Postharvest assessment for the horticulture value chain of smallholder farmers, producing for local and regional markets in Guinea-Bissau

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Abstract

Intro & Background. In Guinea-Bissau, deploying postharvest technologies could help reduce food quality loss, increase local food preservation and nutrition security for smallholder farmers, and improve their income.

General problem, knowledge gap. However, the effectiveness of any postharvest technology is dependent on the complex interplay of farmers, farm size, produced foods and their value, distance to market, business opportunities, transportation infrastructure, import/export dependencies, competing technologies, climate (change) and crop seasonality, financial accessibility, availability of technology, materials, facilities, and services.

Our objectives. We assess which postharvest intervention(s) is best to increase fruit and vegetable quality preservation and, thereby, the income for smallholder farmers in Guinea-Bissau (regions of Gabu, Bafata, Quinara).

Detailed findings and advances. First, we generated and answered 20+ questions to map the target value chain concerning the target farms, farmers, crops produced, and markets. Second, we mapped the country's current situation concerning geography, population, employment, food and nutrition security, facilities, GDP, policy, climate, and the current situation for perishables. We identified trends and previous interventions. Third, we identified 40+ possible postharvest interventions, their current bottlenecks, and challenges they could solve. We scored the interventions and grouped them into three clusters: active cooling, passive cooling, and other postharvest practices. We detailed the most promising interventions.

Take home messages. The viability and added value of cooling technology are strongly linked to the location where they are placed (market gate vs. farm gate) and the volumes of fresh produce available. Cold storage rooms with a few metric tons of capacity are best placed at the market gates, serving multiple neighboring farming communities or vendors that store overnight. Transport from the farm gate to the market gate remains critical. Smaller cold storage solutions are more viable at the farm gate and can be tailored to the capacity needs of the farming communities. These scalable solutions include small fridges or homemade, custom-sized, insulated, cold storage rooms cooled with AC units. Small-scale passive evaporative cooling is also a viable preservation alternative. Postharvest practices are also promising, among others, improved harvesting timing for optimal ripeness at the point of sale and improved packaging and transport services.

Broader perspective and impact. A postharvest impact assessment is essential to develop and implement interventions that are sustainable in the long term for a certain use case. In Guinea-Bissau and neighboring countries, cooling, quality preservation, and energy supply are strongly intertwined. The future of cooling in Guinea-Bissau will depend on the future of energy supply and the evolution of urban and rural food value chains. A successful step-in of Guinea-Bissau into postharvest (cooling) solutions will likely involve low-tech, standard, and readily available hardware. There is a significant potential for evaporative cooling.

Keywords: food loss; fruit and vegetables; cooling; refrigeration; packaging; farmers, LMIC

1 Introduction

In Guinea-Bissau, agriculture forms the backbone of the economy, employing about 80% of the population. Subsistence farming is predominant, where farmers typically practice traditional agricultural methods. Fruit and vegetable production is essential to ensure the population's nutrition security and good diet quality, as a large portion of the population is still malnourished. Other foods are essential for food security (e.g., rice) or household income (e.g., cashew nuts). Multiple horticultural products are grown in Guinea-Bissau (Figure 1), and women play an important but under-compensated role in the postharvest value chain. Despite a favorable climate, the agricultural sector faces significant challenges, including limited production and transport infrastructure, lack of advanced farming techniques, and political instability. For fruit and vegetables, food losses are high, and the farmer's income is low. These issues hinder the productivity and growth of the smallholder farmers. Efforts to modernize agriculture and improve food and nutrition security are ongoing, but substantial investments from international organizations are needed to stabilize the situation.

Figure 1. A geographical map of Guinea-Bissau (*(Wikipedia, 2024a)*, this image is a map derived from a United Nations map).

Several postharvest technologies can be deployed to better preserve fresh produce quality after harvest until the point of sale, including refrigeration, to increase farmer income. These technologies strongly depend on the type of crop and the respective type of value chain that is envisaged. (Figure 2): (1) the cold chain (fruit and vegetable, roots and tubers, meat, dairy, fish); (2) the dry chain (cereals, oil crops, and pulses); (3) the processed chain involving thermal processing to prolong storage life for example through canning or drying (e.g., fruit and vegetables or fish); and (4) the ambient chain for all crops and products that can be stored under ambient conditions and consumed or sold on the market before spoilage. For fruit and vegetables, in particular, the cold, ambient, and processed chains are essential.

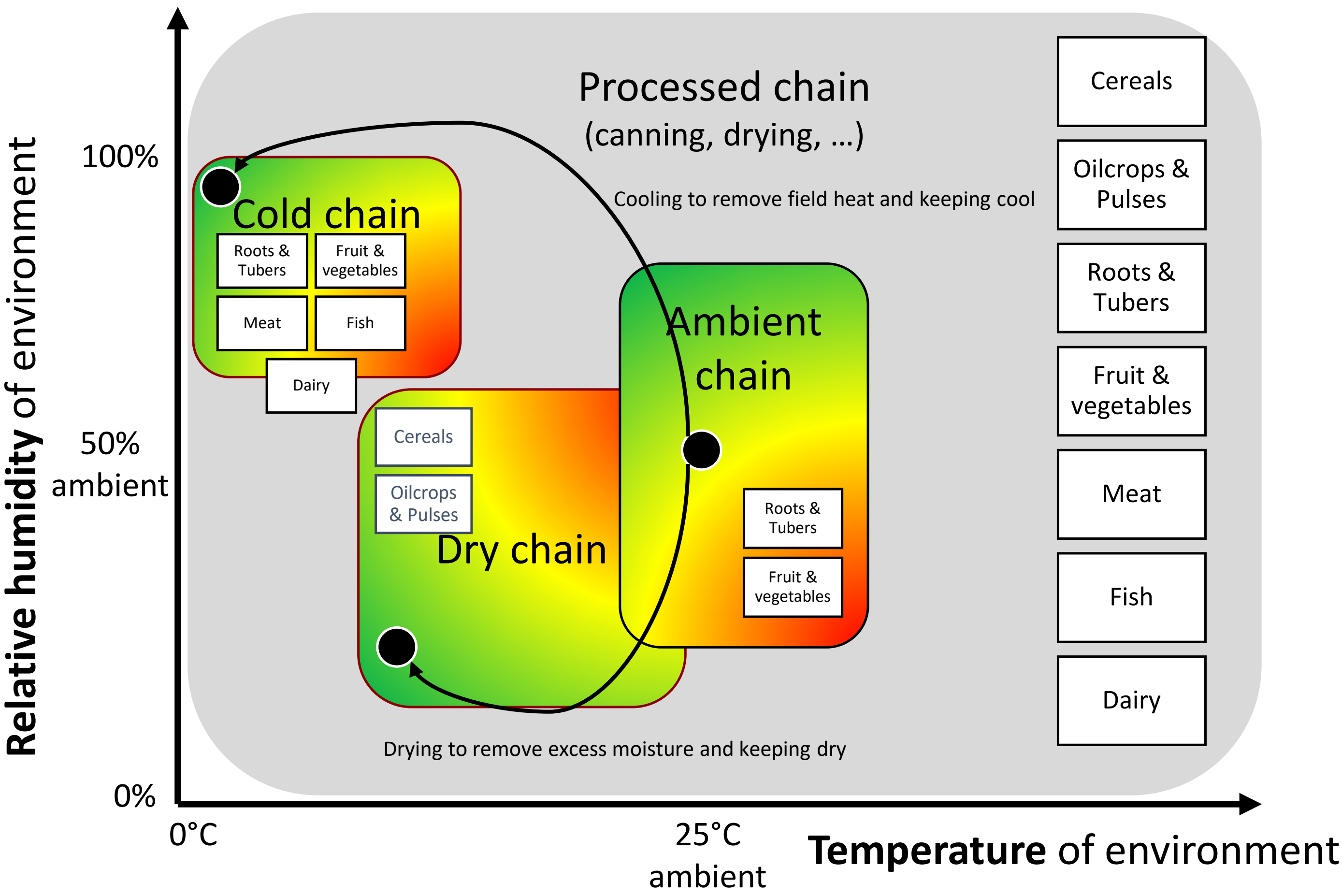

Figure 2. The different types of value chains and the food products that they entail are mapped against their optimal temperature and relative humidity of the environment. Black dots are the typical conditions. The indicated zones are colored from green to red, so from optimal to suboptimal.

When addressing the problem of food quality preservation for a specific use case, there is the risk that only one or a few postharvest technologies are focused on as a solution to the problem. In contrast, others remain unnoticed, have not been explored, or receive less attention. For example, there is a current 'cold rush' in sub-Saharan Africa, where many small-scale, solar-powered cold storage facilities with a few metric tons of food storage capacity are emerging as active cooling technology. These facilities cater to smallholder farmers or farmer communities to preserve their harvested fruit and vegetables through refrigeration. While active cooling at this scale can be viable, some facilities are used sub-optimally or fall into disuse due to high operating costs, lack of maintenance, and low occupancy levels. The root causes for the lack of uptake of cold rooms are related to cooling technology, transport, farmers, markets, occupancy, cold chain infrastructure, location, finance, and regulatory aspects, which differ between countries, regions, and use cases. Some cooling assets become stranded since the cooling technology, or (facility) scale, is not necessarily the optimal preservation option for a targeted market or product in low- and middle-income countries (LMICs). Therefore, other interventions could be more viable for specific use cases, countries, products, and markets. Furthermore, interventions that can be deployed widely within a region or country should be targeted so that they are scalable to a wide cohort of farmers, farmer communities, or cooperatives. Stand-alone pilots or showcase facilities that cannot be deployed widely should be avoided. In addition, challenges often remain to maintain and service this equipment.

The best postharvest intervention depends on a complex interplay between the market, farmer, product, consumer, and technology. The link between the product and production, market sophistication, and technology is depicted in Figure 3. The viability range of selected technologies and the type of supply chain (ambient or refrigerated) required for several produce types is also depicted. Smaller farmers often do not have direct access to distant markets or high-end technologies. Middlemen or intermediaries can enable smallholder farmers to still reach export markets (Figure

3) by providing additional services and technology to reach these. Examples are cooling service providers, refrigerated and unrefrigerated transport companies, or entrepreneurs providing other postharvest services. However, these services come at a price and increase the farmer's dependency. We also notice that some markets can be served with the ambient chain.

In addition, several boundary conditions make up the sandbox in which the interventions can be deployed, such as farmer, farm size, produced foods, distance to market, business model (push or pull) opportunities based on the type of target market, transportation infrastructure, consumer preference, export dependencies, competing technologies, climate (change) and crop seasonality, financial accessibility to technology, available training, local availability of materials and services provided. Therefore, choosing the most optimal postharvest intervention for the given boundary conditions is essential to ensure sustainable, long-term adaptation and deployment. A detailed multifactorial assessment is essential to provide the right intervention for the right use case. For this purpose, a comprehensive postharvest impact assessment methodology has been developed recently to map the sandbox in which interventions can be developed and tailored to a specific use case (Oostewechel et al., 2022).

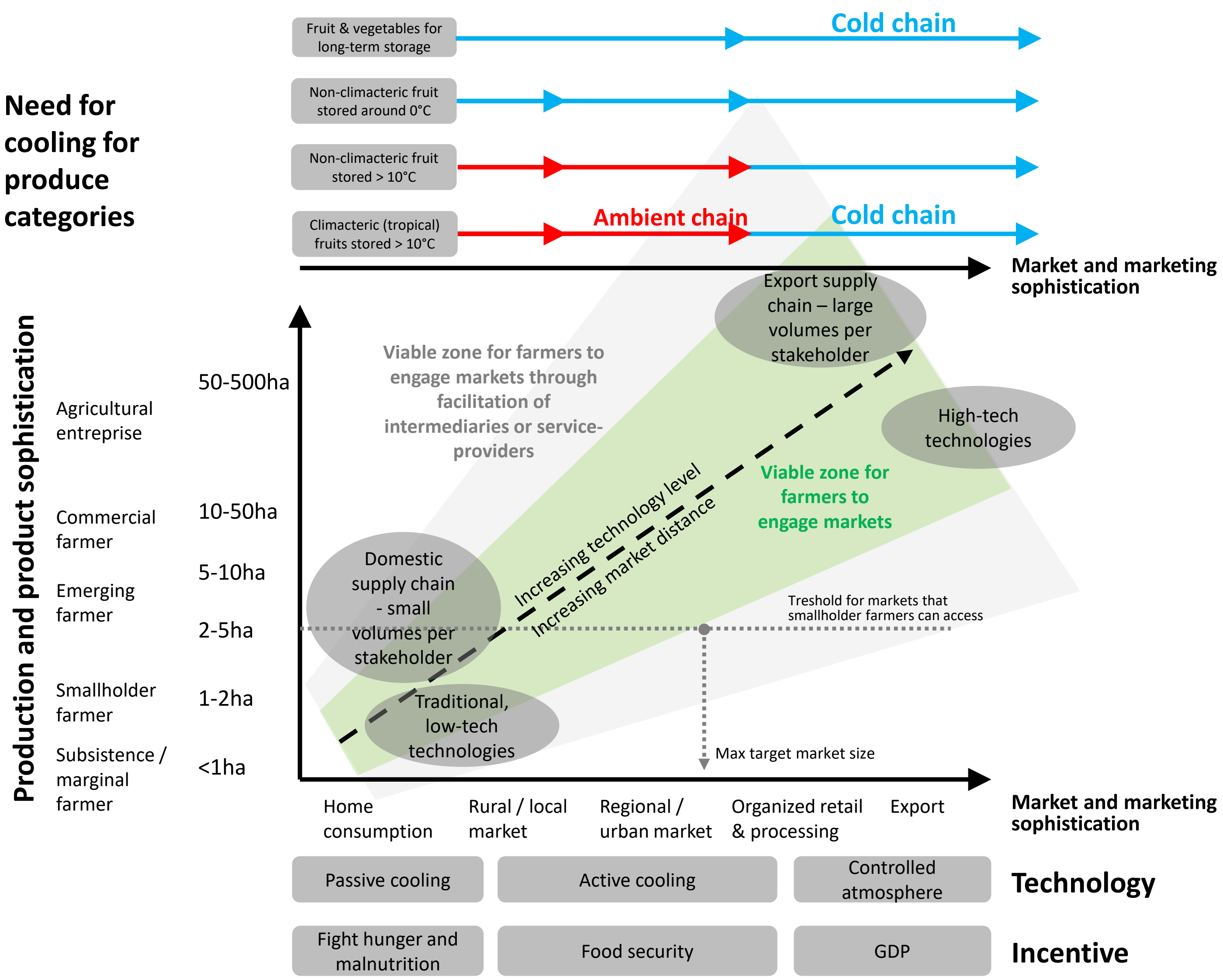

Figure 3. Schematic representing the sophistication of production and product versus the sophistication of the market. The type of supply chain (ambient or refrigerated) is also indicated (adjusted from (Oostewechel et al., 2022)***). Climacteric fruits continue to ripen after being harvested, and non-climacteric fruits do not ripen significantly after harvest and, thereby, must be picked at their envisaged ripeness since their quality does not improve afterward.***

In this study, we deploy and further develop this postharvest assessment methodology in Guinea-Bissau. The aim was to identify the most feasible postharvest interventions/solutions to increase fresh fruit and vegetable quality preservation and, thereby, the income for subsistence/smallholder farmers and nutrition security. We focus on the regions of Gabu, Bafata, and Quinara. We develop 20+ comprehensive questions to map the target value chain concerning the target farms, farmers, crops produced, and the market, among others, through a field visit to 20 farmer communities. Second, we map the complex environment where the intervention will be implemented, Guinea-Bissau, and the current situation for perishable food products. We identified previous and current trends and ongoing interventions by other organizations. Third, we identified a list of 40+ possible postharvest interventions (solutions) and the current bottlenecks and root causes the interventions address, which we combined in an intervention matrix. We propose systematically scoring different postharvest interventions based on their feasibility and impact. We outline the most promising interventions and do a risk assessment.

2 Materials and methods

2.1 Methodology for postharvest impact assessment of postharvest interventions for Guinea-Bissau

We assess which postharvest intervention is most suitable to reduce food loss, improve local fresh fruit and vegetable preservation, and increase income for subsistence/smallholder farmers in Guinea-Bissau. This assessment is based largely on the postharvest assessment methodology that was previously developed (Oostewechel et al., 2022). We made adjustments to include other information and to better streamline the process for our specific use case. Our impact assessment was performed by a desk study in collaboration with a local consultant in Guinea-Bissau and interviews with farmers and country representatives of international organizations. The key steps of the impact assessment for postharvest interventions are to:

- Define the **scope and objective** of the interventions (sections 2.2, 2.2.4).
- Define the **starting point** of the study, i.e., the use case: What is the target value chain, and who are the beneficiaries (section 3.1).
- Assess the **current situation** in the country and regions of interest concerning growing fruit and vegetables. This also includes market trends and the impact of the changing climate. The results are included in the supplementary material to keep the study more concise.
- Identify the environment where the intervention will be implemented according to a **diagnostic** with 11 criteria (section 3.2): resource potential, benefits for chain partners, policy and legal issues, knowledge, finance, markets, technology, input supply, logistics, storage, and processing and retail.
- Identify the related **bottlenecks** and their root causes, as well as a list of possible solutions (section 3.3.1).
- Shortlist the most promising **interventions** (section 3.3.2).
- Conduct a **risk analysis** for each proposed solution and associated mitigation measures (section 3.3.3).
- Identify the **follow-up actions** for the impact assessment of postharvest interventions (section 3.4).

We report several numbers and statistics below. These numbers are dependent on the source of the data gathered and the year in which they were gathered. As such, there will be differences between sources and years, so the numbers should be considered indicative rather than absolute.

2.2 Scope, purpose, and objective

The aim is to determine a specific purpose and scope with the relevant stakeholders. We define the scope, i.e., the problem we want to solve through interventions (Figure 4), and distill the purpose of the study. The starting point analysis above is used as a basis to distill the scope.

2.2.1 Scope

2.2.1.1 Scope of this study

The **problem** we want to solve is **to improve the livelihoods and nutrition security of local farmers and communities.** Postharvest losses of food quality and the food itself are high, including entire fruits and vegetables that are thrown away or high cut losses of spoiled parts of single products.

Our **scope** is to deploy cold storage technology to stabilize nutrition insecurity in the horticultural supply chain or to deploy other postharvest storage technologies to improve postharvest preservation in the horticultural supply chain.

The envisaged **impact** is that cold storage technology (= intervention) or postharvest technologies (= intervention) and a combination thereof can help reduce postharvest quality losses and the amount of food (parts) being thrown away. This can increase volumes to be sold and, thereby, farmer income, which can, in turn, stimulate farmers' food and nutritional security. Apart from extending the storability of produce and improving product quality, such interventions can improve product shelf-life and, therefore, transportability so that farmers can access regional markets. The increased storability can also increase the availability of fruit and vegetables at the end of the harvest season or the end of the peak season for a few weeks. Hence, farmers could sell at a higher price instead of rock-bottom prices in peak season, for example, and at the same time, extend the availability of nutritious food.

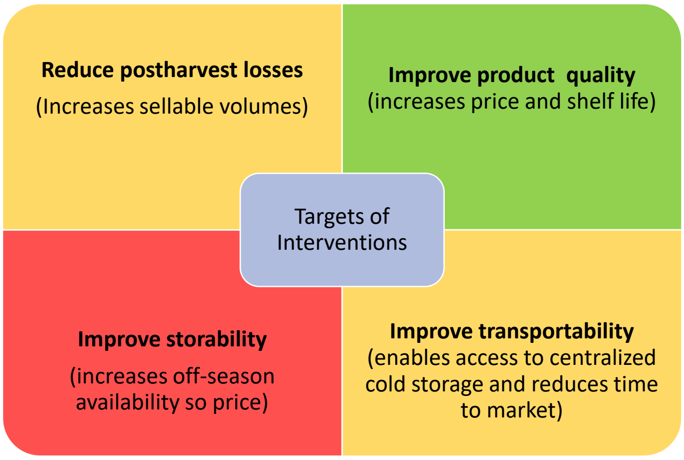

Figure 4. Possible targets of interventions and their impacts on the food and the supply chain. Those that are prioritized in this study are highlighted from green (high priority) to red (low priority) (adapted from (Verschoor et al., 2020)***).***

2.2.1.2 Other potential scopes

We list scopes that are not targeted in this study but can be of interest in the future or for other projects:

- Increase year-round nutrition security and availability of more fruit and vegetables in the lean season, which, for example, entails long-term storage.
- Improve the product starting quality and yield level in primary production, which additionally affects storability.
- Increase the income of professional farmers by reducing postharvest losses, improving storability, and maybe improving product quality, such as grade A products for export to international markets.
- Increase the food supply to cities to ensure food and nutrition security of Guinea-Bissau's rapidly growing cities/urban population. Postharvest food losses are high, and transport infrastructure is limited. Interventions could improve the transport or production and preservation of fruits and vegetables in the peri-urban areas, particularly developing an ambient chain here. The capital, Bissau, has a green belt suitable for this purpose and where there are already areas planned for agricultural and horticultural production.

2.2.2 Purpose

The purpose of this study is to assess the feasibility of the intervention 'cold storage' or 'postharvest technologies' to increase food quality preservation and reduce food quality loss for the horticultural crop value chain in the regions of Bafata, Gabu, and Quinara for smallholder farmers supplying local/regional markets in Guinea-Bissau. Cold storage can be installed at the farm, at a local market near a farming community, or at the regional market, where food from different farming communities is pooled.

2.2.3

2.2.4 Objective of intervention

AIM. The aim is to assess the objectives for the country and regions of the foreseen intervention.

OBJECTIVES. The main objectives of the planned intervention (Figure 5) are to (1) **reduce food quality loss** after harvest (so increase postharvest life and quality) and enable local food preservation for subsistence farmers or smallholder farmers, and (2) improve the **income** of smallholder farmers. Secondary objectives are to (1) enhance the diet to be more **nutrient-rich diets** by increasing the availability of fruit and vegetables and (2) empower women's participation in agriculture, more specifically in horticulture.

The following are not the objectives of this study: (1) enable the **export** of produce (e.g., mangoes) to neighboring countries through the development of an export cold supply chain; (2) increase **year-round** food/nutrition security and availability to have more food in the lean season; (3) increase the **food supply to large cities** (e.g., Bissau, Ziguinchor in Senegal).

