GUIDELINES ON DEVELOPMENT AND MANAGEMENT OF SMART STORAGE SYSTEMS

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FOODLAND

GUIDELINES ON SMART STORAGE SYSTEMS

Leader: AGRO
Participants: ENAM, SUA, UoN, MAK, UoM, UNIBO, and NGO partners

1. Introduction: smart storage systems

Agricultural products are perishable, seasonal in nature, their storage, transportation and preservation of freshness is a real challenge for the trade and food industry. Intelligent storage technologies allow for continuous remote detection and monitoring of changes in quality parameters and storage environment of products and foods during storage, so that necessary controls and adjustments can be made in their preservation and storage environment to reduce losses or maintain quality.

Smart monitoring technologies mainly include smart sensors for monitoring changes in the storage environment. These smart storage technologies applied to agricultural products must be efficient, non-destructive, well adapted to local contexts and with competitive prices.

A. Food Hub: Ait Ouallal Bittit – Ait Yazem (MA)

Case study - Food Product: Vegetables (onion)

1.1 Production and storage context

In Morocco, the cultivation of onion (Allium cepa L.) extends on a surface varying between 18.000 and 20.000Ha and appears among the principal market garden crops. As for bulb production, it varies between 300,000 and 400,000T/year [1] [4]. The Saıs region supplies 50% of the national market of onions [2] and El Hajeb province alone accounts for 41% of the national area and 52% in terms of production [3].

During the previous campaign the area devoted to onions has reached 5000 Ha and production 280.000 tons.

Table 1: Place of dry onion in the province of El Hajeb

Crop	Area (Ha)	Percent (%)
Onion	5.000	37,37
Potatoes	4.400	32,88
Tomatoes	5.000	3,74
Other vegetables	3.480	26.01
Total	13.380	100

The dry onion occupies the first place after the cultivation of potato in the region of El Hajeb. It represents, about 33.50% of the total area of vegetable crops for the agricultural year 2016-2017.

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According to the graph below, the area of the culture of dry onion has experienced a remarkable evolution, it has increased from nearly 200,000T in 2012-2013 to about 300,000T in 2016-2017.

This evolution is mainly due to the improvement of production techniques to the generalization of drip irrigation and the improvement of land quality (stone removal).

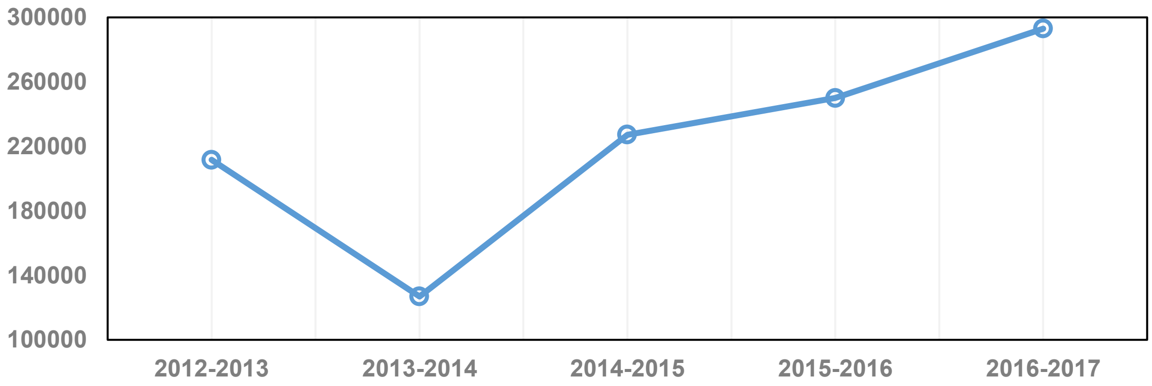

Figure 1: Evolution of onion production over five crop years

The traditional method of onion bulb conservation used in the province of El Hajeb (Ait Ouallal Bittit) is based on the construction of traditional silos composed of two parallel stone walls, each 1 m high and spaced at 80 to 90 cm. The length of the silo is determined according to the quantity of onions to be stored and the geometry of the land.

