GUIDELINES ON DEVELOPMENT AND MANAGEMENT OF PRECISION HARVESTING SYSTEMS

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FOODLAND

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GUIDELINES ON PRECISION HARVESTING SYSTEMS

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

1. Introduction: precision harvesting systems

Farmers currently have difficulties when planting fruits that grow on tall trees. This is a result of the challenges encountered during harvesting. Since the majority of the fruits are still harvested by hand using non-mechanical methods, the procedure is labor- intensive and expensive. The majority of the fruits are intended for the fresh market. The difficulties include obtaining fruit in pristine condition, preserving the health of the trees or plants from which the picking is being done, and assuring the workers' safety. The current methods of harvesting trees include manually shaking the trees, climbing the trees, and employing makeshift pickers constructed from scrap materials

All of these techniques harm people, trees, and fruit among other things. The first concern is the safety of the people who climb the trees since accidents are probable to occur leading to more inconveniences. The second concern is as the fruits fall from high trees to the ground, their quality is affected through bruising and shattering and they end up fetching poor prices on the market or being rejected altogether. Having a harvesting system that preserves the quality of the fruits and the safety of farmers and fruit trees is hence a mulch welcome relief to farmers.

A. Food Hub: Zoyout Dir Beni Mellal (MA) | Food Product: Fruits (olives)

National context:

The olive tree covers more than 65% of the Moroccan arboricultural area and provides more than 51 million working days per year, that is to say the equivalent of 380.000 permanent jobs, of which the participation of women represents 20% [1]. The role of women in olive growing is varied and they are present at all hierarchical levels. Thanks to sustained growth and the governmental support, it is a very promising sector for employment in rural areas in Morocco. In the Beni Mellal region, the olive tree constitutes the regional heritage of excellence in agriculture by occupying an area estimated at 65,500 ha representing 12% in national olive growing and 60% of fruit species at the level of this region [2].

In Morocco, although the genetic diversity is important, we note the dominance of a single variety called "Picholine Marocaine" with dual use: olive oil and table olives and covers 90% of the total Moroccan olive orchards [3]. Its importance is justified by the quality of its products and their age-old uses, as well as its multiple functions of erosion control, agricultural land enhancement and population settlement in mountain areas [4]. Despite its good adaptation, it has an average oleic yield of the 18% and it presents a high index of production alternation as well as a high sensitivity to some diseases and pests [5].

Since 2008, when the Green Morocco Plan (PMV) was launched, the olive sector in Morocco has been the subject of several actions aimed at supporting small-scale agriculture in order to increase the income of rural populations. The MCA Programme's Fruit Tree Project, carried out thanks to US AID, has enabled the planting of 80.000 ha of olive trees, the construction of 20

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olive crushing units with a crushing capacity of 60 to 80t/day and an overall storage capacity of 600t of oil each, and has benefited more than 6,843 farmers and 150 cooperatives [6].

But, until today the right moment to harvest olives is always decided through the visual monitoring of the orchards by the farmer. However, this task is tedious, punctual, time consuming and requires an expert eye to assess the quality and ripeness of the olives.

Currently the start of the harvest season is based on the individual decisions of farmers without any collective consultation in relation to the maturity of production. It would be interesting to set up a system for detecting the optimal harvest date at the zone level. The use of drones to assess the condition of olive groves in relation to the maturity of the fruit will make possible to decide collectively the start date of the harvest at the community level. The implementation of information dissemination solutions on the production of olive oil including the optimal date of harvest through a smartphone application dedicated to the exchange and dissemination of information on the olive tree will certainly contribute to improving production and processing techniques in relation to the production of olive oil.

The staggering of harvesting throughout the region is also important in order to establish a harvesting and crushing schedule that takes into account the harvesting and crushing capacities of each community. In this sense, it is interesting to specify these optimal harvesting dates to make.

Variety characteristics

Name: Picholine Marocaine
Typical variety with double purpose
Average fruit weight: 2.5 to 4g
Ratio pulp/stone: 5.5
Oil content: 16 to 22%.
Well adapted
Sensitive to spilocaea oleagenum
Alternating
Very heterogeneous

1.1 Objectives and description of the innovation

Objectives: The aim of this subtask is to find the best technological solutions by using precision technology in order to increase the production of olive oil quantity and quality by optimising harvest period.