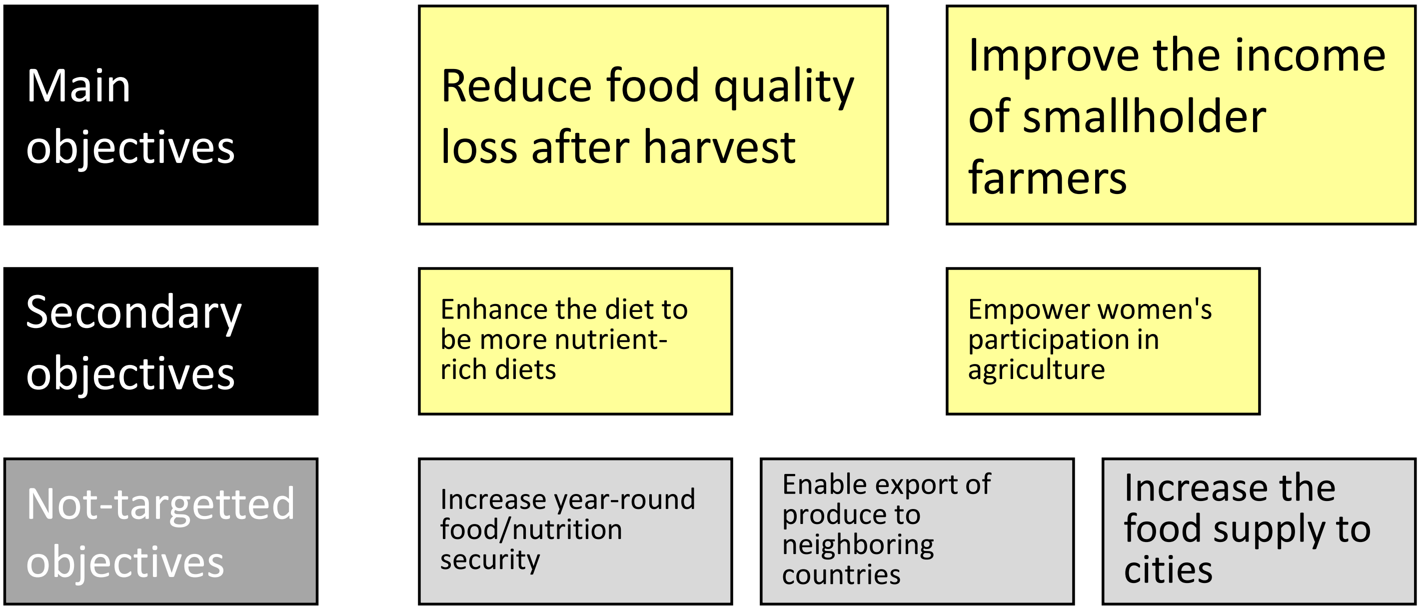

Figure 5. Schematic of the objectives of the study.

3 Results

3.1 Mapping the study's starting point: What is the target value chain, and who are the beneficiaries?

In this section, we aim to define the target beneficiaries (growers and customers) and the target value chain in which interventions will be realized. Laying this foundation is essential to define the use case for an intervention. We do this by defining and answering 20+ questions through collaboration with stakeholders based in Guinea-Bissau who are aware of the local challenges. Therefore, this starting point was defined with the relevant stakeholders, which were, in our case, the German Development Cooperation (GIZ), SWISSAID (in partnership with ADPP in Quinara, COPE in Gabu, and Tostan in Bafata), and local farmers who were organized in farmers' clubs. A field mission was organized where 20 farmer communities were visited and interviewed (Gomes, 2024). Details on the field mission can be found in the supplementary material.

3.1.1 Region and location of farms?

Which regions do we focus on? In Guinea-Bissau, we focus on the regions of Gabu, Bafata, and Quinara (Figure 1, Figure 6).

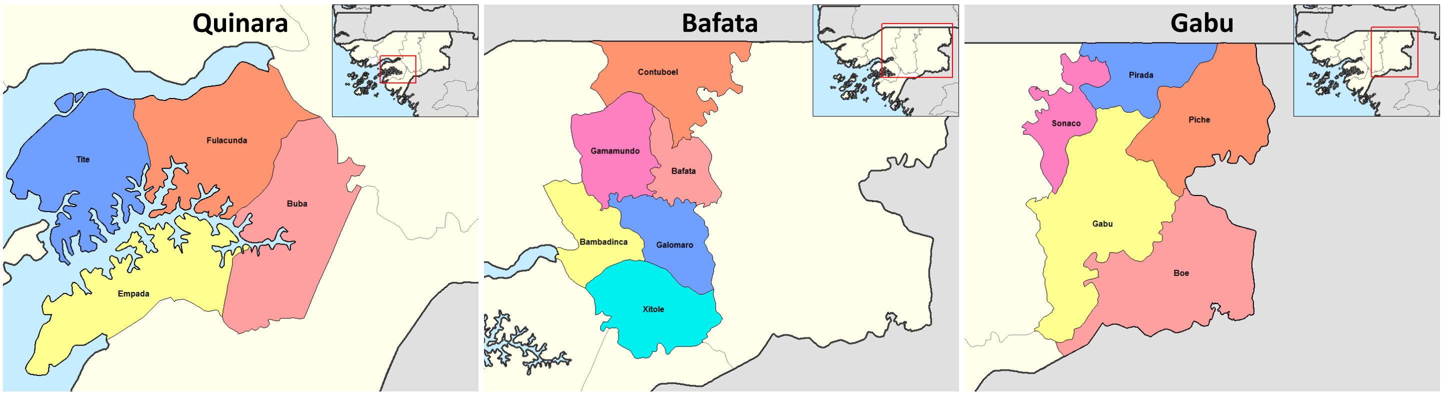

Figure 6. Regions and sub-regions of Quinara, Bafata, and Gabu (Wikipedia, 2024b, 2024c, 2024d)**.**

Why do we focus on these regions? The reasons to focus on these regions are: (1) a large part of the population is food insecure, especially during the lean season (June-July-August-September-October), or malnourished (so nutrient insecure), for which fruit and vegetables play a role; (2) a large part of the population lives in poverty or extreme poverty in these regions with poverty indices averaging over 60% and other social indicators also scoring very low; (3) These regions are amongst the most rural and remote of the country, so less reachable for import/supply of fresh produce and fertilizers; (4) The yearly rainfall is relatively limited in these regions (Gabu and Bafata), compared to the rest of the country, and soil fertility is low; (5) The regions are the focus of several international organizations (IFAD, FAO, WFP, SWISSAID, Tostan, ADPP); (6) The three regions are priority targets of various programs and strategic development plans in Guinea-Bissau since 2010 (DENERP II 2010-2015, TERRA RANKA 2015-2025 and PND Plan National de Dévelopement 2021-2023). Note that these regions were not chosen for specific crops produced here. We also do not focus on farms in the green belt of the large cities (Bissau), which are often larger and supply urban areas with food.

Are the farms located in rural, peri-urban, or urban areas? The farms are typically located in rural areas, often to some distance from the regional centers of Gabu, Bafata, and Quinara. Particularly in Bafata and Gabu, several farmers' organizations, cooperatives, or clubs with agricultural fields mainly focus on vegetable production. Several of these farmer communities and villages are remotely located and far away (> 10 km) from regional cities. Many of them are located in green, forested areas.

Do we focus on food security or nutrition security? An important distinction needs to be made between food security, which refers to consistent access to calorically dense staples (e.g., rice, sorghum, maize, millet, roots, and tubers), and nutrition security, which refers to having enough food that provides essential nutrients, including vitamins and minerals, and that is mainly covered by fruit and vegetables. The respective lean season for food security is June-July-August-September-October, which is also the most critical season for nutrition security.

3.1.2 Crop-value chain and current value chain

Which crop do the farmers focus on? We focus on horticultural crops, which are mainly grown by women farmers. Farmers often grow multiple crops and do not solely focus on a specific crop type, with cropping patterns reflecting a primary focus on sustenance, while the remaining crops are directed toward market sales. They grow vegetables and often have also small fruit orchards. Note that onion is one of the most important foods produced by most farmer communities we interviewed, and it amounted even to 20% of their total production. Okra, tomato, bell peppers were also very popular, and green peppers, which are popular because of their potential high selling prices, along with local crops like djagatu (small African eggplants). With respect to the products produced, the important horticultural crops for Guinea-Bissau are listed in Figure 7. It also indicates which crops are climacteric (so they ripen after harvest) and what the optimal storage conditions are, hinting at the necessity of a cold chain. Some products do not need to be cooled for shorter storage times as their optimal storage temperature is rather high and their shelf life sufficiently long until they reach the point of sale.

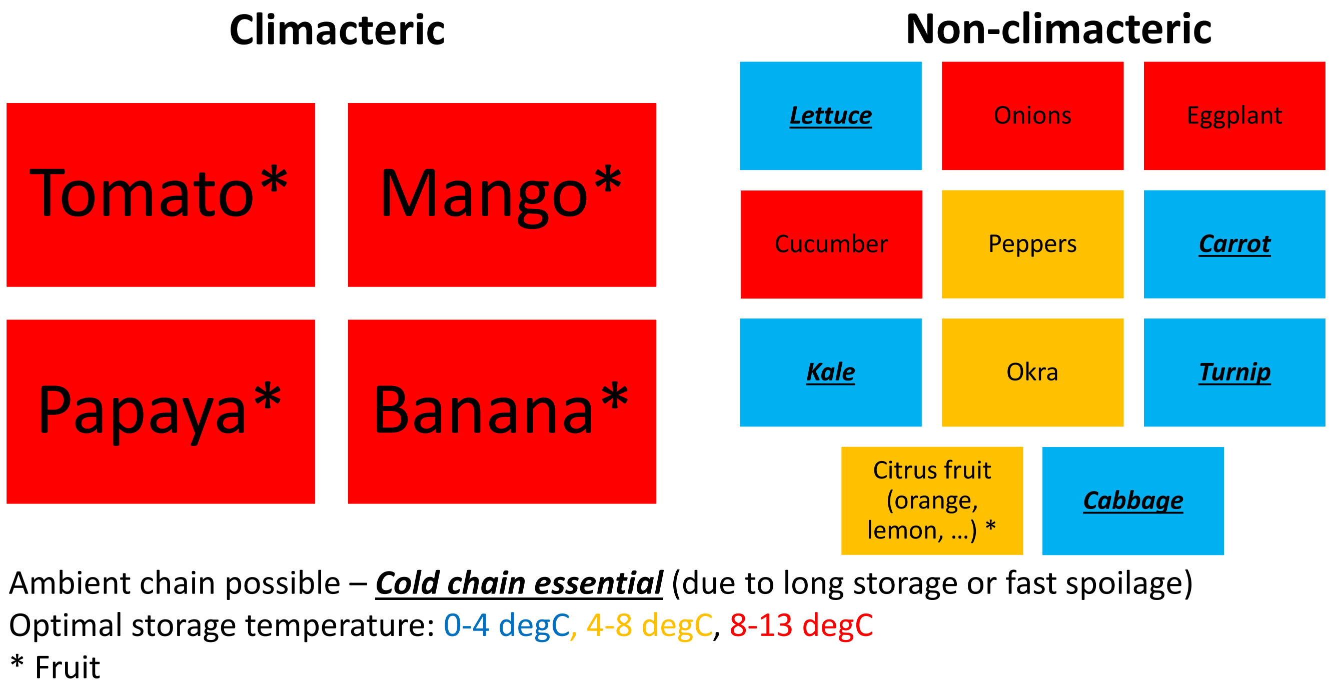

Figure 7. Different fruits and vegetables that are relevant for smallholder farmers and families in Guinea-Bissau, together with their climacteric nature, their optimal storage conditions, and the necessity for a cold chain.

When do crops reach the market, and when is the critical time to have fresher fruit and vegetables? Concerning the harvest and product availability throughout the year, the type of harvested crops and when they are brought to the market depend on the dry/rainy season. A crop calendar is composed in Figure 8. In general, we can state the following:

- Agricultural production is strongly dependent on **water availability** and rainfall. The drought limits agricultural production during the dry season, especially close to the rainy season, from March to May (Spring). Irrigated areas and areas close to the main rivers (Geba and Corubal) even face difficulties. At the end of the dry season, horticulture production occurs predominantly in irrigated areas. Many farmer communities are near waterways, but installed irrigation systems are not commonplace yet. In addition, deep well drilling costs a lot due to low groundwater levels.
- There is a distinction between the growing period and the **harvest period**. The harvest period is mostly of interest as this is the period where postharvest solutions come into play.

- The **workforce** for horticulture is much lower in the cashew harvest season (March-June, spring) and also, to some extent, in the rice harvest (not growing) season (typically September-October to December but strongly dependent on the region). Most farmers are then employed to harvest rice or cashews (cash crops) and have less time to spend on horticulture.
- **Vegetables** can be grown year-round in principle. However, there is a higher production of vegetables outside of the rainy season in Guinea-Bissau, driven by local water resource availability outside of the rainy season and workforce availability. Vegetable production on a large scale starts around September and can go up to April, depending on water availability in the region. Due to a lack of water and a large part of the workforce being occupied in cashew harvesting, horticultural activities are limited in March-April-May. Hence, fewer vegetables are grown near the end of the dry season and the start of the rainy season. As a typical growing period of vegetables is 2-3 months (60-90 days), vegetables are harvested again in larger shares at the earliest in August-September. As such, there is a lack of vegetables in the months of the rainy season. Some crops, such as onions or carrots, are not grown during the rainy season, as abundant water is not beneficial. Lettuce and tomatoes are also not grown in the rainy season.
- **Fruits** are not produced year-round as their production is season-dependent. Fruits like mango and citrus fruit are typically available for consumption from December to June. The main mango harvesting phase coincides with the financially more interesting raw cashew nut harvesting, which leads to high fruit losses.
- **Lean season.** Most horticultural crops, i.e., fruit and vegetables, are grown from the end of the rainy season (September-October, Figure 8) and harvested from November-June, so including in the dry season. As a result, there is a food shortage for multiple types of vegetables in the rainy season, during which traders import horticultural crops. Through Senegal, they import vegetables such as tomatoes, and via Guinea-Conakry, they import fruits such as mango, pineapple, avocado, etc. This lean season for fruit and vegetables is typically from June to October, which coincides with the rainy season. Storing fruit or vegetables during the rainy months is not feasible due to the limited storability under optimal conditions (typically below 1 month, Table 4) and the lack of cold storage technology. The resulting postharvest losses are a leading cause for one-third of the country's population being food insecure (World Food Programme, 2022, 2018). The importing traders also face difficulties in preserving the imported fruit and vegetables and suffer considerable losses, among others, due to elevated temperatures and mechanical damage. Another scenario is also occurring, namely that onions and other vegetables with a long storage life and produced by Bissau-Guinean farmers are bought by middlemen or vendors from neighboring countries at low rates. These vendors have better storage options in these countries. These foods are then later re-sold in Guinea-Bissau at higher rates during the lean season.
- The **storability** of many fruits and vegetables is limited (typically below 1 month, Table 4). This means that, even with optimal, high-tech postharvest storage technology, the shelf life of all fresh produce cannot be extended throughout the entire lean season. Crops that can be stored for a long time are, for example, carrots, cabbage, onions, and some citrus fruit.
- **Other key crops**, such as rice and cashews, are being produced in Guinea-Bissau. Agricultural production of cereals (rice, corn), beans, sweet potatoes, and peanuts occurs during the rainy season, from the second half of May to October.
- The **period for preserving the quality of fresh produce** is around the dry season (November/December-June) because then, fresh produce is available and needs to be stored, the environmental conditions are harsher (especially when the relative humidity is low), and evaporative cooling technologies work best.
- Of particular interest for this project are **crops** that are (1) readily available, (2) financially profitable, and (3) perishable enough to benefit from improved post-harvest preservation practices, such as cooling, (4) can benefit from cold storage until the retail and processing phase.

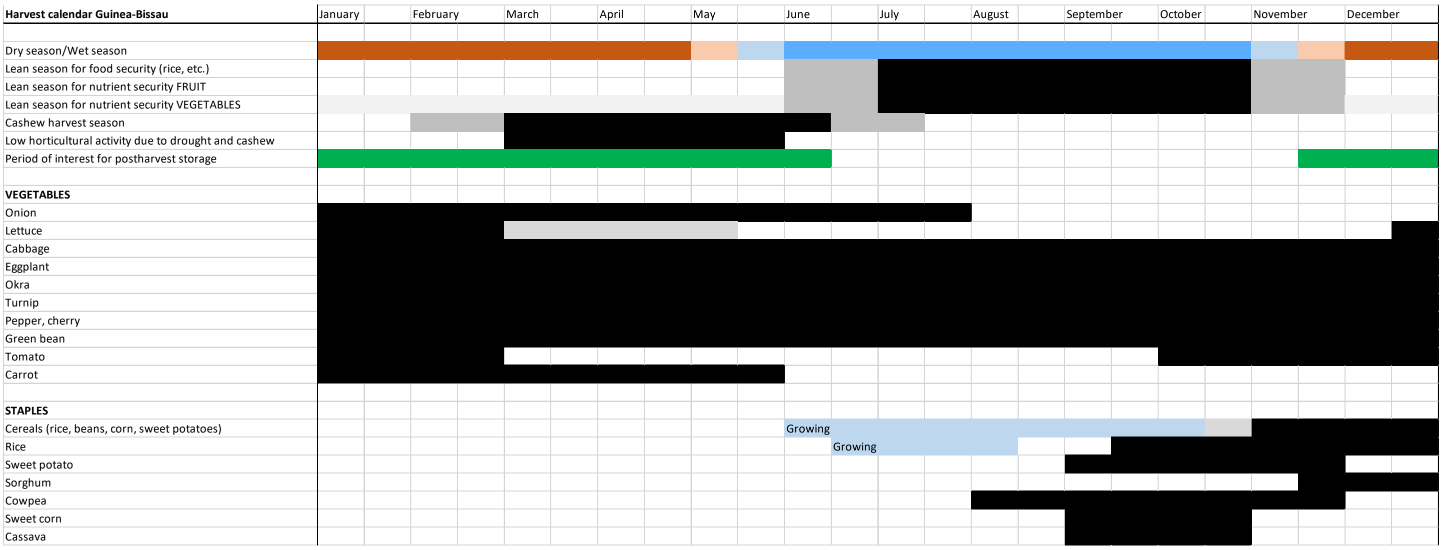

Figure 8. Crop harvest calendar of several fruits and vegetables in Guinea-Bissau (based on data gathered from (FAO, 2024a)***) of the products we have data on, as well as an indication of the rainy season and the lean season, where food availability is low, and additional information on food supply limiting factors.***

Which crops have the most value on the market? The fruits with the most value on the market are mango, lemon, mandarin, and jackfruit. The vegetables with the most value on the market are green peppers, tomatoes, onions, chili, bell peppers, cabbage, and okra. More details on the market prices can be found in the supplementary material.

When are the farmers and their families mainly employed in cashew harvesting in these regions? The cashew harvesting season takes place between the months of February and June in Guinea-Bissau, but the main activity is between March and early June. During this time, entire families are occupied in the cashew harvest process and have little time to perform other agricultural practices. Cashew farming also has a large impact on the household budget available to purchase food in the lean season. Currently, entire families are engaged in the harvest process, which involves picking fallen cashew fruits from the ground, detaching the cashew nuts from the cashew fruits, and collecting them in baskets. The nuts are then cleaned and dried before being transferred to sacks. These sacks are temporarily stored in warehouses along the roads, where larger trucks later collect them to be transported to main warehouses in Bissau for export. Due to the work demands of the harvest, families have limited time for other agricultural activities, as women and children focus primarily on harvesting while men handle cleaning and logistics.

What are the key fruits and vegetables that would help reduce food insecurity and malnourishment, and for which crops should we push the value chain? The main fruits and vegetables that can contribute to food and nutrition security for farming families in Guinea-Bissau are mango, citrus fruits, papaya, banana, tomato, eggplant, cabbage, carrot, lettuce, and cucumber.

Which fruits and vegetables are part of the daily diets in these regions? The main fruits and vegetables that are produced and consumed are listed in Figure 7. From these, mango fruit and tomato are the main staples. Tomatoes are often used in local diets and cuisines. Note that canned tomato is also imported significantly. Next to that, okra and citrus fruit (oranges) are also consumed a lot. Populations of Gabu and Bafata have similar eating habits, which differ slightly from the population in the southern region of Quinara. However, most fruits and vegetables are consumed throughout the country. Budget limitations, particularly during the lean season, often restrict consumption to smaller quantities. During these times, locals may even buy just a portion of a single vegetable to supplement their diet. As a result, rice and meat or fish remain the main components of most meals.

Is there a currently strong import dependency existing or expected that can compete with local crop production (e.g., imported canned tomatoes vs. freshly produced local tomatoes)? There is an import dependency on onions and canned tomatoes in pulp or peeled tomatoes. Fresh tomatoes are often scarcely available, among others, due to the high postharvest losses, their limited availability in season and low storability, and limited tomato processing facilities. The high postharvest losses and lack of preservation (e.g., cold storage) have reduced farmers' motivation to grow tomatoes. Senegal, for example, faces similar issues. The Senegalese government has, however, put mechanisms into place to stimulate local production (of onions) to counteract the import dependency of some crops.

Is the fruit quality at harvest sufficient for refrigerated storage? The quality of the fruit at harvest is generally acceptable but is negatively influenced by the absence of ventilated plastic crates. Common storage in plastic tubs, raffia baskets, or jute bags can lead to mechanical damage during handling and, thus, to an increased susceptibility to accelerated spoilage, especially with increased transport volumes from the field. In addition, the high ambient temperatures and low humidity, depending on the season, lead to a rapid decline in quality directly after harvesting. It is advisable to store the fruits and vegetables in a low-temperature, high-humidity environment after harvest with as little delay as possible.

What are the current value/cold chain and postharvest practices? Farmers use specific traditional methods to preserve food after harvest. No active cooling, humidification, or packaging is applied after harvest until the point of sale at a local market. The ambient chain is in place, including storage under shaded conditions. The typical average ambient temperature is 25-30 °C, and humidity is about 50-90% (depending on the season). As such, the storage life of the products, compared to when stored under optimal conditions (most of them between 2-12°C, Figure 7), is reduced with an estimated factor of at least 2 to 3. The reason is that a decrease in temperature by 10 °C from the ambient, through cooling, typically doubles or triples the postharvest life of fruits and vegetables (Robertson, 2016). Plastic tubs are typically used for packaging and transport. Fresh produce (e.g., tomatoes) is often stored in plastic tubs, after which an elastic textile is wrapped over it to keep the produce in place. Plastic crates are not commonplace and are very rare to find throughout the country. Access to cardboard packaging or plastic liners is rare, as they need to be specifically ordered. Jute bags are commonly used for cashew nut storage. These options for containers that are used to store the produce inside impede proper stacking during transport. Long-term preservation by processing, such as drying (e.g., mango, banana, tomato) or canning, is sometimes practiced. The commercial value per kg could sometimes become lower compared to fresh produce. International organizations actively promote crop processing and set up training programs for farmers. The lack of postharvest cooling and preservation methods leads to many losses of several fruits and vegetables, such as tomatoes, cucumber, mango, and bananas, among others.

What is the required shelf life/storage life to reach the consumer? The storage life of most crops is a few weeks when stored under optimal refrigerated conditions and high humidity (Table 4). In the ambient chain, this reduces to a postharvest life of a week or less. As a result of this short storage life, only local markets can be supplied, as regional markets are too far away. Typically, the distance between production (farm) and the local markets is below 5 km. The limited transportability of the produce to regional markets is due to the bad roads and transport fleet, leading to high losses or too high prices for transport. However, some farmers have a tendency to harvest fruits when they are ripe or almost ripe. Harvesting climacteric fruits like bananas, tomatoes, or mangoes in an earlier ripeness stage (mature but not ripe) helps to extend their shelf-life. Note that some crops, such as onions, can be stored for months, given that correct curing after harvest was performed. For our use case, we targeted optimal conditioning of the fresh produce until the point of sale but not long-term storage to bridge several months, for example, into the lean season.