The spacing between two silos is generally 3 to 5 meters to allow for the movement of transport equipment. The dry onion is placed between the two walls on a 20 to 30 cm thick layer of straw. The height of the pile of bulbs can reach 100 cm at the periphery and 130 cm in the center of the silo in order to form a slope towards the outside and avoid the stagnation of rainwater.

The bulbs are then covered by another 10 to 20 cm layer of straw and a plastic film well attached to the wall by rigid strings. The orientation of the silos is generally parallel to the East-West direction, which is the direction of the prevailing winds.

The daily management of the silos consists in removing or mounting the plastic film to aerate the bulbs when the ambient temperature is high and putting it back on when it is cold or raining.

Generally, the massive production of onions in the province of El Hajeb encourages market gardeners to keep their production (instead of selling it at derisory prices) in order to take advantage of the increase in prices during the off-season. However, the lack of rigorous control of storage conditions in traditional silos leads to significant losses that result in lost earnings for the entire economy (producers and consumers).

Different marketing strategies of onion are used in El Hajeb region and are respectively:

- Sale in the field after the harvest 58% of farmers;
- Direct sale in the field without harvesting (at the plot) 18% of farmers;
- Direct sale to markets and Souks 7% of farmers;
- Storage of the harvest 17%.

The importance of the quantities marketed in the field without storage (76%) is mainly due to the following reasons:

- Lack of cash flow of the farmer (immediate sale);
- The importance of losses in storage due to traditional storage technology (silos);

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- Effects of cultivation techniques on onion storage quality (seeds, fertilization, irrigation, etc.);
- Lack of professional organization.

Figure 2: Some pictures of the onion storage system in the region of El Hajeb

According to a study conducted in 2009 in the province of El Hajeb, it was found that losses during the traditional storage of onions depend on the farmers and the duration of storage. Thus, 20% of farmers store their crop for between 2 and 4 months and lose an average of 20% of their production. The remaining 80% of farmers store their onions for 4 to 6 months and are divided into two groups: The first one (60%) loses 10 to 30% and the second one (20%) loses 30 to 50% of the crop.

The main causes of these losses are sprouting and rotting. These problems depend on storage conditions, but are also related to crop management. Germination occurs when conditions become favorable for the lifting of dormancy, i.e. temperatures of 10 to 20°C.

The traditional device ensures only a relative sealing and allows a continuous exchange with the external environment. Thus the ambient temperature reaches critical thresholds favoring germination which manifests itself by the development of the vegetative bud and the emission of roots, favored by relative humidity higher than 80%.

1.2 Objectives and description of the innovation

<u>Objectives</u>: The aim of this subtask is to find the best technological solutions by using smart storage technology in order to reduce the onion storage losses in terms of quantity and quality by using smart storage silos.

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The objective of our work is to propose a new technology of intelligent storage of onion in order to help the small local farmers to increase the duration of storage and to be able to resell their production at the right time and with a minimum of losses.

1.3 Intelligent control of storage system

Modern onion preservation involves the design of storage structures that allow permanent control of temperature and relative humidity. Agro-industrial devices are expensive and are not within the reach of most farmers in the region who own small areas. In addition, the margins between in-season and out-of-season prices and the risks associated with their variations do not favour private investment in this activity.

Despite the relatively high losses of the traditional onion storage system in the region, it is important to note its significant advantages for farmers. Indeed, the storage system is well adopted by farmers in the area and is inexpensive because it requires, apart from labour, only the use of a few products such as plastic, straw and string to implement it. Farmers who have wasteland next to their fields are better encouraged to practice it and take advantage of any off-season price increase.

In order to further improve this conservation system by reducing losses to a maximum, it is proposed to equip it with an intelligent system of humidity and temperature control through the use of connected sensors installed inside the silos. This control system can be linked to a mechanical ventilation system through the control of the height of the plastic films that cover the silos and also through a ventilation through the use of fans installed on the ends of the silos.

This ventilation will consist of circulating air around and between the bulbs to remove heat, maintain uniform conditions and limit humidity and condensation. The ventilation can be automated through an intelligent control system or manual with the intervention of a manipulator on site.

This storage device will be a combination of the traditional method of storage based on the use of stone silos in the open air and an intelligent system of temperature and humidity control in the silos through the use of connected sensors allowing an automated or manual ventilation of these silos.