The purpose of our work is to relate the use of the precision harvesting management tools in order to help local and small farmers to harvest their olives production at optimal time.

The evaluation of the optimal harvest date of olives is an important factor that determines the quality of the fruit and the extracted olive oil and can vary according to the climatic conditions from year to year. Although a number of scientific simulation models exist for estimating the optimal harvest date in relation to environmental climatic conditions, they are difficult to apply routinely due to the large number of data sets required and the heterogeneity of the orchards and cultivation practices applied in each area. The introduction of RVB images acquired by drones, combined with ground information, can allow a reliable and rapid estimation of the optimal date for olive harvesting.

The images captured can distinguish and separate between olive orchards in relation to their spectral signatures which allows to estimate the expected dates of harvest. New developments in the sector of agricultural drones allow to determine the ideal time to perform the harvest. Currently, for example, drones can fly over a soybean farm, catch a pod and split it open. The farmer can then determine whether his crop is currently ready to be harvested.

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Immature fruits are of poor quality and are subject to mechanical damage, and overripe fruits have a soft and tasteless quality, with a very short shelf life. In general, if the harvest is too early or too late, physiological disorders in the fruits will be caused with the consequence that the shelf life becomes shorter or the quality of the derived products is lower.

In this sense, experimental tests must be carried out in parallel with the collection of images from drones in order to find the best relationship between the visual characteristics of the fruit and the quality of the olive oil produced.

The farmer's goal is generally to have a good yield in terms of quantity of olives harvested and quality of olive oil extracted and would like to know a little early when he will have to start harvesting to achieve this goal. In general, the fruit yield is not the only indicator of the quality of the harvest because the olive oil yield is often the most important criterion in the success of the production and the improvement of the economic margins of the farmer. Up to now, most olive producers carry out random checks on their orchards with a visual appreciation of the maturity of the olives to decide on the date of harvest to be scheduled.

Using drones to monitor the maturity of olives can reduce related to the visual appreciation by the farmer, but also increase the spatial extent, objectivity and repeatability of the analysis.

In general, two types of analysis are needed to define the quality of an olive oil. The chemical analysis measures the free acidity and other physical parameters of the oil, while the sensory analysis focuses on its visual, olfactory and gustatory characteristics. Given the homogeneity of sensory characteristics at the level of the area (climate, type of soil and varieties) it will only be necessary to distinguish the quality of olive oil in relation to its physical characteristics (PH, oleic acid, fatty acids, ...). These measurements should allow to classify the different olive oils for different harvest dates according to their physical quality.

The overall objective is to find a direct relationship between the spectral signature of olives at different stages of maturity from drone images and the quality and quantity of olive oil produced for each sample harvested. A direct correlation model between the physical characteristics of the olive oil and the spectral responses from the drone images should allow to indirectly evaluate the maturity of the olives through the images from the drones and not to need to perform chemical analysis to evaluate the level of maturity (indirect measurement through the analysis of images from the drones). The algorithm developed through the research can serve as an early prediction of the dates of harvesting of olives throughout the region and will allow to propose a harvesting schedule adapted to the differences in maturity in the different territories of the region.

In order to better disseminate information on the optimal date of harvest of olives to farmers, it is planned to develop a mobile application to monitor the maturity of olives intended by farmers. This application can also serve as an information platform on techniques and production of olives (agronomic techniques) and will allow a direct contact for advice and assistance to farmers in everything that concerns the olive tree from production to processing.

As illustrated in the following figure, the distributed monitoring system for detecting the optimal harvest date of olives can be schematized with a part (layer 3) running on mobile devices on the end-user side (farmers and agricultural advisors), as well as on a centralized server on the cloud side.

The centralized server is dedicated to the storage and distribution of the information coming from the learning algorithm for the detection of the optimal harvest date and from the analysis of the quality of the olive oil produced. Layer 2 also illustrates the user interface, developed as an Android application, to allow the users of the system (see Layer 3) to access the information and interact with the system in a convenient way.

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The base layer No. 1 is intended for the actual learning of the system through the linking of direct information from the chemical analysis of olive oil samples and the data collected by the UAV through the analysis of multi-spectral images.

The learning algorithm is implemented directly on the server and can be improved in relation to the quality and mass of information collected on the extracted oil samples and the correlation algorithm with the data from the UAVs.

