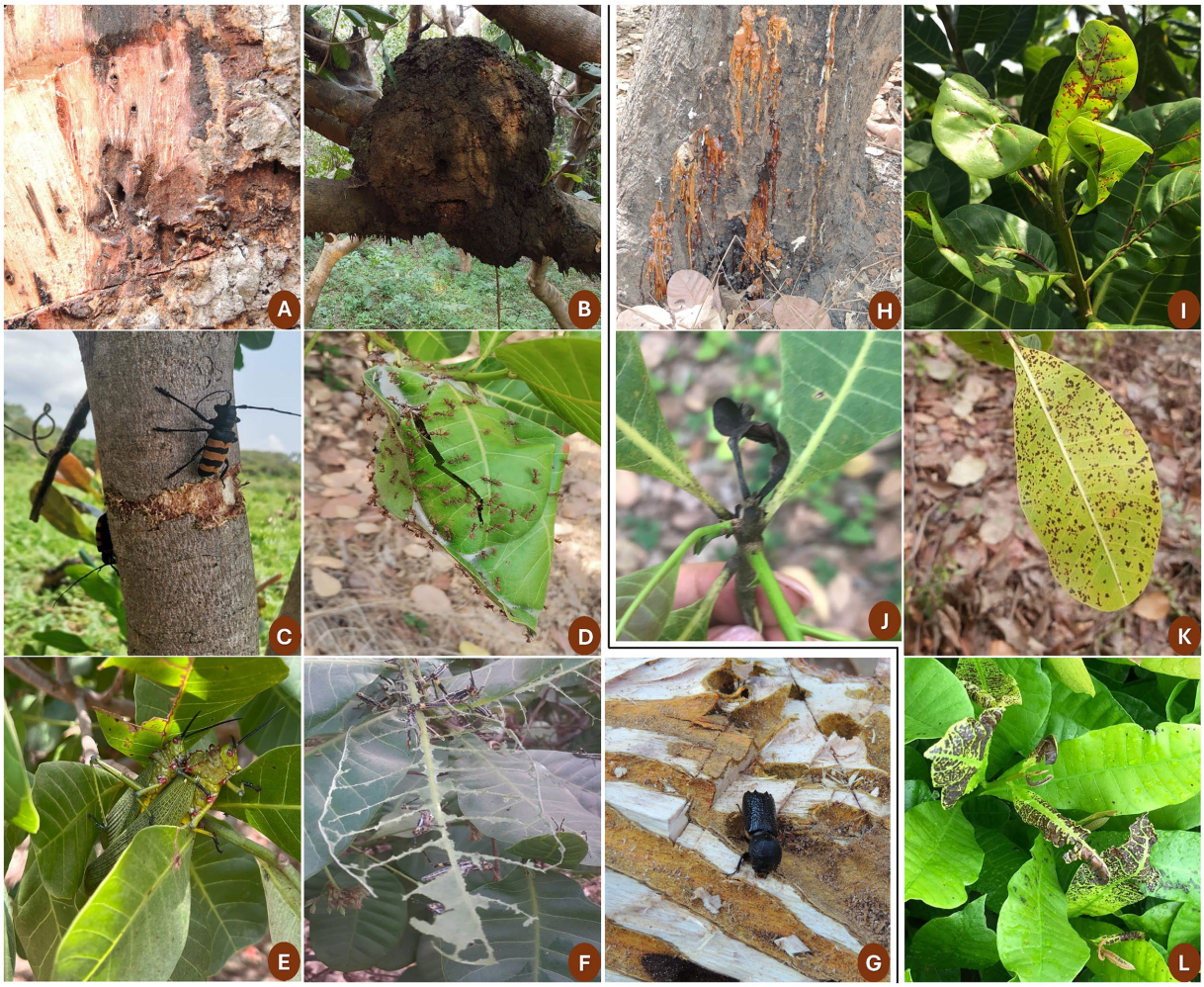

FIGURE 9
The top five pests and diseases in cashew plantations in Guinea-Bissau. **(A)** Termites (Termitidae) damaging cashew stem; **(B)** Termite nest in cashew branches; **(C)** Branch girdler (*Diastocera trifasciata*) damaging cashew stem; **(D)** Weaver ants (*Oecophylla longinoda*) and its nest in cashew leaves; **(E)** African grasshopper (*Phymateus* sp.); **(F)** African grasshopper damage on cashew leaves. **(G)** Stem borer (*Apate terebrans*) damaging cashew stem. **(H)** Stem symptoms associated with gummosis (*Lasiodiplodia* spp.); **(I)** Leaves symptoms associated with anthracnose (*Colletotrichum* spp.); **(J)** Leaves symptoms associated with dieback (*Neofusicoccum batangarum*); **(K)** Leaves symptoms associated with septoria leaf spot (Septoria anacardii); **(L)** Leaves symptoms associated with black leaf spot (*Pilgeriella anacardii*). Photos by Filipa Monteiro **(A–D,F,I–L)**, Paola Sierra-Baquero **(E,H)** and Luís Catarino **(G)**.

study, we can confidently state that powdery mildew is not a phytosanitary issue in Guinea-Bissau.