To allow farmers to remotely monitor the conservation conditions in onion storage silos, it is proposed to develop a mobile application to monitor humidity and temperature parameters and also make remote decisions for the opening or closing of plastic flaps or the activation of fans.

This mobile application will allow farmers to remotely monitor their silos and act in real time for a better conservation of the product. Thanks to the collection and storage of historical data on the evolution of onion storage conditions, it will be possible to use all the data collected to develop a more elaborate onion storage advisory system better adapted to local conditions in the region.

The data collected for several farmers and under different conditions in a dedicated Cloud Server can also be used to improve the conservation process, especially for the construction of technically more efficient storage silos.

The advantage of this solution is the fact that it aims to improve the existing technique already adopted by the farmers and does not present any risk of rejection from them. In addition, the investment costs are modest and can be spread over several years in relation to the depreciation period of the equipment used.

2. Description of the prototype and results

2.1 Operative procedure

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2.1.1 Specific procedure for data collecting and analysing

The objective is to obtain an open and economically viable solution that will reduce onion storage losses and benefit both farmers through reduced losses and consumers through increased supply. This should result in a slight decrease in prices and an improvement in the quality offered (inelastic demand as necessary in Moroccan cuisine).

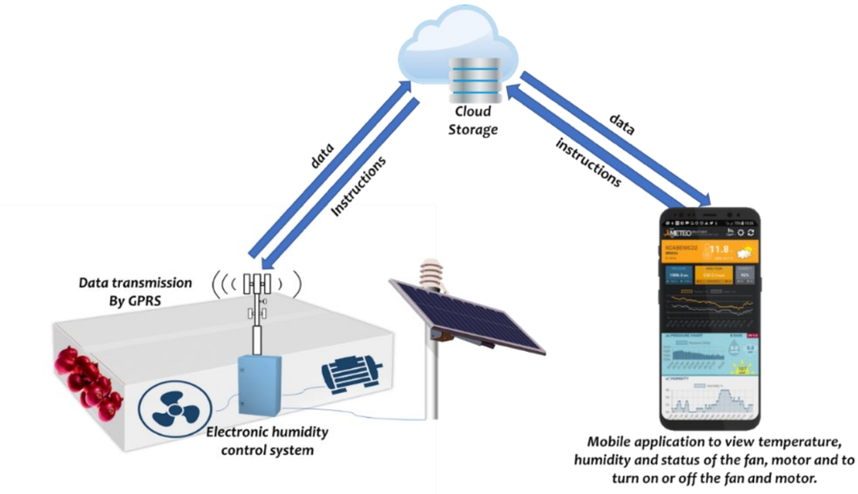

Figure 3: Framework for onion smart storage system and information dissemination

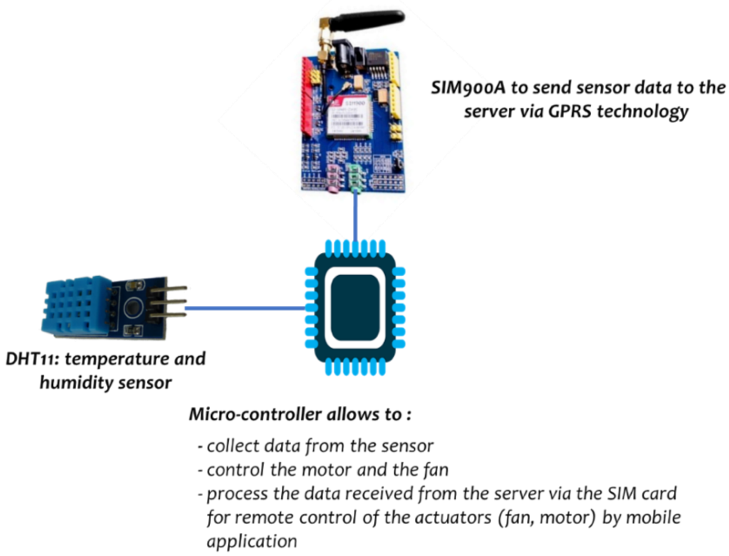

Figure 4: Remote temperature and humidity control diagram

Stakeholders and regional partners:

- National School of Agriculture of Meknes (ENAM);
- Provincial Directorate of Agriculture (DPA El Hajeb);
- Association of producers and exporters of the onion of El Hajeb;
- National Office of the Agricultural Council (ONCA).