3.1.3 Farmer/grower: Which size and type of farmer do we target?

What is the target type of farmer? The horticulture farmers that we target are subsistence and marginal farmers (< 1 ha) and smallholder farmers (1-2 ha). Several farms are family farms, e.g., the majority of the mango growers. They grow fruit and vegetables to feed their families, and some sell a part of their harvest at the local market for (additional) income as a side business. Farmers also produce together in a community of farmers, for example, within a village. Women play a key role in this horticultural value chain, including growing and selling the food. In the farmers' clubs we interviewed, up to 90% of farmers were women. These farmers typically sell and bring their products individually to the market, so do not group in a cooperative. Apart from selling their fresh product on the market, some also transform them into processed products (e.g., dried fruit). However, this further processing is usually practically hindered by a lack of technical and packaging options or compotes. Farming is a part-time occupation for some farmers, and they also perform other occupations, such as teacher, bricklayer, painter, carpenter, student, artisan (lacemaking, tailoring, sewing), community health agent, baker, mechanic, and driver. Several farmers are also part-time micro-entrepreneurs in the horticultural space.

What is the typical requested or ideal (cold) storage time after harvest? The maximum storage time under optimal conditions strongly depends on the crop. However, this is less relevant as farmers typically just want to sell their products quickly but at good quality. The storage time, also for financial and environmental reasons, should be preferred rather short than long since the aim is not to promote the availability of the crops off-season. Since farmers sell at local or weekly regional markets, a workable storage time target would be **1 week or a maximum of 2 weeks**. Now, farmers often harvest the day before the weekly markets to avoid quality loss, as there is no preservation system in place.

What is the typical size and yield (harvested amount) of the target farm(er) or farming community throughout the season and per week? Many different crops are grown throughout the year on a single farm, and it is difficult to generalize yields for different farms and regions. From our field survey, the farming community typically cultivates about 1 hectare, but several communities are looking to expand to a few hectares more. These fields can yield about 10-20 tons per season (annually), but these can include up to 20 different products. When considering a larger farmer community within a 5 km radius, about 50-100 tons are harvested per season. This implies that a 3-tonne cold storage room can be fully filled 17 times throughout the year by a farmer community, yielding a storage time of a maximum of 3 weeks per batch. Each farmer can harvest several crops per week, with an estimated quantity of 35 kg to 75 kg per week. The harvested quantities of onion typically are a factor 3 higher. Often, harvesting is also timed to be close to the weekly market to avoid quality degradation between harvest and the point of sale.

How much of the average yield gets lost postharvest? From the information collected from a survey of 20 farmers' communities in 2024 in Gabu, Bafata, and Quinara, the overall losses were estimated at an average of 40%. Tomatoes represent the crop with the most losses, where about 60% is lost. Some fruits, such as orange fruit and pineapple, are generally more resilient and thereby have fewer losses. The causes for these losses are preharvest agricultural production (e.g., pests/insects, microbiological spoilage, lack of water, adverse weather conditions, roughly 10% of total), postharvest handling (e.g., transport losses, lack of crates/suitable packaging materials roughly 10% of total), and postharvest storage at ambient (not cooled) temperatures, leading to accelerated spoilage (roughly 20% of total). The postharvest losses are thereby around 30% (and 10% preharvest), but this differs strongly based on the use case and crop. Postharvest storage contributes the most to product losses.

3.1.4 Target market and consumers

What are the target markets (home consumption, rural area market, local organized retail, urban (regional) center market, storage, export, processing) and consumers? The farmers produce food that is sold at local markets and at the weekly markets at a regional level (Lumos Table 1). Farmers sell the produce themselves or sell it at the farm gate to vendors or farmer associations that then transport it to the weekly markets for sale. The markets typically start at 7:00 and end at 17:00 throughout the year. A list of these markets is given in Table 1. A very popular market is the Bambadinca market (Portagem de Bambadinca), which takes place every Tuesday. Producers, sellers, and buyers from all regions of Guinea-Bissau attend this market, as its geographical location allows participation from all four administrative zones (Centre, North, East, and South) and also from neighboring counties, for example, Senegal.

In Gabu, there are particularly few markets. One reason is the proximity of Bafata, where producers have been able to develop contacts with buyers from Gabu (town), Bafata markets, and Bafata (town). In Bafata, there is a higher sales volume and the presence of the main buyers from the capital, Bissau. Therefore, intermediaries travel directly to the farmer communities in Gabu (e.g., by truck) and buy larger volumes to resell in the weekly markets in the Bafata region. They often distribute their produce in Bissau. Note that for some farmers, regional markets are not sufficiently accessible through transport or would entail excessive food losses.

Markets are characterized by farmers selling their produce at ambient conditions but stored in the shade in small volumes. Consumers are local households looking to source food for daily consumption or further processing at home (e.g., drying, canning). However, some traders from sub-regions, especially Senegalese, go to these markets to buy some products and return them to their countries. The main retail and wholesale buyers come mainly from the capital, Bissau, and neighboring Senegal and Guinea-Conakry. The market for dried and canned products is limited.

Table 1. List of the main weekly regional markets in the three regions that were identified during a field mission.

Bafata		Gabu		Quinara	
Location market	**Frequency**	**Location market**	**Frequency**	**Location market**	**Frequency**
Bambadinca	Monday	Lumo de Pitchi	Monday	Lumo de Quebo	Thursday
Portagem de Bambadinca	Tuesday	Merché Central/Gabu	Every day	Lumo de Kubumba/ Catio	Saturday
Entroncamento/Contuboel	Thursday	Lumo of Sonaco	Tuesday	Lumo by Buba	Sunday
Djabikunda/Bafata	Friday	Lumo of Mafanco	Sunday	Empada Central Market	Every day
Sarandjobo/Ganado	Sunday				
Merché Central/Bafata	Every day				

Market location and distance and time from farm to target market? The market location is rural or regional. The distance of a farm to the rural or some of the regional markets is typically 1-10 km. Several farms are located over 10 km from the regional capitals and their markets (Gabu, Bafata, Babu, Table 1) and even towns (e.g., Pitche, Gamamundo, Empada). The average distance from farmer communities to the main weekly markets identified in the three regions is about 35 km, from a minimum of 5 km to a maximum of 65 km.

What would be the preferred location of a cold store unit? The preferred location for a cooling unit depends largely on the size of the facility. The preferred location for a large refrigerated store could be the market because it (1) is more centralized for cooling service providers to ensure high occupancy and also to deploy, operate, and maintain the cold store, (2) farmers could leave their produce at the market, instead of transporting it daily back and forth or storing it on their own between markets; (3) the farmer communities might not have the required expertise and legal structure to purchase, operate, manage and maintain the facilities; (4) the production of farmer communities is often too low to occupy a cold store year-round; (5) other facilitators, for example, interested cold store operators or (local or international) organizations providing the necessary support and embedding, are available, which are essential stakeholders to enable management and sustainability of the facilities. However, ownership of the facility and the land to operate it can be less straightforward to find compared to placing a cold store unit near a farming community. Several farmers typically commute with their produce daily from market to market, so they rarely return to the farmer community before all is sold. Practically, this implies, for example, that a farmer or vendor sells one day at a specific weekly market, spends the night in between markets, and sells the rest of the produce at the next market. For such a use case, cold rooms at the market have fewer benefits than farmers storing their produce there for successive days and only taking them out at the point of sale. The reason is that cooling and high humidity storage are only done overnight. As such, products will likely not even be fully cooled down. Nevertheless, such short-term cold storage could be better than storing outside, which could preserve the quality and price of the produce longer.

Many farmers would benefit from on-farm storage for smaller cold storage solutions (e.g., passive cooling, smaller fridges). This would allow them to preserve their products better for their own consumption and only take portions of crops to the local market that they think are sellable without subjecting the other crops to ambient conditions and having to liquidate them at low rates. The deployment of several small-scale units at the farm gate also caters the scalability to the size of the farming community. In this case, proper transport to the market is essential to ensure that all produced crops are sold.

What is the farmers' transport mode to the market? The transport time to more distant (regional) markets depends largely on the transport mode. Typical transport modes for fresh produce in Guinea-Bissau include foot, supported by (improvised) wheelbarrows where available, bicycles, donkey trailers, and (rented) motorbikes for markets within 10 km. Farming communities close to roads use cars or trucks to access the weekly regional markets and also use public transport and taxis to transport fresh produce. Often, women walk to the market to sell their products, placing them on their heads. All transport is unrefrigerated. For many farmers, the regional markets are inaccessible within one day. The transported volumes of fresh produce and the products sold are therefore limited.

Targeted farmer and consumer impact? For the farmers, we aim to help them preserve their products better. Therefore, they can sell larger quantities of products of higher quality at a higher price at local or regional markets and have higher-quality products for home consumption. For the consumers in rural areas, we want to combat malnourishment by providing higher (nutritional) quality products with a longer shelf life and less waste (e.g., rotten spots that need to be cut away for food items).

3.1.5 Summary

We summarize the key findings and suggest the first recommendations for where the postharvest interventions could be aimed. Note that these recommendations could change after the postharvest impact assessment. We target subsistence, marginal farmers, and smallholder farmers in rural areas of Gabu, Bafata, and Quinara. These part-time farmers typically grow fruits and vegetables on small farms (<1 ha) and are organized in villages with farmer communities of 50+ farmers, which are mainly women. We want to improve their nutrition security (not their food security) through preserving fruit and vegetables longer. This intervention would be targeted to preserve crop quality for a few days to a week longer as currently done under ambient conditions (including by using cold storage). The target is not long-term storage to preserve crops outside the harvest season to enable the availability of certain crops in the lean season.

The main findings are:

- The products of interest are many, including fruits (mango, banana, papaya, citrus fruit) and vegetables (tomato, lettuce, onions, eggplant, cucumber, peppers, carrot, okra, kale, cabbage).
- Fruit is especially available only seasonally, namely in the dry season.
- The lean season for fruit and vegetables is typically from July to October, so mainly in the rainy season.
- Fruit and vegetable farming is competing with cashew farming, especially at the end of the dry season (March - June). Cashew farming also has a large impact on the household budget available to purchase food in the lean season.
- Mango and tomato are staples. Fresh tomato is plagued by high postharvest losses and competition from canned imports.
- No postharvest practices such as refrigeration and packaging are used. Current postharvest practices are storage under the shade and transport in plastic tubs.
- Farming communities harvest rather low amounts of fruit and vegetables, typically a yield of 10-100 tons per season per community. This might be too little to make a typical 3-5 metric ton cold storage unit financially viable.
- Postharvest losses are about 30% and are especially high for tomatoes.
- Apart from local markets, regional weekly markets are further away (5-65 km) but are typically a good place to sell products to customers. Every region has a few regional markets.
- For a 3-5 ton cold store, the location should not be at the farming community but rather at the regional markets, given that they can be reached by the local farmers. Reasons are higher occupancy due to low production of a single farmer community, the farmer community's lack of expertise and legal structure to purchase, operate, manage, and maintain the facilities, and potentially the existence of other stakeholders (cold store operators, organizations) that provide the necessary ecosystem. In this scenario, the produce of different farmer communities can be pooled into one facility. Transport to regional markets without excessive food losses is critical, and a third party should provide it. However, it is a current bottleneck. There is already a system whereby wholesalers in Gabu purchase from local farming communities and transport them to regional markets. For the specific case where farmers go from market to market and only store overnight, cold rooms at the market have fewer benefits than farmers storing these at the market for many days and only taking them out at the point of sale.
- For smaller cold storage solutions at the farm gate (e.g., passive cooling, smaller fridges), many farmers would benefit from on-site storage to preserve their products better for their own consumption and selling at local markets. Here, the deployment of several small-scale units would also cater to the scalability of the size of the farming community. In this case, proper transport to the market is essential.

- This lean season for fruit and vegetables is typically from June to October, mainly during the rainy season, during which imports happen from neighboring countries.
- The storability of many fruits and vegetables is limited (typically below 1 month, Table 4). This means that, even with optimal, high-tech postharvest storage technology, the availability of fresh produce cannot be covered throughout the lean season. A market for processing fruits and vegetables is needed, along with training programs for farming communities.
- Of particular interest for preserving the quality of fresh produce is the period of the dry season (December-June) since then fresh produce is available and needs to be stored, the environmental conditions are harsher (especially the relative humidity is low), and evaporative cooling technologies work best.
- Since farmers sell at local or weekly regional markets, a workable target storage time target would be up to 1 week or a maximum of 2 weeks. Storage times with the current ambient chain in place are a few days for the relevant fruits and vegetables – every day gained here has a significant impact on the sales price achieved, which is currently dropping rapidly after harvest.
- It will be key to have partners or institutions involved when implementing cold chain solutions in farmer communities or at markets. This is essential to facilitate and enable the management and sustainability of the facility. Their involvement requires that fruit and vegetable producers are priority beneficiaries since these organizations sponsor projects with this target audience.

3.2 Diagnostic of the obtained information for the objective

AIM. We will compose a diagnostic of the information obtained for the planned objective. We assess the status of the environment/broad context on two aspects (colored differently in Figure 9): (1) the availability of resources ("resource potential"), and benefits ("Benefits for chain partners"); (2) the enabling conditions, which directly or indirectly influence the feasibility of an intervention (some may lead to risks but other can be part of the solution). The aim is to get a general overview of the environment where the intervention will be implemented from different aspects. The diagnostic shows the context within the postharvest intervention will be implemented and whether it aligns with our objectives: (1) reduce food quality loss after harvest to increase local and regional food preservation for subsistence farmers or smallholder farmers; (2) improve the income of smallholder farmers.

RESULTS. The results of the diagnostic are shown in Figure 9, and the rationale is detailed below.

1. Resource potential. *Score 3*

- The availability and intensity of solar radiation is sufficient for photovoltaic-powered cooling.
- Rain is of key importance for agriculture since production is mainly rainfed. Water is available for agriculture for most farmers, even during the dry season, but not for irrigation. Water is not necessarily the problem. Rather, access to water can be. Note that several organizations are looking to improve water availability. The rainy season, however, puts a lot of restrictions on agriculture and transport.
- The harvest season for fruits and vegetables and associated high production volumes is mainly during the dry season, leading to a lean season from June to October. During the rainy season, vegetables are also produced but in lower volumes, leading to the necessity of importing fresh produce.
- The quality of the fruit at harvest is relatively good but deteriorates rapidly due to poor storage and transportation conditions.
- The cashew and rice industry has a large impact on the workforce that is available for growing horticulture, especially when they are working in the cashew harvest season, but also on the household budget available to purchase food in the lean season.
- Electricity or gasoline/diesel-powered generators can be deployed in urban regions. However, in rural areas, both are not viable due to limited access to the grid or lengthy/costly transport of fuel. The electricity grid is not present or reliable in many regions of the country, although improvements are expected by 2025. Even then, the high cost of electricity compared to the low income can be an inhibitor for smallholder farmers to access and use active cooling. This gap can be filled by passive cooling technologies.
- Guinea-Bissau has a young population with a slightly higher share of women, which will increase fast, and thereby, the share of digital natives will increase. A lot of people (particularly women and youth) work in agriculture, particularly small-scale agriculture, and these farmers will need to feed many more people in the future. This seems like scale-up to emerging/intermediate farms, automation, yield increase, or postharvest loss reduction are key.
- Many international organizations are investing in improving the livelihoods of rural farmers and farming communities. They invest many resources with this target audience as beneficiaries.

2. Benefits for chain partners. *Score 5*

- Maintaining the quality and increasing availability of fresh fruit and vegetables will help stabilize nutrition security for the rural population (subsistence farmers, smallholder farmers, and consumers) during the dry season.
- Postharvest preservation is not the main focus of several local partners, so it could be a nice add-on to their current portfolio of training farming communities on pre-harvest and harvest and other income-generating activities.
- Increasing farmer income by preserving and selling food at a higher quality and quantity due to reduced loss can help reduce the financial dependency on cashew (international trade) and rice (domestically) prices.
- Improving the postharvest supply chain is a first step in making more distant markets (regional centers, capital, and export markets) more accessible for smallholder farmers. This contributes to the development of the local economy.

- Several partners have already spent several years in the region and are currently active: SWISSAID, IFAD, WFP, ADB, and FAO.
- The government would benefit as horticulture can help combat nutrition insecurity and also reduce the financial dependency of farmers on monocultures (cashews, rice).

3. Policy & Legal. *Score 2*

- There is rather limited governmental support for agriculture and food supply chains.
- Domestic agricultural production is less well-protected compared to other countries, such as Senegal. There is a large import dependency risk, including for processed tomatoes and onions, and there are no known planned changes in governmental policy to protect the domestic market better.
- Tax reductions or exemptions on imports of cold chain infrastructure are essential to make cooling available financially, as this adds a substantial amount to the total cost of the infrastructure.
- Taxes from the export of cashew nuts are an important revenue stream for the government, hindering policies that strengthen the production of other crops that might compete with cashew for land or labor.

4. Knowledge. *Score 2*

- Standard operating procedures for postharvest handling are scarce and not widespread. Also, the knowledge and expertise to operate, manage, and maintain cold chain equipment is not present.
- There is currently still limited training for smallholder farmers, but this is increasingly being done.
- Training centers have been developed in several parts of the country. HVAC training centers have also been established.
- Most of the training is organized and funded by international organizations.
- Farmers are organized into informal communities (without legal structure) to spread knowledge.
- There is a large potential to train the young generation and population through digital platforms. This enables the creation of a sustainable, long-term knowledge boost for the future generation of farmers. Efforts are underway but could be more extensive.

5. Finance. *Score 2*

- A lot of investment and incentives come from international organizations.
- Only a very small portion of the rural population in Guinea-Bissau has access to a bank account. Monetary transactions among farmers and local communities are done in cash or using mobile payment methods (via rechargeable credit).
- Local banks are generally not interested in financing the agricultural value chain, which is often seen as uncertain and high-risk. Microcredits for smallholder farmers lacking collateral are inaccessible, and small entrepreneurs starting a new business are forced to incur high interest rates until they can prove the viability of their business. Due diligence processes on SMEs are hindered by the lack of trustworthy data to ensure creditworthiness.

6. Markets. *Score 1*

- Local markets are reachable for smallholder farmers, mainly by foot. Regional and urban markets are less within reach, and even when reached, the means of transport lead to a lot of food loss due to bad road conditions.
- Products in the peak season are sold at rock-bottom prices. However, even in this case, if more can be sold at a high quality, this can still improve farmer livelihoods.

7. Technology. *Score 2*

- Access to advanced technology is limited and often needs to be imported at a high cost. For cooling, there is an established HVAC industry to rely on.
- Very few cold rooms and refrigerated trucks are available. They are now mainly used in the fish industry.
- There are already efforts to make cooling for fresh produce available, but these have been discontinued due to a lack of expertise in operation and maintenance.
- Even simple postharvest technologies (e.g., plastic crates) are scarce.

- Transport technology and infrastructure (crates, trucks, roads) are currently a bottleneck in getting produce further from the farms without suffering large losses.
- Energy availability is scarce, but several efforts are underway (e.g., construction of dams) to improve this in the coming years.
- The technology level, availability, expertise/competencies, and readiness in the country are low, indicating that adopting high-tech interventions could be challenging.

8. Input supply. *Score 1*

- Guinea-Bissau has a limited production industry, so a lot of products (and foods) need to be imported, making them expensive. Crates, boxes, and packaging materials are not readily available.
- Clay pots for passive evaporative cooling are readily available at a low cost, as they can be locally manufactured.
- Fertilizer is rarely used and available. Organic manure has a large potential to be used instead.

9. Logistics. *Score 1*

- The road network is present but not of sufficient quality to secure the transport of fresh produce without significant losses during transport. This also hinders the transport or maintenance of cold chain equipment. The rainy season amplifies these restrictions.
- Refrigerated transport is quasi-nonexistent. As such, no export cold chain is established.
  The cost of transporting food per truck is high compared to neighboring countries since there more transport infrastructure is available and the agricultural value chains are better organized.

10. Storage. *Score 2*

- Cold storage is not widely available for domestic use or commercial purposes, for example, at the markets. Per region, there are only a few cold stores available.
- Cold storage is mostly developed for the fish industry.
- The HVAC industry for room cooling has also been established and could thus be leveraged to cool fresh produce.

11. Processing and retail. *Score 3*

- There is a growing population of young people, and urbanization is evident and expected to increase, but not exponentially. This implies that retail will need to be able to cater to these changing demographics and this demand in supply. There is a need for backward-chain integration.
- Training programs are developed that focus on the processing of fresh produce (canning, drying, etc.) by several organizations (SWISSAID) and are stimulated by organizations (NGO AMAE (Confédération des femmes en activités économiques), UNDP for vegetable processing, UNIDO for mango processing).
- There is a risk of competition from imports. Nevertheless, local production may lead to lower costs and thus more competitive prices.
- There are initiatives where remote production areas (e.g., in Gabu) are unlocked by traders to supply regional capitals already by supplying transport options. Food losses are still (too) high, though, so improvements are necessary.

CONCLUSIONS. The composed diagnostic is shown in Figure 9, which includes both the current state and a diagnostic that incorporates several potential improvements to the enabling conditions. The enabling conditions are particularly weak. However, there is a large potential to improve these conditions by training people and improving infrastructure.

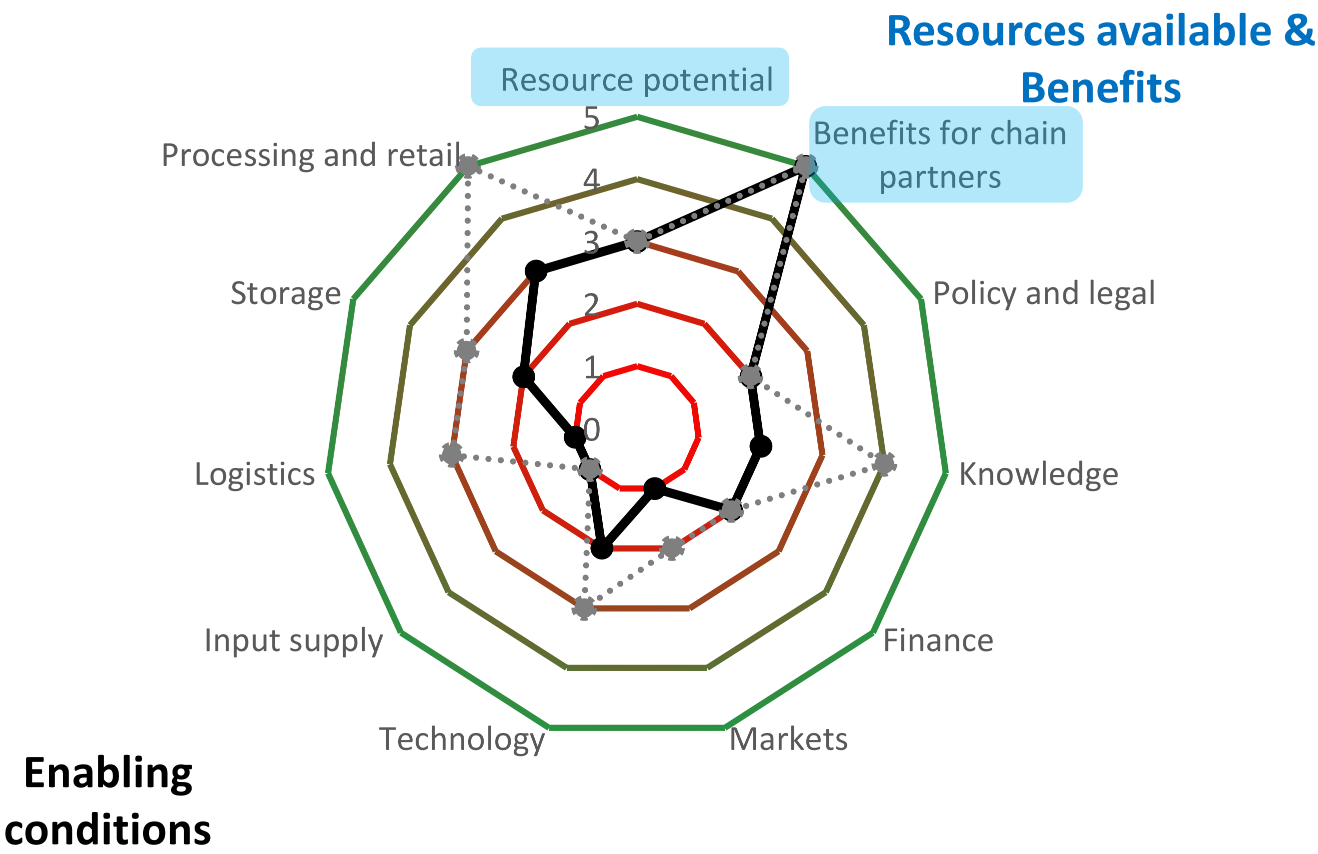

Figure 9. Diagnostic for the planned objective in Guinea-Bissau with a scoring of the current state (full line) and the potential for improving several aspects in the short term through interventions (dotted line). The available resources and benefits, on the one hand, and the enabling conditions, on the other hand, are colored differently.