Besides pests and diseases, two other phytosanitary problems were considered in our study, the African mistletoe, and the invasive siam weed. The higher occurrence of mistletoe in Biombo and Oio (North region) may be attributed to the advanced age of cashew trees in these administrative regions, but also to the prevalence of other fruiting crops such as lemon and orange trees (Adesina et al., 2013). According to Asare et al. (2019), the presence of the hemi-parasitic plant is favored when the host tree possesses larger diameters, a trait frequently observed in older cashew trees. Additionally, Biombo and Oio were the administrative regions with higher cashew areas, a condition that could limit the mechanical control of the mistletoe due to the substantial manpower required (Watson et al., 2020), leading to a high occurrence of the hemi-parasitic plant. Although mistletoes have been recognized as a phytosanitary problem, the knowledge of their effects on yield and tree mortality in horticultural crops is limited, due to the scarcity of published research on the subject, which often relies on subjective evidence or empirical studies based on traditional knowledge (Watson et al., 2020).

In this study, the invasive siam weed was observed predominantly in Biombo and Bolama, in contrast to a previous report (Catarino et al., 2019), indicating its presence solely in southwestern Guinea-Bissau. However, the authors emphasized the likelihood of this species spreading throughout the country, given that the entire Guinean territory typically experiences a rainfall regime conducive to the dispersal of the weed plant (> 1,200 mm/year; Catarino et al., 2019). Furthermore, weeds occupy cleared orchard areas and new agricultural land intended for cultivation. Additionally, the presence of the siam weed plants in cashew plantations is noteworthy because they serve as alternative hosts for certain pests. For instance, *C. odorata* has been identified as an alternative host of the cashew pest, specifically the tea mosquito bug (*Heliopeltis theivora* Waterhouse), during the off-season of cashew in India (Srikumar and Shivarama,

2013). While producers in Guinea-Bissau did not consider the tea mosquito bug as a primary cashew pest, it remains crucial to recognize its potential in cashew plantations in Guinea-Bissau.

4.5 Safeguarding cashew agroecosystem in Guinea-Bissau

Despite the significant importance of cashew as a commodity crop in Guinea-Bissau and the expansion of cashew cultivation, this crop faces challenges related to low and inconsistent nut yields, despite its recognized high kernel outturn internationally. The absence of varietal selection and the prevalence of insect pests and diseases pose major problems in the country, exacerbated by high planting density and the presence of older trees throughout all regions. Future strategies should prioritize germplasm selection and preservation, experimental trials, and the production and distribution of improved cashew planting materials. So far, no genetic characterization of cashew varieties from Guinea-Bissau has been reported; however, two types of cashews are known in the country; "Caju di Mozambique" and "Caju di terra." Despite having smaller nuts, "Caju di terra" predominates in Guinea-Bissauan cashew orchards due to the tastier apples used for juice (Monteiro et al., 2017).

Effective management and breeding for resistance to these diseases and pests are required to boost the yield potential of African cashew germplasm. World cashew production has continued to increase steadily over the years, Africa's share however, must be sustained, and Guinea-Bissau's contribution as the top 10th exporters of cashew nuts should be ensured in the long run.

Research was conducted within Guinea-Bissau on the feasibility of developing cashew as a cash crop in the 1940s, considering prior experience in Mozambique, a major cashew producer at the time (Havik et al., 2018). Several tens of hectares of orchards were planted, and nurseries were created in Bafatá, Bissau, Bolama Island, Canchungo (Cacheu), and Prábis (Biombo) as part of its extension work (Catarino et al., 2015). There is no varietal selection at the smallholder farmer's level. Due to the lack of advancement in cashew cultivars, Monteiro et al. (2017) study brought attention to the detrimental potential of diseases impacting cashew orchards in Guinea-Bissau. The aging of cashew trees and the lack of improved cultivars contribute to low productivity, with local cashew trees being descendants of older genotypes in need of improvement. Pest and disease infestations continue to limit cashew production in West Africa, resulting in low yields and poor nut quality. The lack of genetic diversity and genetic improvement efforts in cashew-producing nations in West Africa are significant concerns. To the best of our knowledge, West Africa has no published records of improved cashew cultivars as found in other producing regions (e.g., India, Brazil), as the result of the lack of sufficient funding for research and development in most of the cashew-producing countries. In Guinea-Bissau, for example, fund scarcity led to the abandonment of compelling research projects that could have been extremely beneficial for cashew production and improvement (Catarino et al., 2015). Also, varietal selection at the small farmer level and the development of orchards to boost productivity have not been prioritized.