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The tasks focus on three main pillars namely:

1. Develop a prototype of smart, connected onion storage silos that can be remotely controlled and can reduce storage losses.
2. Conducting a diagnostic on onion storage in the region to assess storage-related issues for small-scale farmers and their readiness to adopt the new storage technology.
3. Support and training of farmers on the improvement of production techniques in relation to good storage (seeds quality, irrigation, fertilization, field drying...), on the use of the intelligent storage system and the mobile application designed for remote control of silos.

2.2 Result

The first preliminary results obtained concern diagnostic on onion storage in the region to assess storage-related issues for small-scale farmers and their readiness to adopt the new storage technology.

2.2.1 Diagnostic of the onion storage system in the area

This preliminary diagnostic work aims to assess the costs of production and storage of onion in the province of El Hajeb and to identify the causes of storage losses in order to propose a new storage technology to minimize losses and improve the margins of farmers.

The specific objectives are:

Technical and economic characterization of onion production and storage conditions in El Hajeb province;

Assessment of farmers' strategies towards onion storage in relation to storage losses and onion market risks;

Evaluation of the perception of the new onion storage technology to farmers to significantly reduce losses and improve farmers' margins.

To achieve the objectives assigned to the preliminary diagnosis, we surveyed a sample of onion farmers in three major production areas El Hajeb, Bouderbala and Agouraï via a questionnaire. The surveys were conducted from March 8, 2022 to March 12, 2022.

The questionnaire focused on the following areas:

General data on the farm (location, total area, onion area, crops grown and legal status of the land)

Technical data related to onion production (irrigation method, types of varieties used, average yield per hectare, type of sale, destination of their production, and quantity sold for each type of sale as well as the sale price).

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Data on onion production costs (land rental cost, land labour cost, seedling purchase cost, transplanting cost, irrigation cost, fertilization cost, maintenance cost, harvesting cost to estimate production cost).

Data related to storage (quantity stored, duration of storage, location of storage in relation to the farm and road network, size of silo, number of silos, quantity stored per silo) and storage cost (cost of storage location, cost of labour, cost of straw, cost of plastic, cost of guarding and other costs to finally estimate the total cost of storage) and the percentage as well as the loss factors related to storage

Farmers' perception and opinions on the new storage technology (innovation).

Data collection and sampling:

The data on technical itineraries, production costs and onion storage methods concern the 2020-2021 season. In the absence of an appropriate sampling frame, the composition of the sample used was oriented and reasoned in consultation with the onion producer associations in the zone. A total of 75 farmers in 3 circles of the province were surveyed and divided into two zones:

Zone 1: **Ait Ouallal Bittit, Bouderballa and Ait Yazem**. This is a favorable zone for onion production given the availability of irrigation water and where some farmers practice storage.

Zone 2: **Iqaddar, Jaaba, Ain Mäarouf and Souk El Gour**. These are also production areas, but some farmers have specialized in storage. These areas are closer to markets and sales outlets.

General onion yield and profitability data:

Total area (ha)	984.25
Area dedicated to onion (ha)	336,00
Average yield (T/ha)	57.39
Average production cost (Dhs/ha)	53.800,00
Average land rental cost (Dhs/ha)	5773,33
Average storage cost per ton (Dhs/T)	259,60
Average selling price before storage (Dhs/Kg)	1,28
Average profit margin per hectare (Dhs/ha)	28.360,00
Average profit margin after storage per ton (Dhs/T)	579,48

Typology of producers according to the modes of sale:

According to the modes of sale, two groups of producers can be distinguished:

- Producers who do not store and sell their production at harvest time (52%)

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- Producer-stockers who sell either at the storage site or directly on the market (48%).

This change is mainly due to:

- Size of production: Generally, small and medium-sized farmers prefer to sell in the field, while larger farmers prefer to sell after storage;
- Debt and lack of cash flow: Farmers with debt or lack of cash flow prefer to sell the entire production right after harvest;
- Risk aversion related to onion prices and storage losses;
- Climate: Generally, farmers located in the higher (colder) zones are more interested in storage. Thus, 67% of farmers in zone 2 practice storage compared to only 39% in zone 1, which is relatively more exposed to high summer heat than zone 2.