3.3 Postharvest interventions

3.3.1 Bottlenecks, root causes, and possible solutions

We aim to group the main bottlenecks and their root causes for each of the objectives and design possible solutions (interventions) for each objective.

Intervention matrix with bottlenecks, root causes, and solutions/interventions

We have listed possible interventions or solutions in Figure 10. The bottlenecks, root causes, and solutions are listed in an intervention matrix in Figure 11, which is focused on low and middle-income countries and low-tech technologies. Several postharvest technology interventions in fresh-food supply chains that focus on high-tech supply chains and that are implemented in high-income countries are shown in Figure 12. Below, this matrix is used to score the viability and impact of each solution.

These solutions target the following objectives (section 2.2.4): (1) Reduce food quality loss after harvest to increase local food preservation for subsistence farmers or smallholder farmers; (2) Improve the income of smallholder farmers. Secondary objectives are: (1) enhance the diet to be more nutrient-rich diets through increasing the availability of fruit and vegetables; (2) empower women's participation in agriculture, more specifically in horticulture.

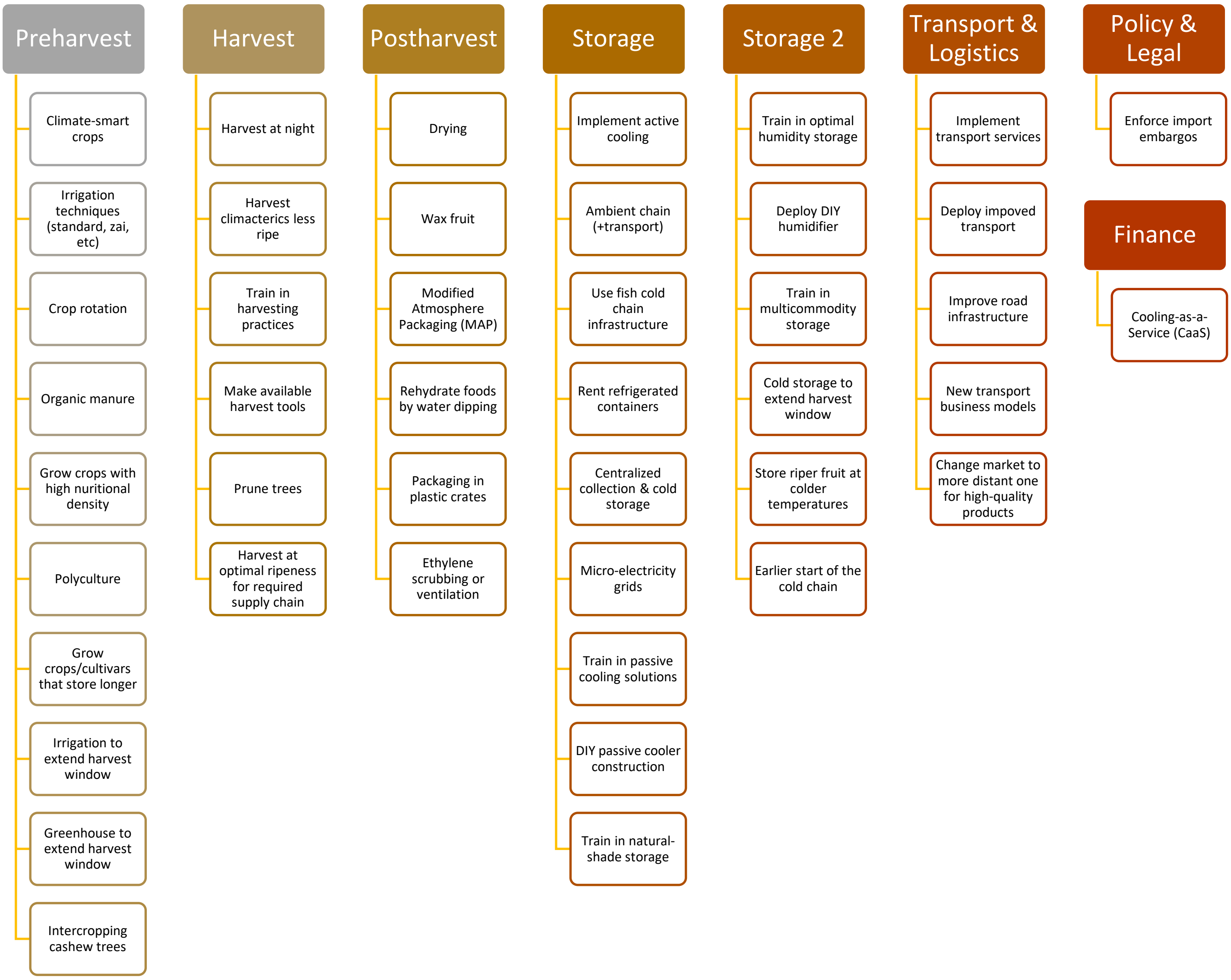

Figure 10. List of interventions/solutions that can be implemented for different stages in the supply chain.

Bottleneck	Root causes	Solution/Intervention		Topic
due to	caused by	Keyword	Description	
High temperatures leading to accellerated spoilage	No/limited active cooling infrastructure and cold chain are implemented or available	**Implement active cooling**	Stimulate entrepreneurs or cooling companies to offer active cooling on site or at markets	Storage
		Ambient chain (+ transport)	Avoid the need for cold storage by optimizing the ambient chain until point of sale, for example by optimizing transport	Storage
		Use fish cold chain infrastructure	Apply or use the equipment of the refrigeration sector for fish in Guinea-Bissau, which is already established	Storage
		Rent refrigerated containers	Rent refrigerated containers that are grid connected or diesel powered	Storage
	Late start of the cold chain	**Earlier start of the cold chain**	Accellerate start of the cold chain by speeding up processes in between harvest and cooling	Storage
	Storage in the sun	**Train in natural-shade storage**	Training and train-the-trainers on storage under natural shade	Storage
	Harvest during daytime	**Harvest at night**	Harvest at night	Harvest
	No access or knowlegde on low-cost passive cooling technologies	**Train in passive cooling solutions**	Training and train-the-trainers on (DIY) passive cooling techniques (shade, evaporative, underground, night ventilation, thermal storage)	Storage
		DIY passive cooler construction	Learn to make passive coolers	
Active cooling **too costly so** cannot be put into operation	Limited access to financial resources to use or purchase cold storage	**Cooling-as-a-Service (CaaS)**	Implement CaaS for cold storage rooms	Finance
		Centralized collection & cold storage	Collect all fruit from farmers centrally in a larger cold store instead of smaller cold stores to be more cost beneficial	Storage
	Grid is too unreliable to implement active cooling, diesel generators are not an option & individual solar is too expensive	**Micro-electricity grids**	Produce electricity by solar-powered microgrids, used for different purposes, and purchase electricity from that	Technology
Low humidity leading to dehydration and wilting	No access or knowlegde on high humidity storage	**Train in optimal humidity storage**	Training and train-the-trainers on high humidity storage (including in passive coolers)	Storage
		Modified Atmosphere Packaging (MAP)	Make MAP packaging available	Storage
		Wax fruit	Wax fruit	Harvest
		Rehydrate foods by water dipping	Dip leafy greens or carrots in clean water to let them rehydrate	Storage
	No humidifiers available	**Deploy DIY humidifier**	Make low cost humidifiers available (e.g. textile wetted or charcoal box) in storage shed/room	
Harvest quality of fruits not sufficient (bruising, latex damage, too ripe, non-uniform ripeness, overall quality not good) leading to lower prices and limited storage time	Lack of training	**Train in harvesting practices**	Training and train-the-trainers on harvesting practices (when to harvest and how to handle harvest)	Harvest
		Make available harvest tools	Make better harvest tools available	Harvest
		Prune trees	Plant and prune trees that are lower and are easier to be harvested	Harvest
	Harvest climacteric fruit at a (too) ripe stage for the intended storage time	**Harvest climacterics less ripe**	Harvest at different ripeness level (mature green instead of tree ripe) so can be stored longer and maybe even in the ambient chain but is of lower sensorial quality and needs to be ripened still (although customers might be willing to accept this lower quality)	Harvest
	Drought or fungal infection or insufficient soil nutrients	**Irrigation techniques (standard, zai, etc)**	Irrigation by building a new irrigation system or water capturing by zai technique or half moon technique	Preharvest
Postharvest damages to product after harvest due to bruising	Appropriate packaging not available	**Packaging in plastic crates**	Use appropriate packaging	Storage
Unfavourable gas conditions leading to highly respiring fruit and accellerated decay	No access to technologies as CA or MAP to reduce respiration	**Modified Atmosphere Packaging (MAP)**	Make MAP packaging available (as CA will be too costly and difficult to implement)	Storage
	Storage ethylene sensitive fruit with ethylene producing fruit	**Train in multicommodity storage**	Avoid storing ethylene producing and ethylene sensitive cropts together for a prolonged time	Storage
		Ethylene scrubbing or ventilation	Implement ethylene scrubbing or ventilation	Storage
Transport (time) to market too lengthy or far	Lacking transport infrastructure (trucks, 2WD, wheelbarrows)	**Implement transport services**	Stimulate transport sector/entrepreneurs to make services available to farmers	Transport & Logistics
	Transport mode is too slow (e.g. wheelbarrow)	**Deploy improved transport**	Stimulate transport sector/entrepreneurs to make services available to farmers to have faster transport	Transport & Logistics
	Lacking road network and condition road network in rainy season is bad	**Improve road infrastructure**	Government improves road infrastructure	Policy & Legal
	Transport costs for fast transport are too high	**New transport business models**	Improve business model so can be offered at a lower price	Logistics
Cheap **imports** that flood market	Open market policy, no embargos	**Enforce import embargos**	Government enforces import embargos during certain times	Policy & Legal
Low yields	Low yields due to crops suffering from climate change	**Climate-smart crops**	Grow crops and species that are more resilient to the climate and droughts and scarce soils	Preharvest
	Low yields due to monocultures	**Crop rotation**	Including nitrogen-fixing legumes (fava, cowpeas, groundnuts, etc.) in the rice farming cropping plan	Preharvest
	Low yields due to lack of financial access to fertilizer	**Organic manure**	Use organic manure use for production of vegetables	Preharvest
	Agricultural land nearby used by cashew industry	**Intercropping cashew trees**	Intercropping cashew trees with other crops (pineapple, banana, pepper, citrus)	Preharvest
Peak production leading to low prices and limited period of availability	Short harvest window due to monoculture/1 dominant cultivar	**Polyculture**	Crop planning and diversification of crops grown so they are more available off season	Preharvest
		Grow crops/cultivars that store longer	Grow other crops with a longer storage life (cabage, other lettuce cultivars, carrot, apple, pear) or change cultivars	Preharvest
		Irrigation to extend harvest window	Extending harvest window (via irrigation) which can be done by building a new irrigation system or water capturing	Preharvest
		Greenhouse to extend harvest window	Extending harvest window (via greenhouse/tunnels)	Preharvest
		Cold storage to extend harvest window	Prolong storage of fruits through long-term postharvest (cold) storage	Storage
	Harvest climacteric fruit all at same ripeness stage, so with a similar time-to-sale in mind	**Harvest at optimal ripeness for required supply chain**	Harvest at different ripeness level (mature green instead of tree ripe) so can be stored longer and maybe even in the ambient chain but is of lower sensorial quality and needs to be ripened still (although customers might be willing to accept this lower quality)	Harvest
	No processing or other preservation methods available to extend storability	**Drying**	Prolong storage by drying fruit and vegetables (e.g. mango, tomato)	Processing
Customers do not want to pay for high(er) quality products	Customer quality standard is lower and/or financial means are not available for customers to buy more	**Change market to more distant one for high-quality products**	Transport to regional or national markets by facilitating transporting with intermediaries	Transport & Logistics
Nutritional quality/density is not sufficient	Crops grown have low nutritional density	**Grow crops with high nutritional density**	Shift to crops with higher nutritional density per hectare	Preharvest

Figure 11. Intervention matrix with bottlenecks, root causes, and solutions/interventions.

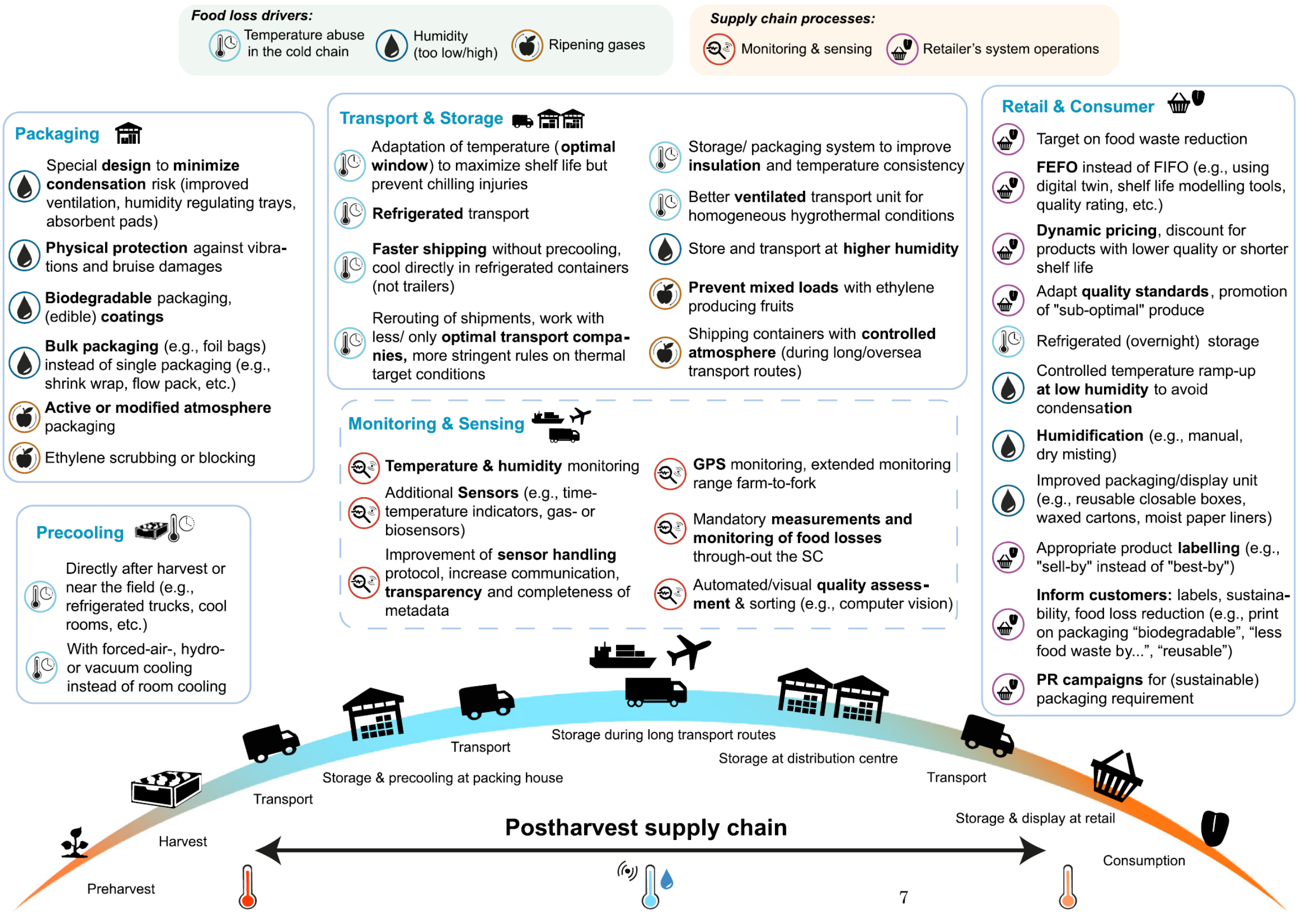

Figure 12. Food loss and waste-reducing interventions, mapped for different drivers and grouped for several stages along the postharvest supply chain of fresh produce, focused on high-tech supply chains implemented in high-income countries. Abbreviations: SC, Supply chain; GPS, Global positioning system; FEFO, "first-expired-first-out"; FIFO, "first-in-first-out"; PR, Public relations (from (Schudel et al., 2023)***).***

Scoring of the interventions and selection of the most promising interventions

The interventions in Figure 11 were scored to identify the most promising interventions for the study's objectives. Several experts scored the interventions: a postharvest technology and supply chain expert, a sustainable energy and agriculture data scientist, a food processing expert, a business developer, and a local agricultural consultant in Guinea-Bissau. The scoring focused on the envisaged impact of an intervention to reach the objectives and the feasibility of an intervention to successfully implement it within the environment and conditions in Guinea-Bissau. The feasibility can also be considered as the probability of success for implementation. The score is the product of the impact and its feasibility (impact from 1 = low - 5 = high, feasibility from 1 = low - 5 = high). This product thus ranges from 1 to 25. The scoring is shown in Figure 13.

The interventions that are promising to implement follow from the scoring of the intervention matrix, namely interventions with an envisaged high impact and a high probability/feasibility to implement. The most promising interventions could be grouped into several intervention clusters. These clusters form the basis for a more detailed feasibility assessment per cluster. We found it more conservative to focus on these clusters rather than single interventions since fine-graining them might unveil that some of them cannot be implemented. The interventions that score the highest (≥ 12) are listed below.

- Interventions related to active cooling
  - Implement active cooling
  - Cooling-as-a-Service (CaaS)
  - Centralized collection and cold storage
  - Earlier start of the cold chain
- Interventions related to passive cooling
  - Train in passive cooling solutions
  - DIY passive cooler construction
- Interventions related to postharvest practices
  - Train in natural-shade storage
  - Harvest at optimal ripeness for the required supply chain
  - Harvest climacterics less ripe
  - Train in optimal humidity storage
  - Packaging in plastic crates
  - Implement transport services
  - Deploy DIY humidifier
  - Train in multicommodity storage
  - Deploy improved transport
- Interventions related to preharvest practices
  - Train in harvesting practices
  - Crop rotation
  - Irrigation to extend the harvest window
  - Polyculture
  - Irrigation techniques
  - Drying
  - Intercropping cashew trees

Note that an initial scoring, as we have done here, provides guidance. With this, we have already singled out those technologies that do not seem, at this point and without more detailed analysis, viable for our use case in Guinea-Bissau. Note, however, that it is possible that the remaining key technologies that were scored high still can have a key hurdle that prevents their implementation. These hurdles will become evident when the interventions are refined in a feasibility analysis (see section 3.4, but this is not part of this study).

Solution/Intervention	Postharvest technology and supply chain expert	Sustainable energy and agriculture data scientist	Food processing expert	Business developer	Local agricultural consultant in Guinea-Bissau.	Average
Implement active cooling	20	12	8	15	9	13
Ambient chain (+ transport)	12	6	16	6	9	10
Use fish cold chain infrastructure	12	12	2	1	2	6
Rent refrigerated containers	20	6	4	3	1	7
Earlier start of the cold chain	6	8	15	20	16	13
Train in natural-shade storage	25	12	25	12	16	18
Harvest at night	9	6	16	10	9	10
Train in passive cooling solutions	20	16	25	16	16	19
DIY passive cooler construction	20	12	25	16	9	16
Cooling-as-a-Service (CaaS)	20	12	6	12	9	12
Centralized collection & cold storage	25	6	12	4	12	12
Micro-electricity grids	16	9	12	8	3	10
Train in optimal humidity storage	20	9	25	16	16	17
Modified Atmosphere Packaging (MAP)	9	4	1	8	16	8
Wax fruit	6	4	2	9	9	6
Rehydrate foods by water dipping	8	12	6	6	9	8
Deploy DIY humidifier	12	12	20	12	9	13
Train in harvesting practices	20	12	25	16	16	18
Make available harvest tools	9	6	6	5	16	8
Prune trees	12	4	4	9	16	9
Harvest climacterics less ripe	20	12	25	15	9	16
Irrigation techniques (standard, zai, etc)	15	12	12	10	16	13
Packaging in plastic crates	20	12	15	12	16	15
Modified Atmosphere Packaging (MAP)	6	4	4	10	9	7
Train in multicommodity storage	15	8	16	16	9	13
Ethylene scrubbing or ventilation	3	6	3	8	4	5
Implement transport services	20	8	12	15	12	13
Deploy improved transport	16	8	12	15	12	13
Improve road infrastructure	10	4	10	5	12	8
New transport business models	15	8	9	12	12	11
Enforce import embargos	10	3	1	3	12	6
Climate-smart crops	8	6	8	9	6	7
Crop rotation	20	6	12	9	16	13
Organic manure	12	6	12	9	16	11
Intercropping cashew trees	12	12	16	8	12	12
Polyculture	16	12	8	16	16	14
Grow crops/cultivars that store longer	16	6	8	12	9	10
Irrigation to extend harvest window	15	12	15	10	25	15
Greenhouse to extend harvest window	10	6	15	5	15	10
Cold storage to extend harvest window	20	9	6	9	12	11
Harvest at optimal ripeness for required supply chain	20	12	9	20	9	14
Drying	12	12	15	12	12	13
Change market to more distant one for high-quality products	12	8	8	12	6	9
Grow crops with high nutritional density	8	6	8	12	9	9

Figure 13. Results of the scoring of the interventions by several experts and the average. The maximal score per expert is 25. The scores are colored from red (low) to green (high).

Relevant boundary conditions

We list some important boundary conditions that will impact the feasibility of an intervention.

- The intervention will **not necessarily need to rely on active cooling** or a refrigerated supply chain for several use cases and crops. For example, some fruits (tomato, mango, banana, Figure 7) that are destined for the local or regional weekly market can be transported and stored in an ambient chain for a short time, which is sufficient to reach the market in good quality. Refrigeration can be applied to extend storage life with the main aim of increasing income by selling at the market.
- If **electricity** is required, the intervention will likely not be dependent on the electric grid as this is unstable or is not available on-site in several locations in Guinea-Bissau. Also, diesel generators should be avoided due to logistical problems with fuel provision. As such, solar energy needs to be deployed.
- Even if active cooling is deployed, this likely will need to be **placed in non-remote areas**, such as villages, as management and security risks are higher in rural areas. Here, the opportunity for a grid connection is, if at all, more plausible in the future, thus avoiding the need for solar energy systems. This can also increase farmers' trust in leaving their harvest in a secure place.