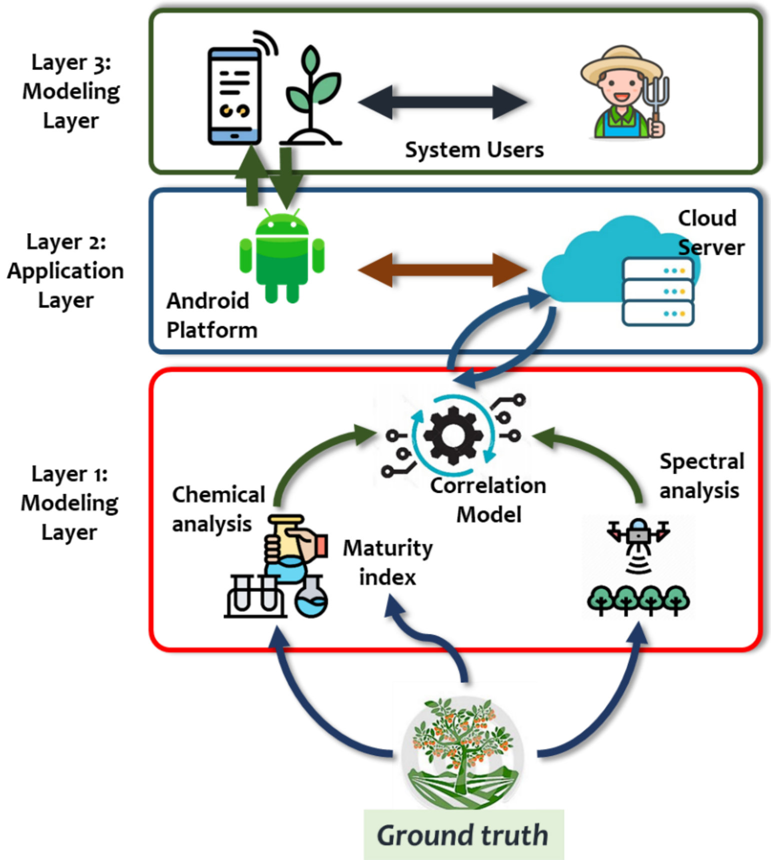

Figure 1: Framework for olive maturity detection by drones and information dissemination

1.2 Determination of maturity

The period of maturity is the time between the appearance of the purplish spots and the moment of the final coloration of the epidermis. The maturity period is variable, depending on climatic conditions and varietal characteristics. Maturity can be determined either by subjective or objective observation. The methods of determining harvest maturity are as follows [7]

- Physical methods: Size, shape, color, texture, etc.
- Chemical methods: Total Soluble Solids (TSS), acidity, etc.
- Physiological methods: Respiration and ethylene production.

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- Apart from the above measures, abscission, accumulated heat unit, specific gravity, duration after flowering, firmness, dry matter, juice content, Oil content, waxiness, tenderness, etc., can also determine the optimum harvest maturity stage.

During the development of olives, several parameters can be used as more or less specific indicators of maturity, namely, respiration [8], the evolution of lipids in the drupe and leaf [9], the variation of the organic acid content of leaves and fruits [10], especially the malic acid/citric acid relationship [11], the variation of iron content as a metabolic component of abscission hormones [12], the viability of the embryo [13], the evolution of polyphenols [14], etc.

The simple visual parameter that can indicate the evolution of the maturity of the fruit is the variation of its coloration. At the beginning, the color of the olives is green, then turns to a yellowish color due to a strong reduction of the chlorophyll constituents [15]; this phenomenon is called the green maturity. Afterwards, there is an accumulation of anthocyanins. The concentration of anthocyanins in the cells determines the intensity of the color [16], which ranges from reddish to intense purplish and ends with a black color.

In the majority of varieties, the epidermis coloration begins at the tip of the fruit and continues to the opposite end located at the point of attachment of the stalk. Afterwards, the mesocarp coloration starts from the most external part until the purplish coloration reaches the nucleus.