Comparison of profit level without and with storage:

For farmers who sell their production after storage, we found that the profit margin is around 1,260Dhs/T. In contrast, the profit margin is only 462 Dhs/T when farmers sell their production immediately without storage. This margin is mainly due to the increase in onion prices between the production season and the period when stocks are sold. The price per kilogram of onion can go from less than 0.5 Dhs/Kg during the harvest period to more than 3 Dhs/Kg in the off-season. But in some years, prices do not vary enough to make the storage investments made by farmers profitable.

In the case of the 2021-2022 crop year, it can be said that the farmers who practiced storage were able to make greater profits than the farmers who sold their produce during the production season.

The volatility of onion market prices at the zone level can profoundly affect the profitability of storage.

Analysis of production and storage costs:

1. **Production cost:**

Items (Dhs/ha)	Amount	Percentage
Working the soil	1.000	2,18
Purchase of plants and seeds	12.500	27,29
Transplantation	10.0008	21,83
Irrigation	9.000	19,65
Fertilization	4.000	8,73
Weed control	3.000	6,55
Phytosanitary treatment	1.800	3,93
Harvest	4.500	9,83

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Total cost without rental value of land	45.800
Rental value of the land	8.000
Actual total cost	53.800

The average production cost is about 53.800.00Dhs/ha whose main expenses are the purchase of plants and seeds with 27%, irrigation which represents 19,6% (without the rental value of the land) and fertilization which constitutes 8%.

2. **Storage cost:**

Items (Dhs/ha)	Values
Workforce	6.750
Cost of the stones	600
Straw	2.250
Plastic	900
Security guard	500
Transport	2.000
Total cost	13.000

Effect of storage time on profit levels

	Zone 1	Zone 2
Average yield (T/ha)	59.38	67.55
Average cost of production (Dhs/ha)	41.750,00	50.937.50
Rental value of the land (Dhs/ha)	7.687,50	5.500,00
Storage cost per (Dhs/T)	496,00	596,88
Average selling price (Dhs/kg)	2.42	2,81
Margin per hectare (Dhs/ha)	23.406.25	36.385,00
Margin per ton (Dhs/T)	1.142,34	1.259,18
Average storage time	2	4

Although the storage cost per ton is high in Area 2 compared to Area 1, the average margin per ton in Area 2 is higher than in Area 1. This is due to the longer storage period that allowed for a more attractive price increase. The average duration in zone 1 is 4 months and in zone 2 is 2 months, which gives farmers in zone 1 the opportunity to sell their produce at the end of the storage season at higher prices.

The variation in the selling price between the price at harvest and the price after storage shows that the longer the storage period, the higher the prices. Indeed, for farmers in zone 1, where the storage period is around 2 months, we note that the average selling price after storage has increased by only 0.56Dhs/Kg, whereas in zone 2, where the storage period is around 4 months, the average price has increased by 0.92Dhs/Kg. This implies the importance of onion storage time in the formation of farmers' profit margins.

In general, as the duration of storage increases, so does the price differential with respect to the in-season price and therefore the interest in adopting a storage technology that minimizes losses by farmers.

Effect of storage time on onion losses:

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Analysis of the relationship between onion losses and storage time shows that as storage time increases, losses are higher. The correlation coefficient between storage time and percentage loss is about 0.71. This implies that the storage technology used is not effective in conserving production and that losses in the quantity of onion become higher and higher over time. If the market price increase is only significant compared to the in-season price, farmers will therefore have to bear greater economic losses.

Farmers' opinion on new storage technology:

On the question of the willingness of farmers to adopt a new storage technology that is more effective in terms of reducing losses, 57% of the farmers surveyed said they were willing to adopt the new storage innovation that would allow them to increase the economic value of their production. The main reasons that seem to slow down the adoption of this new technology are:

- Lack of funding for farmers
- Doubts about the expected results of the innovation (risk aversion)
- Lack of information on the concrete results of the innovation.