- Several **passive cooling technologies** are promising as they avoid dependency on the grid or on more expensive technologies that need to be imported, such as photovoltaics.
- The technology used will likely not be used **year-round** due to the seasonality of the harvest season.
- The financial dependency on the **import of hardware** for cooling solutions is likely hindering large-scale deployment in the country.
- Preference should be given to **locally produced solutions** that can be maintained and serviced using components available in the country or neighboring countries. The technology should be **simple to use and repair** or locally maintainable. Spare parts should be readily available.
- **Modular solutions for active cooling** are preferable over large containers to account for the limited production of fresh produce and the fact that each farmer community has a different production capacity.
- The intervention should serve **individual farmers** directly or indirectly via middlemen since farmers are not organized in farmer cooperatives or associations in Guinea-Bissau. However, villages with farmer communities might evolve into informal farmer associations.
- **Transport** to create market access will be a key part of the intervention.
- A **combination of interventions** is likely the most effective, for example, combining active cooling with harvesting at night, potential packaging, and shortening the time to market or cold store.
- The solution and interventions should be integrated into the **entire value chain** and not be evaluated stand-alone. For example, cooling at the farm will not have a large impact if, afterward, lengthy unrefrigerated transport to the (uncooled) market occurs. A successful intervention will lead to better product quality at sale or less losses throughout the entire value chain.
- **Climacteric fruits** have the advantage that they can be harvested less ripe and stored longer. This gives additional flexibility.

3.3.2 Outline for interventions

We provide a preliminary outline for the key intervention that best suits the formulated objective but only focus on the postharvest interventions. Note that these interventions need to be detailed more specifically to assess their feasibility better and refine the intervention. Note that when refining the interventions, it is essential to have solutions that are scalable throughout the country to serve a large farmer community with a similar production and vending profile.

3.3.2.1 Active cooling

Based on the scoring of the interventions, implementing active cooling was one promising class of interventions.

Different **types** of active cooling technologies are available at different scales and costs, including commercially available cold storage rooms of a few metric tons storage capacity (often solar powered), rented refrigerated trailers or trucks, home-made cold storage rooms that are cooled with AC units, fridges (PV and grid powered), cool boxes that are cooled with ice or PV powered. From the field visit and our assessment, we foresee the following options as the most promising for active cooling at this point. These options are strongly linked to the location where they are placed (market gate vs. farm gate) and the volumes of fruit that are available there (from one or more farmer communities).

Option 1. Commercially available cold storage rooms with a few metric tons of storage capacity at the market gate that serve multiple farming communities. These can be customized cold storage rooms or refrigerated containers. The location is envisaged to be at the regional market gate. Reasons against farm gate siting are that a farmer community has too low production levels to ensure sufficient occupancy, and the farmer community often lacks expertise and legal structure to purchase, operate, manage, and maintain the facilities. At the market gate, stakeholders (cold store operators, organizations) that provide the necessary embedding can also be present. In this case, however, the food of different farmer communities needs to be pooled into one facility to ensure sufficient occupancy. This can be done by wholesalers or famer cooperatives who purchase from local farming communities and transport them to regional markets. Partnering with farmer cooperatives offers the advantage of redistributing the increased earnings from selling cooled produce directly to the farmers. Market gate cold storage could also serve farmers or vendors that go with their produce from one weekly market to the next one the next day. Transport to regional markets without excessive food losses is critical here and is still a current bottleneck. Nevertheless, ownership of the facility and the land to operate it can be more challenging to organize than in a farming community.

Option 2. Smaller cold storage solutions at the farm gate that serve a single farming community. These can be small fridges (with individual PV, connected to the grid or a PV microgrid), home-made, custom-sized, insulated, cold storage rooms that are cooled with AC units and CoolBot technology (StoreItCold, 2024). Farmers would benefit from on-site storage to preserve their products better for their consumption and for selling at local markets. All these solutions are scalable in size (e.g., 1-2-3 fridges and a small or larger insulated room with one or more AC units). The use of multiple small-scale units allows for scalability, accommodating the varying sizes and harvest volumes of each farming community. In this case, proper transport to the market is also essential. Farmers have welcomed such modular solutions during our field visit. Note that the homemade, AC-cooled rooms will need a lot of expertise and equipment to build and operate (e.g., by microentrepreneurs), compared to the other two more plug-and-play solutions, which are not always available.

A follow-up feasibility study should still quantify which scale and type of active cooling technology makes the most sense for our use case at each location. This quantification entails storage capacity, financial aspects (business case and business models), cooling capacity and cooling speed, and the capability of the cooling facility to extend the shelf life (temperature reduction potential) versus the needed shelf-life extension for farmers to the point of sale. After selecting a technology, a pilot is essential to demonstrate that active cooling can increase shelf life and reduce postharvest quality loss, compared to current postharvest storage, which is storage in the shade.

3.3.2.2 Passive evaporative cooling

Passive cooling is another intervention that is promising to be deployed, especially systems that the farmers themselves can construct. From the different options, small-scale passive coolers for smallholder farmers or vendors seem the most viable, especially clay pot-in-pot or pot-in-dish evaporative coolers, and not larger evaporative coolers, such as charcoal coolers or brick-sand coolers. The reason is that pot-in-pot coolers seem, for our use case, the simplest technology that can be applied on a small scale (individual farmers or vendors).

A follow-up feasibility study should quantify which time of the year these coolers would be deployed best for high-temperature reduction and financial aspects (business case and business models). Furthermore, construction guidelines for DIY manufacturing should be set up, and an implementation and training plan should be composed, including impact monitoring. After selecting a technology, a pilot is essential to demonstrate that passive cooling can increase shelf life and reduce postharvest quality loss, compared to current postharvest storage, which is storage in the shade.

3.3.2.3 Longer postharvest storage by a combination of techniques

A combination of individual postharvest practices was also identified as a promising intervention. Different practices are, among others, storage under natural shade, harvesting at a ripeness optimal for good quality at the point of sale for a given supply chain to avoid over-ripe fruit from being transported and arriving at the market, improving packaging and transport services to reduce mechanical damage to the produce and food loss, and storing under optimal (higher) humidity. A follow-up feasibility study should still quantify which intervention is most suitable and impactful for which crop and financial aspects (business case and business models).

3.3.3 Risk and impact analysis and mitigation

AIM. A general risk assessment is performed, and mitigation measures are stated.

RESULTS. We identify and describe each risk and score the probability and impact (Table 2), the product of which leads to a risk score, which is shown in Figure 14. We describe the mitigation measures (preventive and corrective). We score the risk as the product of the envisaged impact and probability (impact from 1 = low - 5 = high, probability from 1 = low - 5 = high). This product thus ranges from 1 to 25. Preventive measures indicated in blue can already be taken in advance to change the risk score. We do the risk scoring evaluation twice before and after implementing preventive mitigation measures.

CONCLUSION. Key risks, even after preventive mitigation measures, with a risk score ≥ 8 are:

- Customers are unwilling to pay the additional price for food stored in cold storage or the resulting prime product quality.

- The occupancy rate in the cold store is too low due to no perceived benefit, lack of awareness, or over-dimensioning of the facility in terms of the amount harvested throughout the year or the off-season dip, which reduces its economic viability.
- Passive evaporative cooling does not convince farmers to keep on using such coolers due to improper use of the technology or use in the wrong season, leading to poor performance and results.
- Increased import of fresh produce because domestic production of fruit and vegetables is less economically attractive than other crops (e.g., due to high cashew prices), because of which less produce is grown.
- The initial quality of the produce is too low to justify cold storage (and the additional storage cost that is involved).
- Transport and import costs are high relative to the cost of cold stores and will render cold storage technology more expensive to deploy.

The key proactive mitigation measures that would need to be taken before implementing technology to reduce the risk scores of high risks significantly or below 8 are:

- A detailed business case calculation and payback time and select economically viable solutions for active cold storage.
- A detailed capacity calculation is needed to avoid low occupancy and deploy a cold storage solution that matches the demands.
- Match the technology to the targeted shelf life for the specific crops in the farmer community to avoid unnecessarily deploying a technology that extends the shelf life beyond the farmers' needs.
- Screen the initial quality of the crops to see if they are viable for cold storage.
- Training and awareness raising on how active and passive cooling work.
- Create a flexible cooling solution that can be adjusted to multiple contexts (e.g., size) to avoid the need for customization of the equipment every time.
- Provide guidelines in local languages and train a superuser in the community to improve expertise in cold storage.
- Select technologies that can be deployed in the majority of the target locations to also serve locations that are difficult to reach.
- Assess in which percentage of the farmer communities a technology can be implemented, and select a technology that is scalable to several communities to avoid a large share of the farmer communities not installing or accessing cold storage.

Table 2. List of risks and their mitigation measures (Probability from 1 = low - 5 = high, Impact from 1 = low - 5 = high).

ID	Title	Description	Category	Probability	Impact	Risk score		Preventive mitigation measure	Corrective mitigation measure	Probability '	Impact '	Risk score '
R1	Customers do not buy product	Customers are not willing to pay the additional price for food stored in cold storage or for the resulting prime product quality.	Active cooling	2	5	10		-	-	2	5	10
R2	High cost cold storage	The additional cost of cold storage is too high for the farmers to provide a competitive price	Active cooling	3	4	12		Detailed business case calculation and payback time and select economically viable solution	-	1	4	4
R3	Discontinued cold storage units	The cold storage units are not being used after the project ends due to lack of expertise to operate or too high costs for maintenance	Active cooling	3	2	6		Engage entrepreneurs with a technical background to operate the units	Find new operating partner (host) of the facility	2	2	4
R4	Low occupancy	The occupancy rate in the cold store is too low due to no perceived benefit, lacking awareness or overdimensioning of the facility for the amount harvested throughout the year or the off-season dip, which reduces its economical viability	Active cooling	3	5	15		Detailed capacity calculation	Increased awareness raising. Store other products as well to increase capacity (meat, dairy)	2	5	10
R5	Too long shelf life	The cold store prolongs the shelf life, on average, longer than the time necessary for the farmers to be able to sell their produce, leading to a too high investment in the technology	Active cooling	4	3	12		Match the technology to the targeted shelf life for the specific crops in the farmer community	Operate the facility at a lower cooling (and fan) power to increase lifetime and save electricity or sell it	2	3	6
R6	Low initial quality	The initial quality of the produce is too low to justify cold storage (and the additional pricing that is involved)	Active cooling	3	4	12		Screen the initial quality of the farmers to see if it is viable for cold storage	Improve harvest quality by training into harvest practices (e.g. SWISSAID trainings)	2	4	8
R7	Slow cooling	The cargo does not cool down fast in the cold storage room due to too much warm cargo loaded or impermeable packaging used (or paper liners in crates), leading to a higher quality decay, especially for short term storage	Active cooling	2	3	6		Design cold storage room and packaging in such a way that fast cooling is feasible		1	3	3
R8	Passive cooling not working	Passive evaporative cooling does not convince farmers to keep on using it, due to improper use of the technology or use in the wrong season, leading to poor performance and results	Passive cooling	3	5	15		Training and awareness raising	Training and awareness raising	2	5	10
R9	Pot-in-pot coolers expensive	Pot-in-pot coolers are too expensive or too complicated to build.	Passive cooling	3	3	9		-	Revert to pot in dish coolers	3	1	3
R10	Currency	Inflation or changes in currency, making imported cold chain technologies more expensive and less economically viable to deploy.	Finance	2	5	10		-	In business case, make sure there is a margin to accomodate for this and choose technology that have a short payback time	2	3	6
R11	Import fresh foods	Cheap imports of fresh produce from neighboring countries (e.g. onions)	Trade	3	4	12		-	Shift to producing other commodities	3	2	6
R12	Import produced foods	Cheap imports of processed foods (e.g. canned tomatoes) from abroad	Trade	3	3	9		-	Regulate imports nationally. Shift to producing other foods	3	2	6
R13	Other agricultural supply chains dominate	Increased import of fresh produce due to the fact that domestic production of fruit and vegetables is less economicall attractive than other agricultural crops (e.g. due to high cashew prices), by which less produce is grown	Market	3	3	9		-	-	3	3	9
R14	Damage to unit	The units are damaged (human and natural disasters) or components are stolen	Active cooling	2	4	8		Locate units where there is some security or social control and where the risk of natural disasters (e.g. flooding, termites, monkeys) is limited. Insure against damage	-	1	4	4
R15	Customization when installing cooling solution	For each new possible site, a new assessment and customization of the intervention (active cooling) needs to be done to check the viability and install and operate the units (now performed by the project team as facilitator). This leads to upscalability issue to more sites	Active cooling	2	5	10		Create a flexible solution that can be adjusted to multiple contexts (e.g. size). Engage cold store provider/entrepreneur as a facilitator/intermediary to take this role	-	1	4	4
R16	Expertise lacking in cold storage	Expertise lacks in cold storage (e.g. optimal temperature, storing different fruit together) by which more quality loss occurs	Active cooling	4	3	12		Provide guidelines in the local language. Train a superuser in the community	-	2	3	6
R17	Saturated market	Prices at the local market drop due to less food loss since more is preservedd better, and the market gets saturated	Active cooling	3	2	6		-	Enable export to regional markets and cities through transport solutions	3	2	6
R18	Transport and import costs high	The transport and import costs are high, relatively to the cost of the cold store (which are funds which are not materialized) and will render the technology more expensive to deploy	Active cooling	4	2	8		-	-	4	2	8
R19	Locations not reachable	A large part of the locations (farmer communities) are not reachable to transport cold units to farmer communities	Active cooling	3	4	12		Select technologies that can be deployed in the majority of the target locations	-	1	4	4
R20	Farmer communities not viable to install cold storage	The farmer communities do not fulfill the selection criteria for installing cold storage with respect to road accessibility, security, access to a rural market, willingness to adopt cold storage and the amounts produced, by which the solution does not become scalable	Active cooling	3	5	15		Assess which percentage of the communities is viable for different technologies and select technology that is scalable to several communities		1	5	5

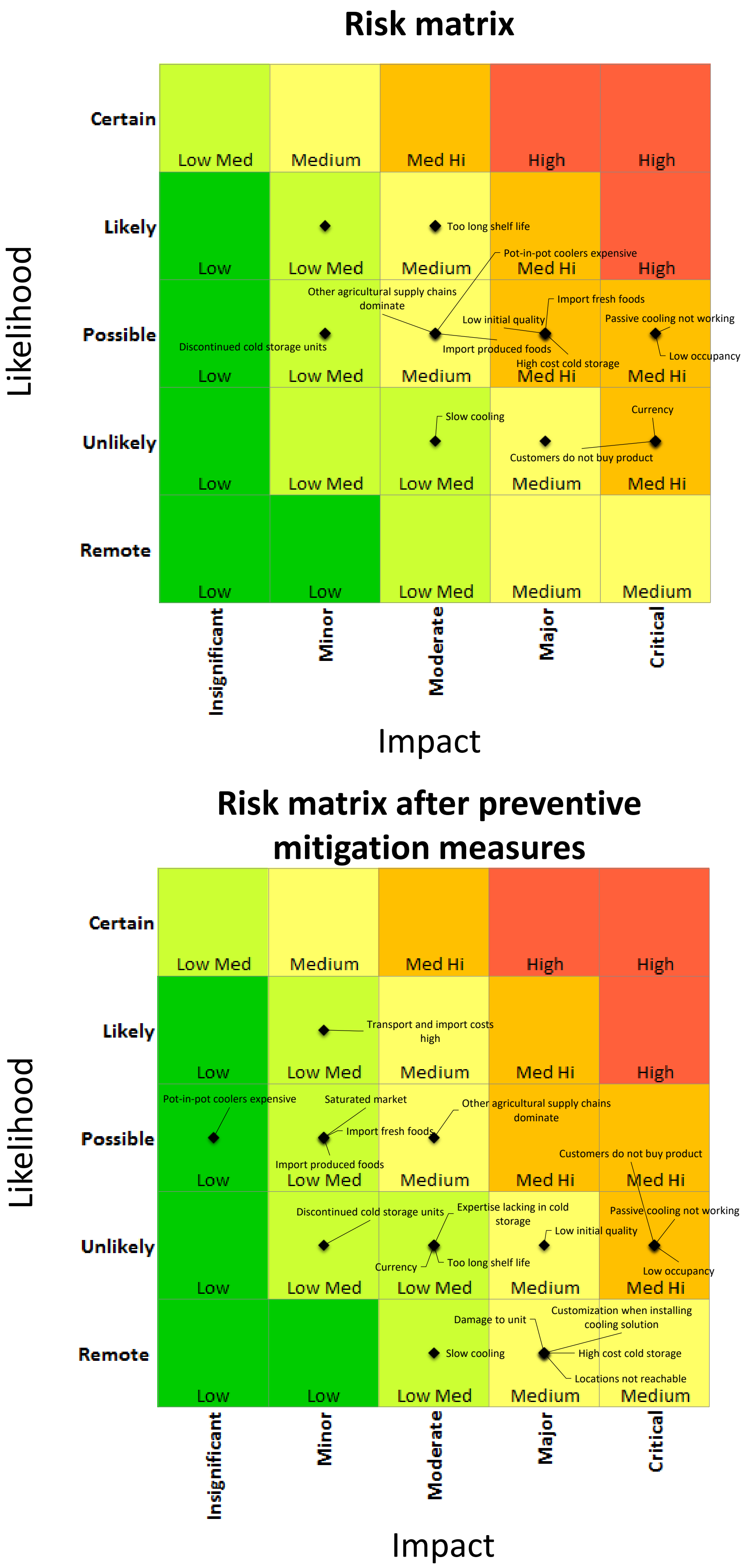

Figure 14. Risk scores as a function of impact and probability before and after preventive measures.

3.4 Actions following the impact assessment of postharvest interventions

We identify which steps need to be taken after the current impact assessment.

Feasibility analysis. A feasibility analysis of the interventions fine-grains how an intervention would look like and provides concrete numbers on, for example, the different systems, cold room size, cooling capacity, cost per crate, farmers served, etc. Here, it is also evaluated if the prerequisites for implementing the technology are present. These include, among others, stakeholders implementing and maintaining the solution over a longer time and taking ownership and responsibility of the hardware and the availability of sufficient fruit at a good initial quality at harvest, which is essential prior to deploying cold storage, for example.

Responsible for actions. We need to identify who is responsible for implementing each specific intervention, identify the other stakeholders involved, and list the corresponding actions.

Peripheral actions to enable the intervention. We need to identify the following actions that provide an enabling environment for the implementation of the intervention.

- Influence by other actors. We assess the spheres of influence of other actors in the food system that are related to the success of policy implementation. We list the actors that can help to stimulate the success of the intervention.
- Additional assessment actions. We determine which elements of the food system need additional assessment with respect to the social, political, cultural, technological, economic, environmental, and natural environments.
- Policies to influence actions. We assess means of influence and potential policies and actions to influence decision-makers at the value chain level. Policy changes can help to stimulate the success of the intervention.

Pilot. We need to pilot the selected technology in the field to evaluate its feasibility as a step prior to larger-scale implementation with the aim of tweaking the intervention.

Business plan. We will detail which business plan makes sense for the farmers to implement the specific intervention. This involves CAPEX and OPEX estimates and ownership identification. Examples of business models are direct purchase, rent, Cooling-as-a-Service, and lease-to-own. This business plan involves calculations and possible financing schemes (entrepreneurs, shareholders, banks, investors, project grants, etc.).

Financing. Identify possible financing organizations and realize the necessary financing based on the business plan set in the previous phase.

Implementation plan. We need to roll out a plan for hardware and staff and define a sales concept, including details on how to operate the cooling solutions, cash flow, maintenance, and impact monitoring.

4 Conclusions and outlook

Our objective is to (1) reduce fresh produce quality loss after harvest, (2) increase local food preservation and nutrition security for subsistence farmers and smallholder farmers in Guinea-Bissau, and (3) improve the income of these farmers. We applied a postharvest impact assessment. The aim was to identify the most promising interventions, including cooling, to help maintain the quality of fresh fruit and vegetables. Interventions that can be implemented in the short term are preferred to stabilize the current situation in Guinea-Bissau and provide nutrition security relief.

4.1 Activities, findings, and outputs

Starting point of our use case (section 3.1). We mapped the specific target value chain in terms of target farms, farmers, crops produced, and the market. This is an essential starting point to further identify and score the possible interventions. **Output**. A set of 20+ comprehensive questions was composed that can be used to pinpoint the use case. **Findings**. Farmer communities produce fruit (in dry season: mango, banana, papaya, orange fruit) and vegetables year-round (tomato, lettuce, onions, eggplant, cucumber, peppers, carrot, okra, kale, cabbage). Farmers sell to local and regional weekly markets but lose about 30% postharvest. As these foods are typically to be preserved for 1-2 weeks to sell at the weekly markets, the key period to preserve them is December to June. Current postharvest practices are low-tech and do not include refrigeration and packaging in plastic crates. The individual farming communities produce too low amounts to fill a typical 3-5 ton cold store and also lack other components for the necessary cooling ecosystem. Therefore, smaller-scale solutions, such as fridges or passive evaporative coolers, are more viable for deployment at the farm gate. Such large units could work at the regional markets that are accessible by multiple farming communities but will be less effective for farmers who go day-to-day from market to market and only store overnight, which many farmers currently do. Transport to regional markets without excessive food losses is a bottleneck, as it induces many food losses, including via mechanical damage.

Environment in Guinea-Bissau for the intervention (supplementary material). We mapped the complex environment in which the intervention will be implemented for Guinea-Bissau, which is also essential to further identify and score the possible interventions. **Output**. The output is a description of the geography, population, employment, food and nutrition security, facilities (water, electricity, roads, cellphone, internet), GDP, policy, and climate. We also mapped the current situation for perishables (agricultural production, import, export, food losses, processing, consumption, and food prices). We identified current trends and previous and ongoing interventions by other organizations. **Findings.** Guinea-Bissau is a densely forested country. Water is available but not that accessible for agriculture, which is mainly rain-fed. It has a young population, particularly women and youth who work in small-scale agriculture, and urbanization is increasing. The cashew and rice industry has a large impact on the workforce that is available for growing horticultural crops. The majority of the farms are smaller than 1 hectare. Few people own refrigerators at home, and few farmers can access electricity via the grid or generators. However, a substantial HVAC and cooling industry and service staff is available. Several international organizations are active in this country to combat malnourishment, hunger, and poverty. They support several food processing activities but fewer postharvest activities.

Postharvest intervention identification and scoring (section 3.3). We identified a list of 40+ possible postharvest interventions (solutions), as well as the current bottlenecks and root causes that the interventions address, which we combine in an intervention matrix (output). We proposed a systematic way to score different postharvest interventions based on their feasibility and impact. We did a risk assessment of the interventions. **Output**. This intervention matrix and scoring can be useful tools in other projects. **Findings.** The most promising postharvest interventions can be grouped into the following clusters: active cooling, passive cooling, and postharvest practices.

- For active cooling, the technology to be deployed is strongly linked to the location where they are placed (market gate vs. farm gate) and the volumes of fruit and vegetables that are available there (from one or more farmer communities). Commercially available cold storage rooms with a few metric tons of storage capacity must be placed at the market gates to ensure occupancy. They serve multiple neighboring farming communities and vendors that sequentially frequent weekly markets and need to store their produce overnight. Transport from the farm gate to the market gate remains critical. Stakeholders (cold store operators, cooling companies, farmer cooperatives, international organizations for capacity buildings) that provide the necessary embedding are also essential. Smaller cold storage solutions are viable at the farm gate to serve a farming community. These can be small fridges or home-made, custom-sized, insulated, cold storage rooms that are cooled with AC units. Such scalable solutions cater to the varying sizes of each farming community.