The identification of strong parental lines is also crucial for improving the efficacy of the hybridization procedure. It is necessary to conduct a thorough assessment of cashew-growing regions, record existing genetic resources (Guterres et al., 2023), and evaluate (characterize) these materials for practical agronomic and yield qualities across the country and select the best-performing accessions according to the different agroecological conditions, to guarantee the best yield. To ensure sustainable cashew production in Guinea-Bissau, it is essential to develop high-yielding selections with desirable quality profiles to supply planting materials for renewing old orchards. Enhancing planting materials, expanding the gene pool, and building capacity among stakeholders can increase cashew production, improve livelihoods, and stabilize prices in the international market, thereby boosting the country's income and supporting smallholder farmers.

Empowering farmers in Guinea-Bissau in collective finance, marketing, and cultivation management not only enhances their livelihoods but also contributes to overall agricultural development and economic growth. Farmers have been engaged in empowerment initiatives at different institutional levels: at cooperatives and farmers associations specially on bargaining power and improving access to more competitive and fair market resources. Government initiatives, specially promoted by National Cashew Agency (ANCA-GB), aim at providing financial support as well as facilitating access to international markets, and several NGOs (e.g., IANDA Guiné, Tiniguena) and international organizations (ex. FAO, World Bank, United Nations Development Programme/UNDP) who offer support for improving financial literacy and market access competitiveness. Besides, several farmer empowerment initiatives are conducted by NGOs (e.g., Kafo Federation, COAJOQ) that work closely with the country's Ministry of Agriculture, farmer training on best agriculture practices on cashew production, encouraging crop diversification to reduce dependency on cashew and provide additional income for farmers. Though successful, the acquired knowledge is not always applied overtime due to the lack of extension services and technical assistance outside of project execution. Through the effective collaboration and coordination among the different stakeholders (e.g., NGOs, farmers, local traders and exports, government, research institutions, cooperatives, financial institutions) involved in cashew sector would be possible to the success and sustainability of the cashew sector in Guinea-Bissau., by improving productivity, higher quality products, and better economic outcomes for all involved.

5 Final remarks

Cashew is a primary agricultural commodity in Guinea-Bissau and crucial for rural household income. Cashew systems in Guinea-Bissau were characterized by mainly older male producers with small plantations, aged trees, and low cashew nut yields. The prices of cashew nuts per kilo set by farmers were lower than those set by the government in 2020, and most of Guinea-Bissau's administrative regions exhibited a negative relationship between farmers' cashew nut prices and yield. Key characteristics were distinguishing administrative regions and zones, for instance, Biombo (North) exhibited larger cashew areas, older trees age, high occurrence of African mistletoe, and low yield. Cacheu (North) showed high tree density, younger trees compared to the country average, and high yield. However, Oio (North) had the lowest yield, despite having

below-average tree ages, likely due to high cashew pest and disease occurrences. In contrast, Gabú (East) had the lowest pest and disease occurrences. Therefore, cashew faces productivity challenges, mainly from pests and diseases, as these challenges may risk both the economy and food security of Guinea-Bissau. It is imperative to continue characterizing pivotal factors influencing the cashew agroecosystem by the identification of key pests and diseases affecting crop productivity, their spatiotemporal distribution, and population dynamics is essential. This will aid in developing integrated management strategies to enhance the sustainable production of cashew in Guinea-Bissau. Additionally, it will serve as a tool to facilitate effective interventions by agricultural experts and government actions, encouraging the adoption of practices among producers to improve cashew productivity and strengthen the rural economy of Guinea-Bissau.

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

PS-B: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing, Software, Validation, Visualization. SC: Data curation, Formal analysis, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. GC: Formal analysis, Investigation, Methodology, Writing – review & editing. AB: Data curation, Methodology, Writing – review & editing. ZC: Data curation, Funding acquisition, Project administration, Writing – review & editing. MF: Data curation, Funding acquisition, Writing – review & editing. EV-D: Writing – review & editing. MR: Investigation, Methodology, Writing – review & editing. LC: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Writing – review & editing. MD: Conceptualization, Formal analysis, Investigation, Methodology, Writing – review & editing. FM: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing.

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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.2024.1439820/full#supplementary-material

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