Conclusion

Overall, we note that losses from storage are quite high, averaging 22% in the zone, and can be an obstacle to the adoption of storage techniques by farmers. This implies a higher availability of onion production during the production season and a significant effect on market prices. In the absence of storage, market prices at harvest time will be very low and will not allow farmers to make significant profit margins. Storage is therefore an effective means for both producers and consumers because it allows the availability of the product to be spread over a longer period and reduces the price gap over the year. The interest of the innovation is therefore to minimize storage losses for producers and to put more products on the market in order to increase product availability for consumers.

The results show that the obstacles to the adoption of storage by farmers are mainly technological in relation to the mastery of production techniques for better onion conservation (seeds, irrigation, fertilization) or in relation to the use of the storage technology itself.

The new technology proposed, even if its installation cost could be higher than the traditional technology whose average cost is about 260Dhs/T, should allow a better conservation and quality control of the production and will allow a longer conservation. This will contribute to the improvement of the profits of the farmers who practically store the product by decreasing the storage losses to less than 10%.

2.2.2 Prototype implementation

The precision storage system was developed to store onion in a specific silo. As shown in Figure 3, the prototype storage silo we developed includes an onion storage bin, an electronic system for collecting and transmitting temperature and humidity data over several depths of the silo, and a fan with a perforated pipe integrated into the silo structure. The collected data is transmitted via internet to a data storage cloud for processing.

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The system communicates to the cloud service via a microcontroller (Figure 4). It is therefore possible to program the microcontroller to operate autonomously to trigger the ventilation and the opening of the shutters (protective curtain) or to use a smartphone application for remote control.

To automate the opening of the upper shutters of the silo, it is also possible to automate the operation by installing a motor in the upper trap of the prototype and have it activated remotely in relation to the ventilation needs of the onion. In addition, we have installed a fan outside the silo to be able to communicate with the manipulator via the microcontroller.

(a) **(b)**

Figure 5: Prototype installation and testing. a: Prototype installing, b: Onion preparation

2.3 Expected results

a. Improvement of the onion storage system in terms of quality and quantity by reducing losses by less than 10% compared to the current situation (22% on average). Improved farmers' income through better control of onion storage.

b. Reduced storage costs and improved sustainability of regional agriculture in the face of resource scarcity and climate change impacts. Increased farmer income due to reduced storage losses.

3. Guidelines for the Development and Management

3.1. Site Selection and Design

- **Location**: Choose a site with minimal environmental risks (avoiding extreme temperatures, direct sunlight, and high humidity). Accessibility for transportation is key.
- **Structure**: Ensure the silo is designed to maximize airflow and ventilation, allowing for proper onion storage and preventing spoilage. (see the prototype model proposed)

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3.2. Monitoring and Automation

- **Sensors**: Deploy sensors to monitor temperature, humidity, and other critical environmental factors. These sensors should be connected and capable of sending data to a central system for remote monitoring.
- **Automated Systems**: Implement automated systems that can adjust internal conditions (like temperature or humidity) based on real-time sensor data to maintain ideal storage conditions (ventilation).

3.3. Data-Driven Management

- **Real-time Data Access**: The data from the sensors should be made accessible in real-time to managers or farmers for easy monitoring and troubleshooting.
- **Predictive Algorithms**: Use robust predictive algorithms to forecast potential changes in storage conditions and prevent potential risks of spoilage based on historical data.

3.4. Maintenance and Operations

- **Routine Inspections**: Schedule regular checks of sensors, ventilation systems, to ensure all systems are functioning correctly.
- **Issue Alerts**: Implement an alert system to notify staff immediately if there are any significant changes or failures in the environmental controls or system performance by using dedicated mobile application.

3.5. Sustainability

- **Efficient Resource Use**: Focus on ensuring that the silo's energy use is optimized, leveraging natural ventilation or energy-efficient systems where possible.
- **Waste Minimization**: Minimize waste and spoilage through careful management and tracking of inventory, potentially improving the overall sustainability of the operation.

3.6. Collaborative Knowledge Sharing

- **Community Engagement**: Create a platform for knowledge exchange between farmers and agricultural advisors, allowing for collective decision-making and information dissemination.
- **Training and Support**: Provide training resources within the app for farmers to understand the onion storage management system and use the features and technology effectively.