- Small-scale passive coolers for smallholder farmers or vendors seem like a viable technology, especially clay pot-in-pot or pot-in-dish evaporative coolers.
- A combination of individual postharvest practices was also identified as a promising intervention. Different practices are, among others, storage under natural shade, harvesting at a ripeness optimal for good quality at the point of sale for a given supply chain to avoid over-ripe fruit from being transported and arriving at the market, improving packaging and transport services to reduce mechanical damage to the produce and food loss, and storing under optimal (higher) humidity.

The next steps are to do a feasibility analysis of the interventions to fine-grain how an intervention would look like, identify who is responsible for implementing, running a pilot, and developing a business and implementation plan (section 3.4).

4.2 Outlook

Unlike several other countries in sub-Saharan Africa, Guinea-Bissau has not yet experienced a 'cold rush' due to logistical and financial bottlenecks. This leaves a potential to shape postharvest preservation, including cooling, sustainably. Concerning the future of refrigeration in Guinea-Bissau, we make the following closing remarks:

1. For several reasons, including poverty and the large dependency on imports, low-tech, standard, and readily available cooling solutions should be pursued rather than high-tech interventions. An example is using fridges or HVAC systems instead of specialized cooling units that need to be imported and serviced by specialized staff. The latter might be viable in other countries, but Guinea-Bissau is not yet ready. The success of these pilot interventions, combined with targeted capacity-building, is crucial for creating demand and progressively enabling the uptake of more high-tech solutions.
2. The farms' food production scale/values, combined with transport options to the market, make or break the viability of postharvest technologies.
3. Several postharvest options could compete with cold storage. Improved packaging and transportation to bigger markets, like Bissau, are among them.
4. Cooling and energy supply are strongly intertwined, so the future of cooling in Guinea-Bissau will depend on the future of energy supply via solar, hydropower, or other sources. We should choose our cooling technologies so they cater to the electricity supply of the future, keeping in mind that cooling is only one of the many applications of electricity by households and farmers. Tailoring the cooling solution to the current energy situation could make more sense rather than vice versa.
5. Cooling and food quality preservation are strongly intertwined. We should not cool to preserve the foods as long as possible, but cool to preserve them until they are sold at the market.
6. There is an increasing awareness of using passive cooling and locally constructed active cooling solutions (such as insulated rooms with local materials). These alternatives to companies providing off-the-shelf solutions are less effective in preserving crop quality, but we can already go a long way compared to storing under shade.
7. The partnership between international organizations and local institutions is critical to facilitate the implementation of cold chain solutions in farmer communities or markets.

A comprehensive postharvest assessment using the postharvest assessment methodology is advised for each use case. This is essential to identify to which extent postharvest interventions depend on the complex interplay of the farmer, farm size, produced foods, distance to market, transportation infrastructure, consumer preference, export dependencies, competing technologies, climate (change) and crop seasonality, financial accessibility to technology, available training, local availability of materials and services provided. From this assessment of Guinea-Bissau, surprising results surfaced, which would likely have remained hidden otherwise. Therefore, we believe such a holistic assessment, even when more rudimentary than the one presented here, is essential to develop and implement long-term sustainable interventions for a certain use case.

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Thijs Defraeye: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Grammarly (full paper) to improve the spelling, grammar, and style of the text. ChatGPT4.o was used to improve some parts of the text with respect to spelling, grammar, and writing style, and DeepL was used for translations. No original content was generated using these AI-assisted technologies. After using this tool/service, the authors reviewed and edited the content as needed and took full responsibility for the publication's content.

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5 Supplementary material: Mapping the environment in Guinea-Bissau

5.1 Current situation in the country

Geography

Guinea-Bissau is located in West Africa and borders Senegal and Guinea. It has a surface area of 36,000 square kilometers and is divided into 9 regions: Bissau, Biombo, Quinara, Bafata, Gabu, Oio, Bolama, Tombali, and Cacheu. The country has a low altitude, with the highest point in Gabu of 262 m. Guinea-Bissau has two ecoregions: Guinean mangroves and the Guinean forest-savanna mosaic (Figure 15). Several parts of Gabu, Bafata, Quinara, and Tombali are protected parks or ecological corridors. There are multiple rivers running through the country towards the coast (Figure 1). About 70% of the country is forested, and this area is decreasing steadily by about 3% every 10 years (The World Bank, 2024).

Conclusion. The country is flat and densely forested.

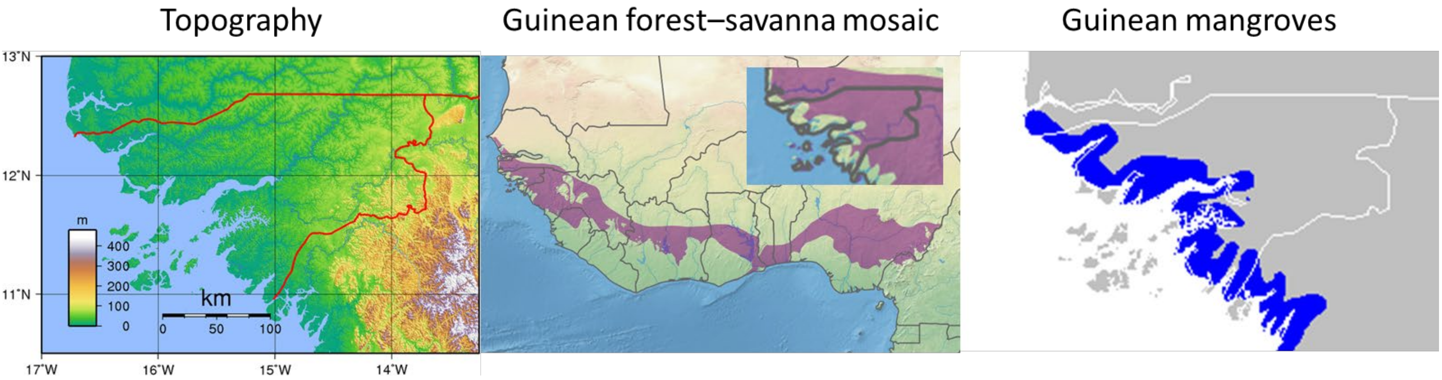

Figure 15. Topography of Guinea-Bissau (Wikipedia, 2024a)***, Guinean forest-savanna mosaic*** (Wikipedia, 2024e)***, and Guinean mangroves (***(Wikipedia, 2024f)***, work by Terpsichores, original image).***

Population and employment

Guinea-Bissau had a population of 2 million people in 2022 (The World Bank, 2024), equally divided between males and females (Figure 16). Most of the people, roughly 60%, live in rural areas (FAO, 2019). The share of people that live in urban areas is increasing more compared to the rural population, indicating an increase in urbanization. About 500,000 people live in the capital Bissau, and the second and third largest regions are Bafata and Gabu. The population is very young, with 60% of the population below 25 years old. About one-third of the population are Millennials (born between 1981 and 1996) and youth (Gen Z, born between 1997 and 2012). The population in Guinea-Bissau is expected to increase to 3.2 million by 2043 (ISS African Futures, 2023) and double by 2050 (FAO, 2019).

About 60-70% of the people are employed in agriculture (FAO, 2019; Food Systems Dashboard, 2023), of which 65% are women and 35% are men. This number is decreasing steadily. 88% are smallholder farmers with land under 2 ha (FAO, 2019). Even though the population has been rising, this relative reduction in the workforce to feed the country will increase the gap between production and demand. This can be counteracted partially by increasing the yield per hectare and mechanization and automation. The unemployment rate is 3.6% (The World Bank, 2024).

Conclusion. Guinea-Bissau has a young population that will increase fast, and thereby, the share of future digital natives will also increase. A lot of people (particularly women and youth) work in agriculture, particularly small-scale agriculture, and they will need to feed many more people in the future. Thus, scale-up to emerging/intermediate farms, automation, yield increase, or postharvest loss reduction is key.

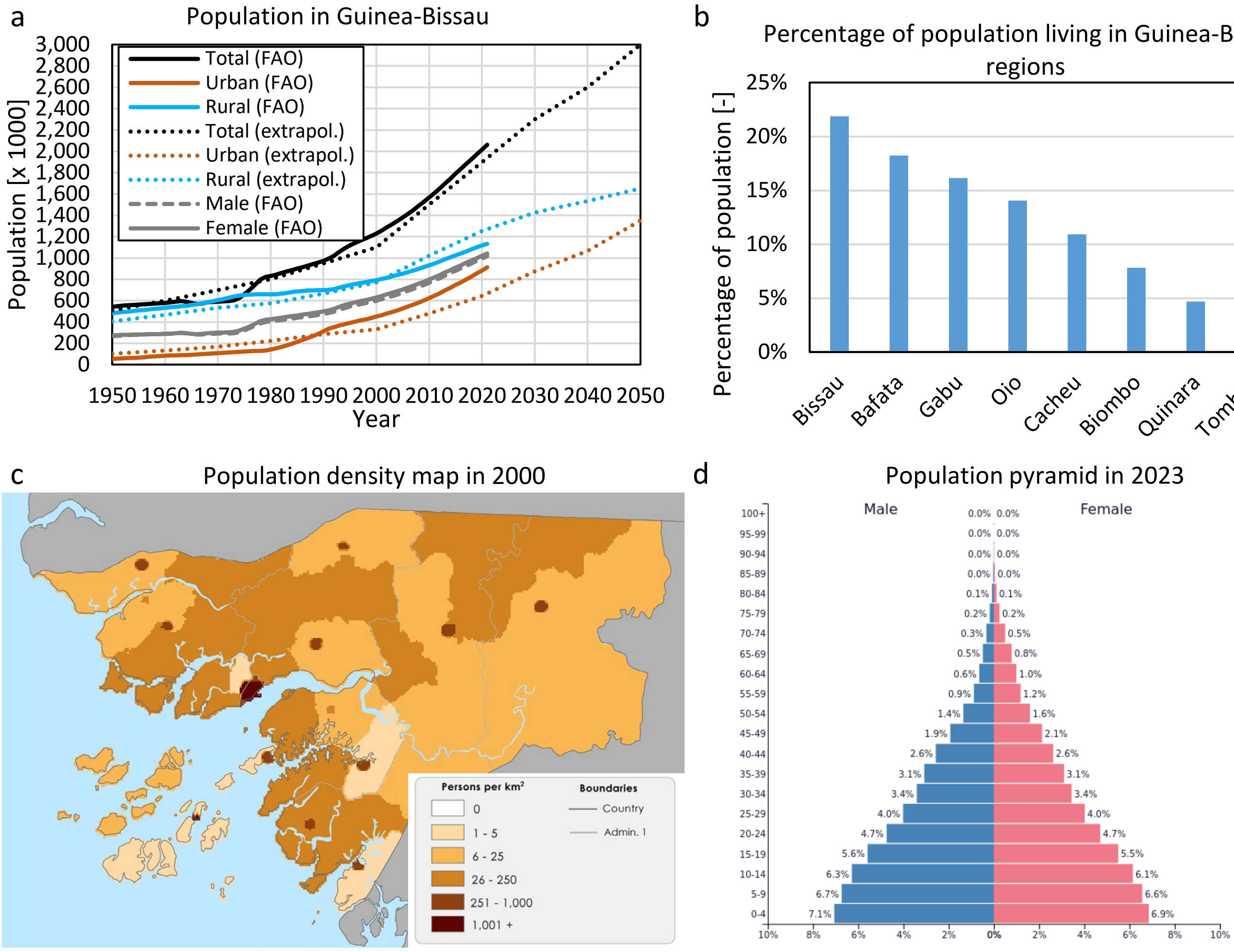

Figure 16. (a) Population in Guinea-Bissau over 7 decades (FAO, 2021) ***and an extrapolation (extrapol.), (b) percentage of population living in the different regions of the country in 2019 (data retrieved from the Area Database of the Global Data Lab, https://globaldatalab.org/areadata/, version v4.2*** (Global Data Lab, 2024; Smits, 2016)***), (c) population density map in 2000 (by SEDACMaps, original image,*** (Wikipedia, 2024g)***), (d) population pyramid in 2023 (b PopulationPyramid.net, original image,*** (Population Pyramid, 2024)***).***

Food security, nutrition, and cost and affordability of a healthy diet

Food and nutrition security is strongly linked to income, food prices, and food availability. 70% of the people live with less than 1.9 USD/day, which is below the national poverty line (FAO, 2019). 76% of the poor people live in rural areas. On average, 87% of the household budget is spent on food. The cost of a diet that meets the minimum energy requirements would be 2.35 USD/day for a household of seven people (World Food Programme, 2022) (or 0.9 USD/capita/day [1]). 28% of the people cannot afford such a diet. Next to covering the minimal calories, a healthy and nutritious diet costs 4 USD/day for a household, and 68% cannot afford this[2]. 28% of the children are currently chronically malnourished [3], leading to stunting and wasting. About 30% of children below 5 years suffer from stunting and 5% from wasting [4] [5], with higher prevalence in Bafata and Gabu. Bafata, Gabu, and Quinara are among the regions with the highest poverty levels and a high index of food insecurity.

Conclusion. Nutritious food needs to become more affordable and available.

[1] https://www.foodsystemsdashboard.org/countries/gnb
[2] https://www.wfp.org/countries/guinea-bissau
[3] https://hungermap.wfp.org/
[4] https://globalnutritionreport.org/resources/nutrition-profiles/africa/western-africa/guinea-bissau/
[5] https://www.fao.org/countryprofiles/news-archive/detail-news/en/c/1471318/

Facilities: Water, electricity, roads, cellphone, internet and cold storage facilities

69% of the population has access to potable water, but only 55% in rural areas (FAO, 2019). Several organizations are working on improving water availability through infrastructure (boreholes and wells), as well as alternative water management strategies.

Different sources report that 15-21-29% of the population has access to electricity, but only 4-6-10% in rural areas (FAO, 2019; ISS African Futures, 2023; USAID, 2017; World Bank, 2019a). The average cost of electricity lies around 0.4 USD/kWh. Only a few households in the country, especially in rural areas, currently have access to active cooling at home (Figure 18). A new barrage will become operational in June 2024 to generate electricity for adjoining regions. This initiative is driven by the OMVG (Organisation pour la Mise en Valeur du Fleuve Gambie), which covers the basins of the rivers Gambia, Corubal, and the Geba. Several families are expected to be compensated for their lost land, which could be in the form of electricity [6].

A significant part of the country's electricity is provided by a powership. The company Karpowership (part of the Karadeniz Energy Group) is one of the world's largest operators of floating power plants. These power ships typically burn fuel to generate electricity. Karpowership has been supplying electricity as of 2019 in Guinea-Bissau in partnership with Electricidade e Aguas da Guiné-Bissau (EAGB). This dependency, however, led recently to a planned power blackout in late 2023 [7] [8] due to a period of non-payment. The several regions of Guinea-Bissau are also poorly connected with respect to the electricity grid, which is under construction. Therefore, regions have different ways of supplying electricity. In the city of Gabu, for example, part of the electricity is supplied by a private company's diesel generator that runs part-time. There is also a solar mini-grid operated by the Dutch NGO FRES [9]. They offer prepaid/pay-as-you-go solar electricity access.

Regarding transport, the country does not have a railroad network. There are 2,700 km of roads, 28% of which are poorly asphalted. As a result, only 52% of the rural population lives within 2 km of an all-weather road, which would allow them to more easily connect to rural and regional markets (ISS African Futures, 2023). Many people in the country live more than 2 hours away from regional centers (Figure 17). An important aspect is that the road conditions are season-dependent, as in the rainy season (May-November), transport via road is more challenging. The road infrastructure is also dependent on the region, as in some regions, this was prioritized or received more international funding. Almost all households (95% [10] [11]) have a cellphone, with an average of 1.1 cell phones per person in 2020. Only a small part (10%) of the population owns a smartphone [12]. Access to the internet is about 5% - 35%, but growing fast.

An evaluation of existing cold storage facilities was done in the context of helping phase out hydrochlorofluorocarbons (HCFCs) in the refrigeration sector [13]. A 2011 report shows that the refrigeration sector in Guinea-Bissau is mainly made up of domestic air-conditioning [14]. They conducted a survey with importers, distributors, and key sub-sectors, including hospitals and other governmental institutions, servicing institutions, supermarkets, mobile air

[6] https://www.afdb.org/fr/documents/guinee-bissau-projet-de-centrale-hydroelectrique-de-saltinho-guinee-bissau/omvg-preparation-de-projet-rapport-devaluation-sefahttps://www.afdb.org/fr/documents/guinee-bissau-projet-de-centrale-hydroelectrique-de-saltinho-guinee-bissau/omvg-preparation-de-projet-rapport-devaluation-sefahttps://www.afdb.org/fr/documents/guinee-bissau-projet-de-centrale-hydroelectrique-de-saltinho-guinee-bissau/omvg-preparation-de-projet-rapport-devaluation-sefa

[7] https://www.reuters.com/world/africa/bissau-darkness-after-turkish-power-firm-cuts-off-supply-2023-10-17/

[8] https://www.bbc.com/news/world-africa-67154067

[9] https://fres.nl/

[10] https://globaldatalab.org/areadata/table/cellphone/GNB/?levels=4

[11] https://www.worlddata.info/africa/guinea-bissau/telecommunication.php

[12] https://watra.org/guinea-bissau/

[13] http://www.multilateralfund.org/85/English/1/8530.pdf

[14] https://downloads.unido.org/ot/11/72/11723398/Guinea%20Bissau%20HPMP%20Final%20for%20submission%20Rev%202.docxhttps://downloads.unido.org/ot/11/72/11723398/Guinea%20Bissau%20HPMP%20Final%20for%20submission%20Rev%202.docxhttps://downloads.unido.org/ot/11/72/11723398/Guinea%20Bissau%20HPMP%20Final%20for%20submission%20Rev%202.docx

conditioning, and abattoirs. There were an estimated 152,611 domestic AC units and 73 cold rooms in the country. A division over the different regions is given in Figure 19. This study was done in association with the Refrigeration Association and the National Statistic Office. The sector is mainly composed of repair and maintenance shops. An estimated 950 technicians service the country from 150 workshops, which all service fridges, AC, and mobile AC systems.

Conclusion. Electricity or gasoline/diesel-powered generators can be deployed in urban regions, but in rural areas, both are not viable due to limited access to the grid or lengthy/costly transport of fuel. Even then, the high cost of electricity compared to the low income can be an inhibitor for smallholder farmers to access and use active cooling. This leaves potential for passive cooling technologies. Few people own refrigerators at home, and few farmers can access electricity via the grid or generators. However, a substantial HVAC and cooling industry and service staff is available.

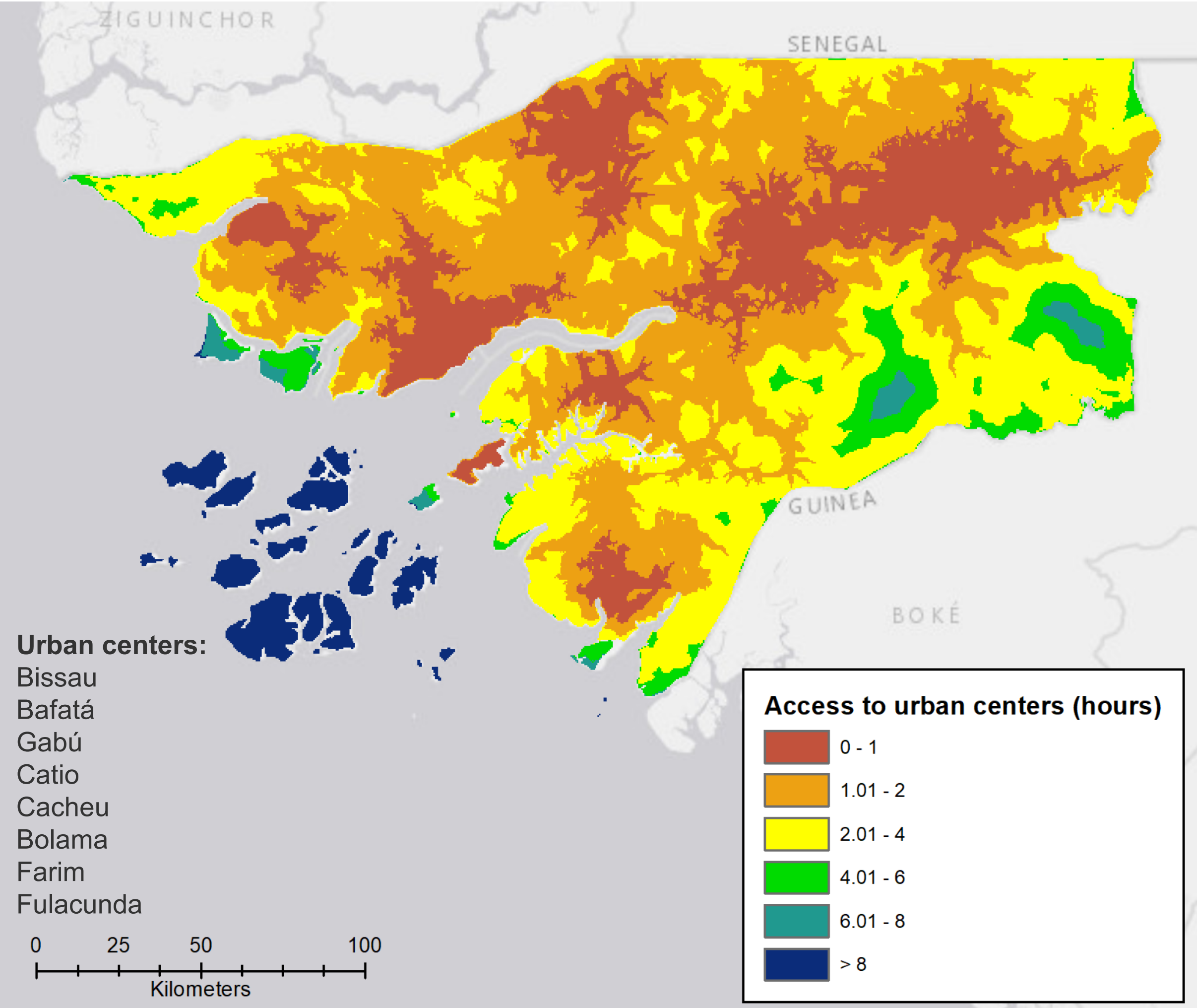

Figure 17. Travel time-cost to major cities (by FAO, original image, (FAO, 2024b)***).***

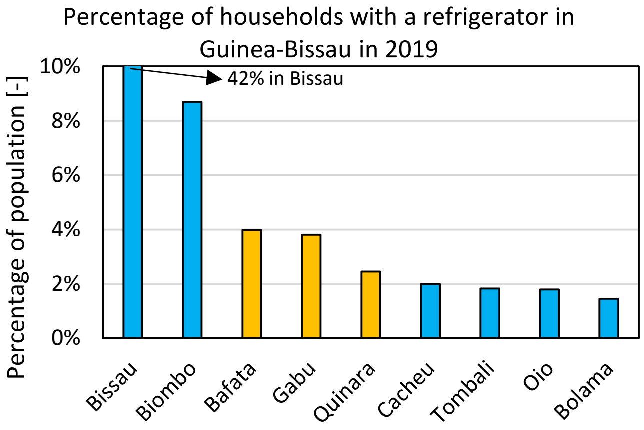

Figure 18. Percentage of households with a refrigerator in Guinea-Bissau in 2019 [15]. The regions of interest are highlighted in orange.

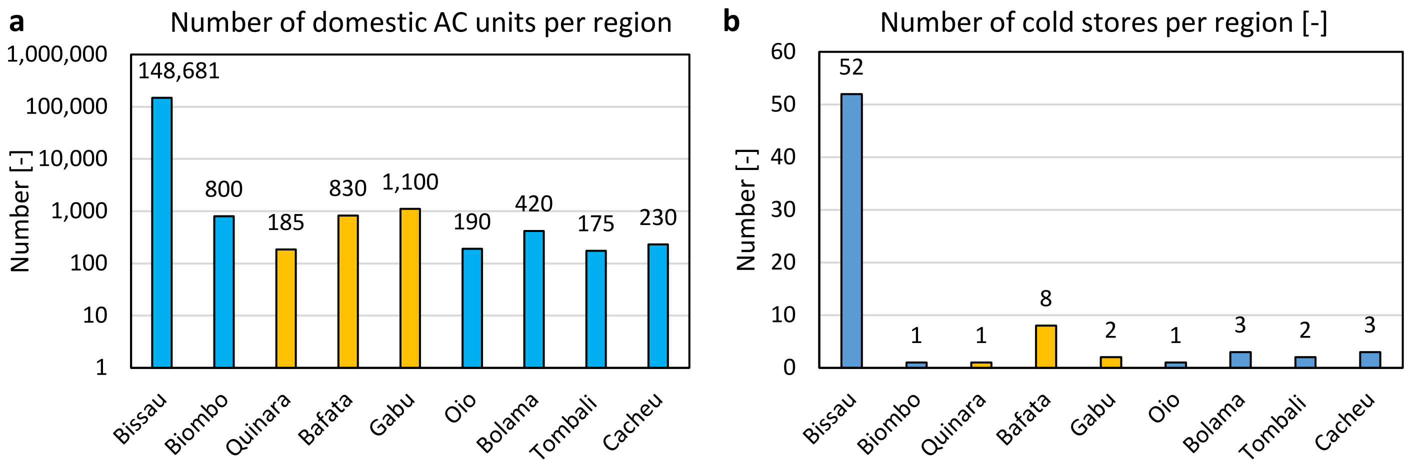

Figure 19. (a) Number of domestic AC units per region and (b) number of cold stores per region. The regions of interest are highlighted in orange.

GDP and legislative support of the agricultural sector

The GDP for Guinea-Bissau in 2022 was 1.63 billion or 775 USD/capita (The World Bank, 2024). The agriculture sector accounts for almost half of the country's GDP [16]. However, public spending in agriculture is extremely low: the Agriculture Orientation Index (AOI), which represents agriculture's share of public spending relative to its share in the economy, is about 2% (Figure 20). Guinea-Bissau's government expenditure on agriculture is lower compared to neighboring West African countries. In Senegal, for example, there has been a gradual increase in the state budget for the agricultural sector, from 4.5% to 10%, for a programmed value in 2023 (219 billion FCFA - 334 million Euros) for agriculture, 86% of which is earmarked for investment in modernization and innovation.

Several major projects have been set up and financed by development partners (IFAD, ADB, World Bank, FAO, WFP, ECOWAS). However, the cycle of political instability has hindered viable follow-up of implementation. These agricultural projects have, therefore, not always induced transformative effects to enable the country to achieve constant production, higher yields, and improved quantity and quality.

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[15] https://globaldatalab.org/areadata/regpopm/GNB/

[16] https://documents1.worldbank.org/curated/en/341991563831364596/pdf/Guinea-Bissau-ASA-Agriculture-sector-Report.pdfhttps://documents1.worldbank.org/curated/en/341991563831364596/pdf/Guinea-Bissau-ASA-Agriculture-sector-Report.pdfhttps://documents1.worldbank.org/curated/en/341991563831364596/pdf/Guinea-Bissau-ASA-Agriculture-sector-Report.pdf

In Guinea-Bissau, importing food is seen as a solution to meet domestic demand. Despite hectares of land available for domestic production, the country still imports rice for an average quantity estimated at 100,000 tons a year. In Guinea-Bissau, there is no specific policy of protectionism to protect the national market against cheap imports. The country must open its food market to various imports to meet domestic demand.

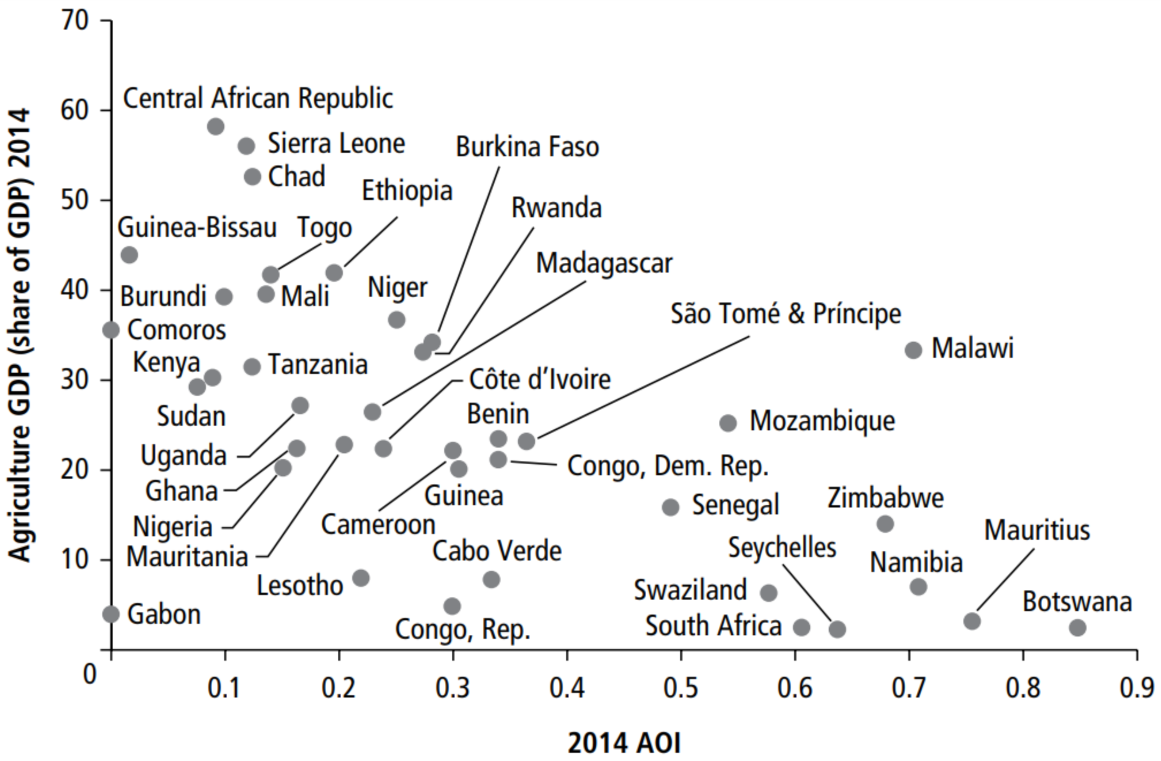

Figure 20. Public spending in Agriculture relative to agriculture's weight in GDP in Africa (original image from (Aparajita and Nash, 2017)***, License: Creative Commons Attribution CC BY3.0 IGO).***

Climate

The climate of Guinea-Bissau is tropical savanna, according to the Köppen-Geiger climate classification [17]. The bordering climatic regions are the hot semi-arid climate (Sudan) and the tropical monsoon climate (Guinea). The temperature and rainfall in the capital are given in Figure 21. There are two clear seasons in Guinea-Bissau: the hot, rainy summer season, which lasts from May to November, and the hot, dry winter season, from November to April. Three agroecological zones can be differentiated by their climatic conditions (FAO, 2019; World Bank, 2019b). Major droughts occurred in 1977, 1979, 1980, 1983, 2002, 2004, and 2013 (FAO, 2019).

We can conclude that:

- Although the average temperature stays rather constant throughout the year, there are large differences between minimal and maximal temperatures. Temperatures in winter and spring can rise to 35-40 °C.
- The relative humidity is rather high, namely 50-90% [18], depending on the region and the season. High humidity can be beneficial for storage of foods to avoid wilting. Lower humidities can be recorded from December to March.
- The rainfall is abundant in most parts of the country for agriculture and horticulture, which adds to the surface water and groundwater resources (World Food Programme, 2018). Guinea-Bissau is one of the countries with the highest rainfall in the continent [19]. Nevertheless, this rain falls in one season, and from December until April, there is limited rainfall.

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[17] https://climateknowledgeportal.worldbank.org/country/guinea-bissau

[18] https://climateknowledgeportal.worldbank.org/country/guinea-bissau/climate-data-historical

[19] https://compass.onlinelibrary.wiley.com/doi/epdf/10.1111/gec3.12136

- The potential for photovoltaics is high and comparable to or higher than that of other countries such as Nigeria or India [20].

Guinea-Bissau is estimated to be the fourth most vulnerable country to climate change. Climate predictions show that by 2050, the rainfall will decrease by 5-9%, especially in the northern and eastern parts (FAO, 2019), whereas the temperature will rise by 1.5-2 °C.

Conclusion. Water is not necessarily the problem. Rather, access to water is. The temperatures are very high, which is detrimental to fresh food preservation. There is a high potential for solar energy generation.

Table 3. Three agroecological zones in Guinea-Bissau.

Agro-ecological zone	Climate	Average rainfall	Vegetation	Farming systems
Eastern zone (Gabu, Bafata)	Semi-arid climate climate	1200-1500 mm	savanna woodlands, dry and wet grasslands	poor and lateritic soils
Northern zone (Oio, Cacheu, Biombo)	Guinean maritime climate	1500-1800 mm	Mangrove forests, savanna woodlands	
Southern zone (Tombali, Quinara, Bolama)	Tropical savanna climate	2000-2500 mm	Dense, dry forest patches and thick mangrove forests	fertile ferralsols and fluvisols

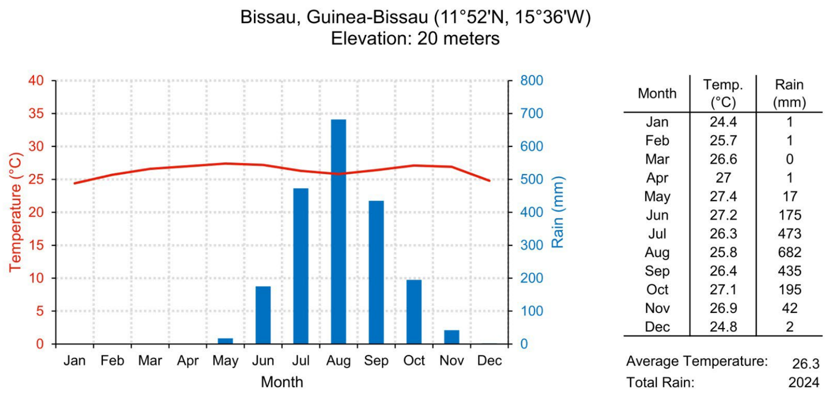

Figure 21. Temperature and rainfall in the city of Bissau (**(Wikipedia, 2024h) ***by Auguel).

5.2 The current situation for perishables

We aim to assess the current situation for perishables in the country and regions, including identifying first bottlenecks.

Production, export, import of produce

Guinea-Bissau produces mainly rice, cashews, groundnuts, edible roots and tubers (e.g., yam and sweet potato), oil palm, plantains, cassava, various fresh vegetables, coconut, millet, maize, sorghum, mangoes (Figure 22). The key horticulture crops are tomatoes, lettuce, peppers, bell peppers, carrots, eggplant, mangoes, onions, kale, citrus fruits, papaya, banana, cabbage, cucumber, turnip, and okra (section 3.1.2, Figure 7). Imports include mainly rice, wheat, and onions. The key export products are cashew nuts with shells and, to a lesser extent, peaches and nectarines, eggplants, tomatoes, and strawberries. Fresh mango and lime exports are limited [21]. A lack of cold chain infrastructure

[20] https://globalsolaratlas.info/

[21] World Bank Document, p. 61

or other processing (e.g., drying facilities). The yields per hectare of fruit and vegetables, with some examples, are given in Figure 23. Typical yields are about 4-5 tons per hectare but go up to 12 tons for bananas.

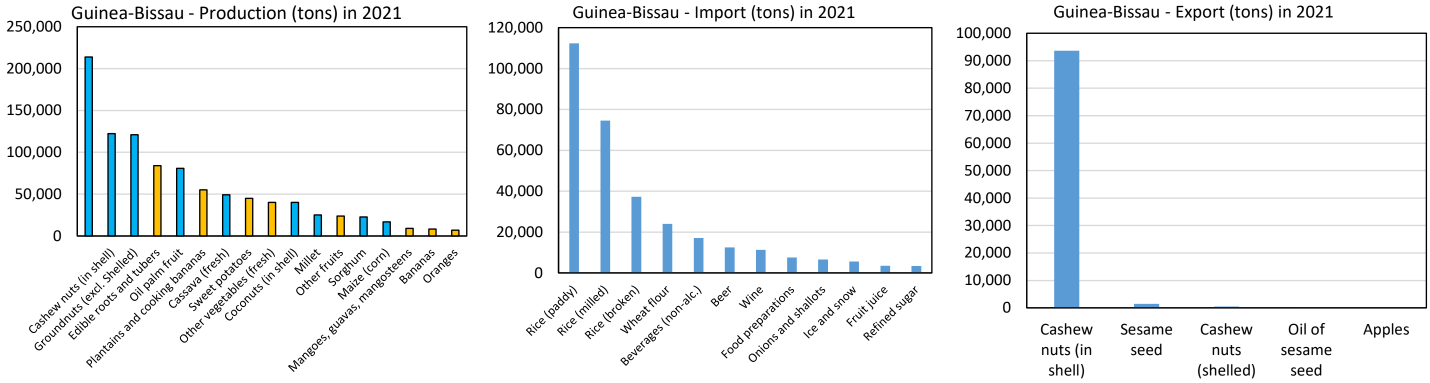

Figure 22. Production, import, and export of Guinea-Bissau in 2021 (FAO, 2021)**.**

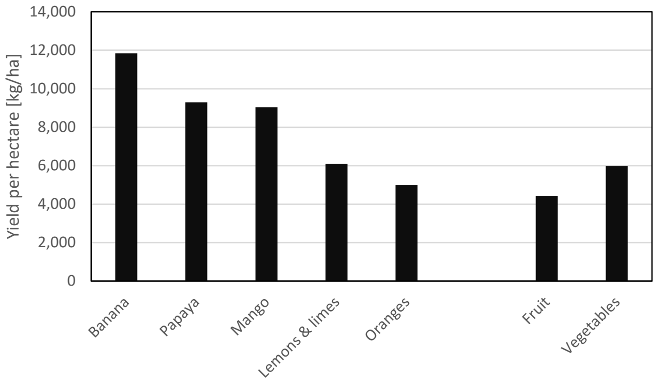

Figure 23. Yields per hectare from different fruits and the categories of fruits and vegetables [22]**.**

Cashew production has a large impact on the production of other crops. 50% of the arable land is used to produce cashew nuts (with shells). About 80% (African Development Bank Group, 2015) of the agricultural workforce is employed in the cashew industry. Guinea-Bissau was the fourth largest exporter of raw cashew nuts in 2014-2018. Raw cashew nuts are processed in other countries, such as India, the Ivory Coast, and Vietnam. One key reason is that limited infrastructure is available to process the raw nuts in Guinea-Bissau mechanically, and manual processing is much slower, less economically viable, and more hazardous due to the oil released by the cashew shells. Many farmers in Guinea-Bissau depend on the cashew nut export industry and are thus extremely vulnerable to fluctuations in international prices. The government also received revenues from the export tax on cashew nuts. The cashew nut price dropped significantly from 2018-2020, namely from USD 1.4/kg in 2017 to USD 0.5/kg in 2020 (World Food Programme, 2022). This made it challenging for people to access food during the lean season, as it needs to be purchased instead of grown. The already strong dependency on the global market price of cashew raw nuts is exacerbated by the fact that Guinea-Bissau harvests only towards the end of the global season and comes after East Africa and Asia. This implies that Guinea-Bissau has limited influence on the market price of raw cashew nuts [23].

On a final note, onions have a long shelf life and have to be stored under lower humidity conditions. This means that onions produced by Bissau-Guinean farmers are bought by middlemen or vendors from neighboring countries at low rates. These vendors have better storage options in these countries. These foods are then later re-sold in Guinea-Bissau at higher rates during the lean season when onions are scarce. This is possible due to a free trade agreement where agricultural products are not taxed for import/export among several countries.

[22] https://ourworldindata.org/explorers/global-food

[23] World Bank Document, p. 23

Conclusion. The cashew and rice industry has a large impact on the workforce that is available for growing horticulture, especially when they are working in the cashew high season, but also on the household budget available to purchase food in the lean season.

Agricultural production specifics for horticultural crops

CROP CALENDARS and SEASONALITY. The crop calendars for several horticultural crops are given in Figure 8. The key information and findings are detailed in section 3.1.2, which covers when crops enter the market and when is the critical time to have fresher fruit and vegetables. There are a few important considerations to stress here.

Most horticultural crops, i.e., fruit and vegetables, are grown from the end of the rainy season (September-October, Figure 8) and harvested in the dry season (October-June), primarily between December and February. As a result, there is a food shortage for multiple types of food in the rainy season, during which traders import horticultural crops. This lean season for fruit and vegetables is typically from June to October, during a large part of the rainy season. Vegetables can be grown year-round in principle, but production in the wet/lean season is lower intensity. Fruits are not produced year-round as their production is season-dependent.

As such, during the lean season (June to October), communities struggle to meet their basic needs. With dwindling rice stocks, they often resort to relying solely on whatever rice remains. While meat and fish may be available occasionally, the lack of access to fresh fruits and vegetables during this period leads to severe nutritional deficiencies. Farmers and cashew collectors, primarily women and children, often receive rice as payment for cashews, sometimes with a small additional fee. The cashew sales season ends in June, and the rice and money saved during this period typically run out by October. This dependence on unreliable cashew income creates a critical situation of food insecurity.

To preserve the quality of fresh produce, which is the focus of our study, the harvest period is mostly of interest as this is the period where postharvest solutions come into play. This period is typically around the dry season (December-June), and since then, fresh produce is available and needs to be stored. The environmental conditions are also harsher (especially since the relative humidity is low), and evaporative cooling technologies work best.

An important boundary condition for horticulture is that harvesting cashews is a key economic activity with Guinean-Bissau households. Entire families gather during the harvest season to pull the nuts from the fruit from the trees, remove the nuts from the fruit, and pack them into bags bound for export. The cashew harvesting season is typically from February to June. During this period, there is limited time to devote to growing horticultural crops, and need to rely on imports. One reason that Senegal has more optimal production conditions and thereby also crops to export is that the government actively supports investing from abroad, importing and local/domestic production, and promoting better diversification of crops. In addition, the rural exodus also makes agricultural labor scarce at the community level since young people are moving to urban areas.

TYPE. Horticulture is mainly rainfed as there is little irrigation, with only a few percent of the agricultural area being irrigated due to limited availability of surface water in some regions or challenges with drilling for groundwater due to the low water table in several regions (FAO, 2019). Hence, access to water for farming, irrigation, and other purposes is a basic problem for local communities and populations. As a result, there is a large dependency on local rainfall, which leads to vulnerability to climate and climate change, such as droughts and flooding. Gabu, Bafata, and Oio are particularly vulnerable to (horticultural) food insecurity as they experience limited rainfall and poor soil fertility. The southern regions with higher rainfall levels are more suitable for horticulture. Very few fertilizers are used due to the cost, but organic fertilizers are promising. Greenhouse production is also quasi-non-existent. In addition, production is still rudimentary, traditional, and not mechanized, although some agricultural machinery is already available through aid projects in various regions.

WHO and WHERE. Horticultural crops are mainly grown by women, including in urban and peri-urban areas. In rural areas, the production takes place in the vicinity of villages (within a 5-10 km radius). As an example, onion production is an almost exclusive women's value chain in Guinea-Bissau. Guinea-Bissau has about 1.5 million hectares of arable land, of which 150,000, so 10%, is irrigable (80% on plateaus, 200,000 hectares in freshwater valleys, 106,000 in saltwater valleys, and 100,000 square meters of areas with industrial wood) (World Food Programme, 2018).

Conclusion. Rain is of key importance. The cashew and rice industry has a large impact on the workforce that is available for growing horticultural crops.

Food losses and consumption

The food losses for fresh fruit and vegetables during storage and distribution are reported to be 15-20% for vegetables and around 16% for fruits. These are, thus, the upper limits that can be saved (Food Systems Dashboard, 2023). When taking into account all losses due to agricultural production and after interviewing farmer communities, the total losses of smallholder farmers are typically 40%.

The consumption of vegetables in Guinea-Bissau lies around 50 g/capita/day (the world average is 230 g/capita/day), so 18 kg/capita/year or 127 kg/year per household of seven people (Food Systems Dashboard, 2023). This implies that subsistence farmers need to at least produce more than 125 kg of vegetables to feed their households, which will increase seasonality and food losses into account the fact that this amount likely is not sufficient for a healthy, nutritious diet.

Conclusion. Food losses of fresh fruit and vegetables are substantial.

Farms

Most farmers (88% (FAO, 2019)) are smallholder farmers with land under 2 hectares, which is also confirmed by older data (Figure 24), showing 70% of the farms are even below 1 ha (10,000 m^2). Knowing the yields per hectare for specific crops for Guinea-Bissau (FAO, 2021), we can calculate the maximum harvest amount of a farm. For a 0.5-hectare smallholder farm, there would be roughly 4,500 kg mango, 1,600 kg plantain, 3,300 kg edible roots, or 2,500 kg sweet potatoes (FAO, 2021). Note that these numbers are highly dependent on growing and harvesting methods, and not everything is harvested at once. However, they indicate the amounts a farmer would need to store and preserve throughout the season.

Conclusion. Small farms are abundant (< 1 ha) and produce just enough to fill a small-scale cold storage room of a few metric tons over an entire season. Several farmers will need to pool into a cooling facility to have year-round occupancy.