3.7. Risks and mitigation measures

- **Risks related to the use of the smartphone:** Ventilation activation and onion storage quality management (especially for farmers with low levels of education). This will require specific training to enable farmers to properly interpret the information provided and schedule the remote interventions on the silos.

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4. Technology and production key performance indicators

The guidelines presented here and the work carried out so far contribute to the achievement of the following key performance indicators, foreseen in the project grant agreement:

- Reduction of storage losses below 10% and improvement of storage quality: in terms of applied technology, it is expected that the knowledge and capacity of farmers to manage onion storage quality during the off-season through the use of smart storage silos and a specific mobile application.

At the overall regional level, onion availability is expected to increase in terms of quantity and quality. This should result in better distribution of production throughout the year and improved market trade with increased income for farmers. For the quality component, improved quality should result in better availability for the final consumer.

- PPT-ST: 10-15% reduction of food waste through efficient storage: in relation with the use of useful information from the mobile application by farmers and the improvement of their know-how.

- PPI-LT: 20% increase of small farmers and SMEs' income by reducing storage losses and production quality (average).

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B. Food Hub: Kamuli (UG), Mukurweini, Kitui (KE), Laelay Machew (ET), Mvomero, Morogoro (TZ)

Case study - Food Product: Tomato

5. Objectives

The overall objective is to fabricate and test a smart evaporative cold storage system that maintains the produce fresh quality between production and marketing
The specific objectives are to:

i. Fabricate an evaporative cold storage unit
ii. Determine the effect of the prototype on the temperature and relative humidity of the air within the storage chamber
iii. Demonstrate the operation of the cold storage unit in Kitui Food Hub;
iv. Assess technology acceptance of the cold storage unit in Kitui Food Hub; and
v. Analyse the economics of investing in a business for commercial production of the evaporative cold storage unit.

6. Smart storage prototype

Agroscope developed a smart storage system. It is a cold storage innovation that involves placing charcoal in the folds created using gunny bags. The charcoal loaded bag is then wrapped around a crate containing vegetables. Water is then poured on the bag and is absorbed by the charcoal. During the hot parts of the day, the water evaporates from the charcoal and creates an evaporative cooling effect inside the crate to prolong the shelf life of the produce. The technology targets market vendors who lose fruits and vegetables due to unfavourable conditions at the market. The technology has been tested in Uganda and will now be tested in Kenya for comparison.

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8. Expected Results

Results on variation of the temperature and relative humidity of the storage environment when the storage chamber is loaded with green leafy vegetables (kale) will be obtained. The results will show two scenarios: When the sack cloth and charcoal are wetted with water and when they are dry. Demonstration of the performance of the cold storage technology will be done in Kitui Food Hub where the technology assessment results will also be done. The results of analysis of the profitability of investing in a business venture producing the smart storage units will also be presented.

9. Procedure and Required actions

The smart storage prototype should be up-scaled to accommodate the quantity of produce to be cooled. This may involve having a bigger size of each individual unit and/or installing as many units as required. Skilled tailors are required to to cut and sew the sack cloth that holds charcoal.

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The fruits and vegetables being cooled and maintained at the desired low temperature should be loaded in plastic crates that are placed in the space at the centre of the cooling unit. The selected perishable produce must not contain bruised, damaged or diseased units/parts.

Incompatible product mixes should not be stored in same containers. However, produce stored together should be able to tolerate the same temperature and relative humidity in the storage environment.

The storage units should be placed/installed in a shaded area or in a shed with open sides that allow natural air circulation. The sack cloth and the charcoal it holds should always be adequately wetted with water during storage.

10. Technology and production key performance indicators to be gathered

a) Temperature and relative humidity around the stored produce.
b) Technology acceptance by the farmers in Kitui Food Hub
c) Profitability of a commercial enterprise investing in the production of the cold storage units.

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11. Work plan

Activity No.	Activity	2023				2024				Comment (If any)
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
1	Construction & Testing of the cold storage prototype									At UoN
3	Validation activities									SME and Kitui Food Hub
4	Economic analysis									At UoN

12. Risks and mitigation measures

No major risk is envisaged.

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