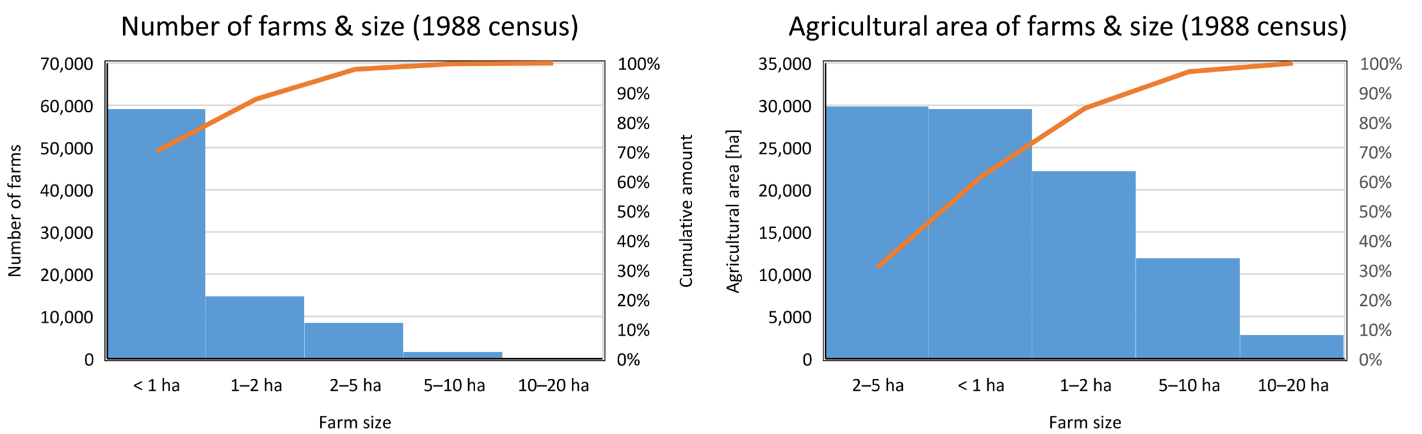

Figure 24. The number of farms is a function of the size of the farm and the agricultural area of these farms, where the orange line represents the cumulative amount from the most recent census (Lowder et al., 2021)**.**

Crop factsheets of target crops

Here, we list key fruits and vegetables and their optimal storage conditions. These conditions are essential to evaluate for which cooling can be used to store them in the optimal range. This selection was made based on the most produced fruits and vegetables. The crops relevant to Guinea-Bissau are highlighted in grey. Typical storage temperatures range between 0 to 13 °C, whereas for most crops, a temperature of 7 °C or higher is fine. Storage life is typically a few weeks under optimal conditions. Note that the storability of many fruits and vegetables is limited (typically below 1 month, Table 2). Even with optimal, high-tech postharvest storage technology, we cannot cover the availability of fresh produce throughout the lean season. Crops that can be stored for a long time are, for example, apples, pears, grapes, and some citrus fruit.

Conclusion. Most produce of interest in Guinea-Bissau can be stored at 7 °C or higher for a few weeks.

Table 4. List of specific horticultural products and their storage conditions (data from (Cantwell, 2001) and (MITD-Lab, 2021; Verploegen et al., 2018)***, italic text – if no italic text is added, this implies similar values from the two sources, CA: controlled atmosphere). The crops relevant to Guinea-Bissau are highlighted in green.***

Product	Details	Optimal storage temperature [°C]	Optimal humidity [%]	Ethylene production	Ethylene sensitivity	Storage life	Comments
Apple	Not chilling sensitive	-1.1 – 0, *-1 – 4*	90-95	VH, *H*	H	3-6 months, *1-12 months*	CA viable
Avocado	cv. Fuerte, Hass	3 – 7, *3-7 (ripe), 7-10 (unripe)*	85-90, *85-95*	H	H	2-4 weeks, *no data*	CA viable
Banana (ripe)		13-15, *13-16 (ripe), 17-21 (unripe)*	90-95, *85-95*	M, *M (ripe), L (unripe)*	H	1-4 weeks, *no data*	CA viable
Broccoli		0	95-100	VL	H	10-14 days	CA viable
Cabbage	Common, early crop	0	98-100	VL	H	3-6 weeks	-
	Common, late crop	0	95-100, *98-100*	VL	H	5-6 months	CA viable
Carrots		0	98-100	VL	H	3-6 months, *7-9 months*	No CA benefit
Cassava		0-5	85-90	VL	L	1-2 months	No CA benefit
Citrus, Lemon		10-13	85-90	-	-	1-6 months	CA viable
Citrus, Orange	CA, dry areas	3-9	85-90	VL	M	3-8 weeks	CA viable
Citrus, Mandarin		4-7	90-95	VL	M	2-4 weeks	-
Cucumber		10-12, *10-13*	85-90, *95*	L, *VL*	H	10-14 days	CA viable
Eggplant		10-12, *8-12*	90-95	L	M	1-2 weeks, *1 week*	CA viable
Grape		-0.5 – 0, *-1-0*	90-95, *85*	VL	L	1-6 months, *2-8 weeks*	CA viable
Kale		*0*	*95-100*	-	-	*2-3 weeks*	-
Lettuce		0	98-100	VL	H	2-3 weeks	CA viable
Mango		13, *10-13*	85-90, *85-95*	M	M	2-3 weeks	CA viable
Melon	Canteloupe	2-5	95	H	M	2-3 weeks	CA viable
Okra		*7-10*	*90-95*	*VL*	*M*	*7-10 days*	-
Onion		*0-2*	*65-75*	*VL*	*L*		-
Papaya		7-13, *10-13*	85-90, *85-95*	M	M	1-3 weeks	CA viable
Peach		-0.5 – 0, *-1-0*	90-95	M, *H*	M	2-4 weeks	CA viable
Pear	European	-1.5 to -0.5, *-2 to -1*	90-95	H	H	2-7 months	CA viable
Bell pepper		7-10, *7-13*	95-98, *90-95*	L	L	2-3 weeks	CA viable
Pineapple		7-13, *10-13*	85-90, *85-95*	L	L	2-4 weeks	CA Viable

Plantain		13-15	90-95	L	H	1-5 weeks	-
Potato	Early crop	10-15	90-95	VL	M	10-14 days	No CA benefit
	Late crop	4-8	95-98	VL	M	5-10 months	No CA benefit
Strawberry		0	90-95	L, *VL*	L	7-10 days, *3-7 days*	CA viable
Tomato	Mature green	10-13, *13-21*	90-95	VL, *L*	H	2-5 weeks, *1-3 weeks*	CA viable
	Firm ripe	8-10, *13-21*	85-90, *90-95*	H, *M*	L	1-3 weeks, *4-7 days*	CA viable
Turnip		*0*	*95*	*L*	*M*	*4-5 months*	-

Nutritional value of crops

A table with the nutritional value of the targeted crops is given below, which enables us to identify the fruits and vegetables with the highest potential to improve food and nutrition security. Note that several fruits and vegetables cannot contribute to food security as they contain a low caloric content. However, many of them contain several vitamins and antioxidants (e.g., carotenoids, for example, carotene in carrots and lycopene in tomatoes). As such, they contribute to nutrition security rather than food security.

Table 5. Nutritional value of selected fruit and vegetables (per 100 g of serving) and the recommended daily intake of all components (IU: international unit).

Product	Calories	Carbs (g)	Fiber (g)	Sugars (g)	Protein (g)	Vitamin C (mg)	Vitamin A (IU)	Vitamin B6 (mg)	Vitamin D (IU)	Vitamin E (mg)	Vitamin K (µg)
Mango	60	15	1.6	13.7	0.8	36.4	1082	0.119	0	0.9	4.2
Banana	89	22.8	2.6	12.2	1.1	8.7	76	0.367	0	0.1	0.5
Papaya	43	10.8	1.7	7.8	0.5	60.9	950	0.038	0	0.3	2.6
Orange	47	11.8	2.4	9.4	0.9	53.2	225	0.063	0	0.2	0
Tomato	18	3.9	1.2	2.6	0.9	13.7	833	0.08	0	0.54	7.9
Lettuce	15	2.9	1.3	0.8	1.4	9.2	7405	0.09	0	0.22	102.5
Onions	40	9.3	1.7	4.2	1.1	7.4	2	0.12	0	0.02	0.4
Eggplant	25	5.9	3	3.5	1	2.2	23	0.084	0	0.3	3.5
Cucumber	16	3.6	0.5	1.7	0.7	2.8	105	0.04	0	0.03	16.4
Peppers	20	4.7	1.7	2.4	0.9	127.7	370	0.224	0	1.58	4.9
Carrot	41	9.6	2.8	4.7	0.9	5.9	16706	0.138	0	0.66	13.2
Okra	33	7.5	3.2	1.5	1.9	23	375	0.215	0	0.27	31.3
Kale	49	8.8	3.6	0	4.3	120	9990	0.271	0	1.54	704.8
Cabbage	25	5.8	2.5	3.2	1.3	36.6	98	0.124	0	0.15	76
Recommended Daily Intake	2000	300	28	N/A	50	90	5000	1.3	400	15	120

Food processing

Note that there is currently limited formal fruit and vegetable processing industry in Guinea-Bissau. In the past (1980), there was a formal industry at a national level, which covered the value chain with fruit processing plants and a national distribution system. Since 1990, the agricultural processing sector has gradually deteriorated. Guinea-Bissau is currently in the process of resuming activities through a number of projects financed by development partners to empower young people and women in the field of fruit and vegetable processing and preservation. NGO AMAE (Confederação da Associação das Mulheres de Atividade Econômica) is the main driver to stimulate food processing in partnership with several development partner institutions. Examples are UNDP for vegetable processing and UNIDO for mango processing. Various projects (e.g., European Union, SWISSAID) target fruit and vegetable processing projects, which are, however, more short-term initiatives.

Food prices

Indicative prices of some fresh produce and other crops are given in Table 6. Note that these prices can strongly fluctuate throughout the season, the location of the market, and the national and global economic situation. With respect to price stability, the prices of locally produced horticultural crops have been relatively stable, but some fluctuations have been observed over the past year, for example, with millet [24]. Cooking banana prices have remained largely stable, reflecting their role as a widely produced and consumed crop in the region. Local production satisfies most of the demand, helping to keep prices steady. In contrast, mango prices fluctuate significantly with the seasons. During peak mango season, prices decrease due to an abundance of supply, while in the off-season, prices tend to rise. This seasonal price variation is typical for mango production in Guinea-Bissau.

Table 6. The food price range on the market for several horticultural crops was determined by a survey and FAO's Food Price Monitoring and Analysis (FPMA) Tool [25]. The minimum and maximum prices are indicated between brackets.

Food item	Price per kg	Source
Tomato	700 FCFA/kg	(Gomes, 2024)
Cucumber	500 FCFA/kg	(Gomes, 2024)
Okra	700 FCFA/kg	(Gomes, 2024)
Bell pepper	800 FCFA/kg	(Gomes, 2024)
Bananas	653 XOF/kg (558-792)	FPMA (07/2021-01/2024)
Sorghum	608 XOF/kg (484-945)	FPMA (07/2021-01/2024)
Millet	655 XOF/kg (491-785)	FPMA (07/2021-01/2024)
Tomato	865 XOF/kg (695-1406)	FPMA (07/2021-01/2024)
Beans	999 XOF/kg (923-1318)	FPMA (07/2021-01/2024)
Groundnuts	802 XOF/kg (677-1243)	FPMA (07/2021-01/2024)

5.3 Trends and trends that could be picked up

We identified the following trends in Guinea-Bissau or trends that have not yet picked up. In Guinea-Bissau, the trend of a 'cold rush' [26] in several countries on the African continent has not yet taken place. This cold rush implies that refrigeration, often small-scale and solar-powered, is made available to support smallholder farmers and vendors in preserving their produce longer, obtaining a better price at the market, or enabling access to more distant markets, even export markets. In Guinea-Bissau, such a cold rush is hindered, amongst others, by the fact that most technology needs to be imported and transported into the country, which is costly. In addition, there are no financial mechanisms to support the farmers in purchasing, leasing, or using these cold stores. There are also no businesses and cold store operators that offer these services. Note that if solar-powered technology, for example, is not introduced from the

[24] https://www.fao.org/giews/countrybrief/country.jsp?code=GNB

[25] https://fpma.fao.org/giews/fpmat4/#/dashboard/tool/domestic

[26] https://www.newyorker.com/magazine/2022/08/22/africas-cold-rush-and-the-promise-of-refrigeration

start, then the country is at risk of being flooded by end-of-life appliances that are imported from Europe, which has been the case in other African countries [27].

There is a trend toward willingness to export more crops, including in neighboring counties. The Regional Alliance Mango West Africa was formed in 2016 between Burkina Faso, the Gambia, Ghana, Guinea, Guinea-Bissau, the Ivory Coast, Mali, and Senegal (Havik et al., 2018). Their aim was to stimulate mango exports to international markets. However, currently, mango production in Guinea-Bissau is still primarily focused on the local and regional markets due to the limitations on value chains and infrastructure that could enable that. No large agricultural transitions towards export are observed.

There is a trend towards urbanization. The growing urban population will push a food supply shift to the cities. This can be done by enabling current rurally located smallholder farmers (e.g., in Gabu, Bafata) to sell their crops to traders, who then transport their crops to the regional cities and the capital. Another development could be the strengthening of agriculture in peri-urban areas.

There is a nascent trend toward local processing of fresh produce (canning, drying, etc.), which is supported by several strategic partners, including training programs.

5.4 Past and ongoing interventions

The aim is to assess interventions that are in line with the foreseen interventions that have already been implemented in the past (if applicable) or compare them with international examples.

Organizations and activities

We first list the national and international organizations in the country that are relevant to the intervention we plan as they have ongoing activities or policy-making interests.

National

- Guinea-Bissau government: Ministry of Agriculture
- Private sector (AgroSafim, AgroGeba, AgriMansoa)
- National Institute for Agrarian Research (INPA)
- General Directorate of Rural Engineering
- The Refrigeration Association [28]
- Vegetable Protection Department of the Ministry of Agriculture (responsible for monitoring and assisting plant production at the national level)

International

- FAO – Food and Agricultural Organization of the United Nations. They have several projects in Guinea-Bissau, but none are known to be related to the horticultural value chain [29]. Their focus is on poverty reduction and hunger eradication. FAO's mandate and activities are structured to strengthen the operational capacity of the country and farmers for the development of the agricultural sector, development of production factors, and increased level of yield in production
- WFP – World Food Program of the United Nations (World Food Programme, 2022). WFP's mandate and activities are structured to facilitate access to food for the most vulnerable populations, as well as ensure quality and quantity availability. The mission is complementary to that of FAO.
- IFAD – International Fund for Agricultural Development. IFAD is an international financial institution and a specialized agency of the United Nations dedicated to eradicating poverty and hunger in rural areas of developing countries. Since 1983, IFAD has supported four programs and projects in Guinea-Bissau, investing 27.6 million USD and directly benefiting more than 155,000 rural households [30]. The current focus is on the

[27] https://news.trust.org/item/20200624102543-fbvis/

[28] https://downloads.unido.org/ot/11/72/11723398/Guinea%20Bissau%20HPMP%20Final%20for%20submission%20Rev%202.docx

[29] https://www.fao.org/countryprofiles/index/en/?iso3=GNB

[30] https://www.ifad.org/en/web/operations/w/country/guinea-bissau

regions of Quinara and Tombali, as these are poor and disaster-prone areas. Strategic objectives are (1) to stimulate diversified and sustainable family farming to improve family diets, creating marketing surpluses and increasing income; (2) to have fairer market conditions for producers to better leverage trade networks (local, sub-regional, regional, and national) and strengthening entrepreneurship of young people, women, and farmer organizations.

- SWISSAID. They work in agroecology in Guinea-Bissau, Niger, Tanzania and Tschad. Their focus is on income generation, organic food production, adaptation to climate change through agroecological production methods, access to and control over production resources, and empowerment of rural youth and women so that they can represent their interests and implement their own projects. The focus in Guinea-Bissau is particularly on ecological agricultural production so that families can increase their income [31].
- AfDB - African Development Bank. A multinational, multilateral, regional development finance institution established to contribute to the development and social progress of African countries. The AfDB has been active in Guinea-Bissau for over 20 years. To address Guinea-Bissau's current development challenges, the Bank's new strategy focuses on promoting diversification and structural transformation of the economy, laying the foundations for inclusive, resilient, and sustainable growth. Several ADB projects are underway in Guinea-Bissau, including the Bissau-Dakar corridor road construction project, the Lusophone Pact project for private sector reforms to stimulate investment, the energy and transport infrastructure development project, the judicial capacity-building project, and various projects in youth and women entrepreneurship and agricultural value chain development. AfDB is currently also strengthening SMEs in the country, providing credit lines through the local banking system.
- UNDP - United Nations Development Program. As a multi-sectoral strategic actor in Guinea-Bissau, UNDP is currently implementing several projects in partnership with the government and other partners. These projects focus on developing sectoral development policies and strategies, promoting employment for young people and women, fostering local development, strengthening judicial institutions, and contributing to the digital transformation process.
- SOS Children's Village of Guinea-Bissau. An international organization dedicated to safeguarding and protecting vulnerable children. In partnership with the European Union, German Cooperation, and others, SOS runs several projects aimed at reinforcing and assisting vulnerable families in preventing child abandonment, promoting entrepreneurship for women and young people, providing vocational training for youth, and promoting employment and self-employment. SOS Children's Village operates in Bissau Capital, Canchungo Cacheu Region, and Gabu in the Gabu region while also collaborating with other institutions in regions such as Bafata and Oio.

Local

- Confédération des Organisations des Femmes en Activités Economiques (AMAE): A support organization for women in economic activities, working in partnership with several international organizations and entities (UN WOMEN, UNFPA, UNDP, UNIDO, ILO, European Union, AfDB, World Bank, and others). AMAE intervenes in trade, agriculture, agro-industry, and the processing of agricultural products.
- ONG DIVUTEC (local NGO in Gabu): The Guinean association for the study and dissemination of appropriate technologies. In partnership with development partners (United Nations Agencies, European Union, and others), DIVUTEC works in the fields of local development, promotion of agro-industry, and technology for access to renewable energy.)

Projects

The Restoration Initiative in Guinea-Bissau

The TRI Guinea-Bissau project supports farmers, especially women, in establishing new horticulture areas, as well as solar salt farms and oyster farms. The aim is to help local communities diversify household income sources that do not depend only on rice production. The country's coastal communities currently depend heavily on rice production. As a horticultural initiative, about 600 women from seven villages prepared areas for gardening. A designated area

[31] https://www.swissaid.ch/de/laender/guinea-bissau/

(e.g., 5,000 m^2) was fenced off in each village, water wells were dug, and tools and seeds were provided. In these horticultural areas, onions, tomatoes, chilies, peppers, okra, and African eggplants were grown.

FAO's Hand in Hand Initiative

The Hand in Hand Initiative for Guinea-Bissau is closely aligned with the National Strategy for Poverty Reduction through investments in four key value chains (rice, onion, eggs, chicken) that will contribute to import bill reduction, job creation and will improve the availability of key nutritious commodities by adopting climate resilient technologies and practices. The focus on onions is in Gabu, Biombo, and Oio.

For the onion value chain, there is a strong rise in the amounts of onions that are imported, namely from 2,000 tons in 2019 to 5,700 tons in 2022. This value chain is stimulated to reduce dependency on imports. Problems currently are:

- Lack of infrastructure (tracks, transportation, storage, and warehouses).
- Rudimentary production systems (manual irrigation)
- Lack of protection perimeters for animals
- Low level of access to quality agricultural inputs

Planned measures are, among others, to irrigate 200 hectares, build 50 small storage units and 20 large storage units, 400 manual seeders, and 50 motorized tillers, upgrade the national seed lab, link producers with processors and processors and retailers, and strengthen the supply chain.

UNEP project for HCFC phase-out management plan and fishing sector links

Several actions were taken by UNEP to help phase out hydrochlorofluorocarbons (HCFCs), including in the refrigeration sector [32]. Although refrigeration is not present for fresh produce in Guinea-Bissau, it is well established for fish, particularly as there are food safety issues when fish is not properly cooled and kept cool. In this context, the national refrigeration and air-conditioning (RAC) training center was upgraded, and a new training center was established in Gabu. Training involves, among others, good refrigeration practices and the repair and maintenance of cold rooms in the fishing sector. More information on survey results on the cooling sector is given in the supplementary material.

IFAD's PADES project

IFAD's Economic Development Project for the Southern Regions (PADES)[33] aims to promote the sustainable development of the southern region of Guinea-Bissau. The focus is to reduce poverty in Quinará, Tombali, and Bolama/Bijagós by increasing and valorizing agricultural production, strengthening the socio-economic capacities of the beneficiary rural communities, and developing complementary income-generating activities.

[32] http://www.multilateralfund.org/85/English/1/8530.pdf
[33] www.gw-pades.org

6 Supplementary material: Field mission

A field mission was performed in April 2024 by visiting 20 groups of farmers in the three priority regions of the project (Bafata, Gabu, Quinara), so an average of 7 groups per region. The results of the field mission are integrated below, and more information can be found in (Gomes, 2024).

The **goals** of the field mission and activities are listed:

- The mapping of rural communities within the farmers' clubs in the three administrative regions is available.
- Data on agricultural production patterns and types in the identified rural communities, particularly the farmers' clubs, are available.
- The causes, factors, and levels of production deterioration in various farmers' clubs communities have been identified and documented.
- Options for the storage and preservation of perishable products in different farmers' communities have been identified.
- The primary distribution, wholesale, and retail markets for products in the regions have been identified and documented.
- Information and data on the transportation systems for moving products to the main community markets have been gathered.
- Data and information on access to electrical and telecommunication networks (phone and internet) in the different farmers' clubs communities are available.
- Meeting local providers that can offer active cooling solutions and maintenance services
- Gaining a better understanding of the organization and governance structure of local stakeholders who can play an active role in operating an active cooling facility.
- Conducting short training sessions on passive cooling solutions with local farmers to gather preliminary feedback on their receptiveness to implementing these measures for better crop preservation.

The following **methodology** was applied:

- Utilization of the study questionnaire for data collection, information gathering, and projecting specific study responses.
- Pre-definition and programming of a list of locations and findings.
- Conducting focus group meetings with farmer clubs and other stakeholders in local communities.
- Semi-structured interviews with key strategic actors, including:
    - Supervisors and animators assigned to farmers' groups
    - Leaders of other structured organizations, institutions, and projects
- Compilation, data processing, information analysis, and report writing based on findings and responses to key study questions.

The **questionnaire** that was used as a basis for the discussions and interviews is listed in Table 7.

Table 7. Questionnaire that was used.

BASE FACTORS	FUNDAMENTAL QUESTIONS
1. PHYSICAL LOCATION	- Is the location accessible by road throughout the year? - Is there sufficient space with adequate solar radiation for equipment installation? - Are there safety considerations for the site post-installation? - Are there similar projects or conservation equipment existing in the community or nearby?
2. USER ACCESSIBILITY	- Is the area easily accessible to farmers, traders, and consumers? - Are there any restrictions for women? - Is public transportation available to the location and activity zones? - Are there markets within a 10 km radius? - What is the market operating schedule (seasons, days, hours)? - What is the availability and total area of agricultural fields for clubs or communities? - Is there a need or interest in active or passive conservation mechanisms?
3. USAGE NEEDS	- What is the number of members in the local farmers club? - What is the estimated number of community producers within a 10 km radius? - What types of production (fruits and vegetables) are prevalent? - Which productions have the highest rate of accelerated deterioration? - What is the level of production during the high season? - What quantities are produced, and during which harvest season? - What quantities are commercialized or sold? - What are the levels of losses, wastage, and deterioration? - What are the main reasons for these losses? - What conservation methods are practiced, and what is the maximum conservation time for crops? - What are the average sales prices of identified products? - What are the main sales markets for community producers?
4. JUSTIFICATIONS FOR INTEREST IN STORAGE OR PRESERVATION	- How can cold storage reduce losses and obtain higher prices? - How does cold storage enhance safety and minimize risks, considering proximity to agricultural operations? - What is the proximity to the sale location? - What is the community's ability to contribute to product preservation (kg or tons)? - What modes and means of transportation are used for product transportation? - What quantities of products are transported in one trip? - What are the production and harvest periods and seasons?
5. LITERACY AND CONNECTIVITY	- What is the literacy level in the community or the farmers' club? - What percentage of farmers have mobile phones, and what types of phones (basic or smartphones)? - What is the level of internet access? - What is the level of access to electricity? - What is the availability of electrical, telephone, and internet networks? - Is there any entrepreneur or merchant interested in utilizing the cold storage chamber?