Figure 2: Olives coloration change from deep green to black at different maturity stages

The process of variation in the coloring of the olives, with the accumulated experiences, allows to easily establish the index of maturity as proposed by [17]; thus the olives can be classified in eight classes or categories. The practical method is as follows:

Fruit color is used to determine the maturity index, which expresses the average coloring of a sample of fruits. The Jaén index is the most widely used [17]. It is calculated by collecting approximately 2 kg of olives a shoulder height from around the tree. A sample of 100 olives is then selected and the fruits are sorted into the following categories:

0 = skin color deep green
1 = skin color yellow-green
2 = skin color green with reddish spots on < half of fruit surface; start of color change
3 = skin color reddish or light violet on > half of fruit surface; end of color change
4 = skin color black with white flesh
5 = skin color black with < half of flesh turning purple
6 = skin color black with flesh turning purple almost through to the stone
7 = skin color black with all the flesh purple to the stone

The number of olives A, B, C, D, E, F, G and H in each category 0, 1, 2, 3, 4, 5, 6 and 7 are counted and the maturity index is calculated as the weighted average of the values obtained:

Maturity index = (Ax0+ Bx1+ Cx2 + Dx3 +Ex4 + Fx5 + Gx6 + Hx7)/100

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The destination of the olives (production of table olives or oil) influences the degree of maturity appropriate for each destination to make the harvest:

Case of olives intended for the production of oil

The oil is totally formed when the maturity index reaches the value of 3.5; that is, the majority of the fruits are located in classes 2 and 3, some have black skin (class 4 or more) and few olives are still green-yellowish (class 1) [18].

Case of table olives

The type of preparation defines the most suitable degree of ripeness [19]. If the olives are prepared green, the color should be green or yellowish-green (class 0 and 1) at the time when the stone can be separated from the pulp, no olive should be in class 2. If the olives are prepared as black type, the yellowish color is recommended (class 1), however, the existence of some fruits located in class 2 can be tolerated. On the contrary, for natural black olives the moment of harvesting must be more advanced: the purplish color of the pulp must penetrate up to 2 mm from the stone which corresponds to a maturity index of 5 to 6.

2. Description of the experimentation and results

2.1 Operative procedure

2.1.1 General procedure for detection of optimal period of harvesting

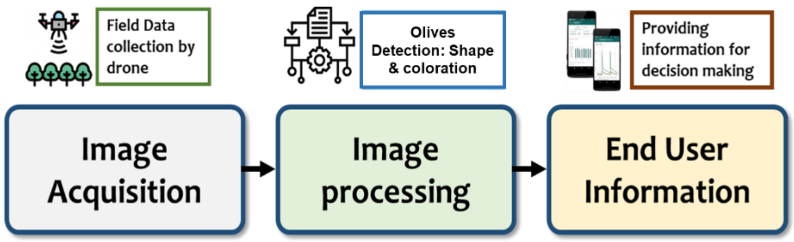

Figure 3: Global detection of optimal period of harvesting by using drone

2.1.2 Specific procedure for data collecting and analysing

Non-destructive methods are very interesting for in-field maturity assessment, but the most challenging problem is how to relate this assessment to predict yield and optimal harvest date [20].

This task is further complicated if one considers the variation in plant behavior in relation to changes in the environment and its effect on crop cycles and production maturity.

Yield or maturity assessment models are generally based on the specification of a prediction model by selecting the most discriminating input (explanatory) variables in relation to the available scientific tools (technologies) and plausible hypotheses on the dependency relationships between

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these assessments and yield levels or maturity stages. The question is therefore to find this calibration model with the strongest possible linkage (% explanation of the observed variance) and which also takes into account variations in the behavior of the plant or the crop in relation to changes in the environment (temporal precision).

In this research, drone images will be collected for olive maturity classification. According to the characteristics of these images, the maturity stages of the olives will be divided into several classes (from light green to black) taking into account the quality of the images to identify the maximum possible classes. The maturity stages of the olives based on the counts made have been divided into 8 classes (see classification above).

We will focus on the use of multi-spectral wavebands (red edge and near infrared) and spectral vegetation indices as relevant features for predicting the optimal olive harvesting period. The data collected by the drone will also be used to detect the shape and coloration of olives in order to calibrate the model for estimating the maturity stages based on the classification [17].

A deep learning method will be adopted for training and evaluating the dataset, which are commonly used in AI and is good for object detection and classification from images or videos.

The objective is to apply one of the latest deep learning methods, YOLOv7, to speed up the data analysis process and quickly and accurately identify more detailed olive maturity classes from UAV images (4 or 5 classes) and digital near-ground images (five classes).

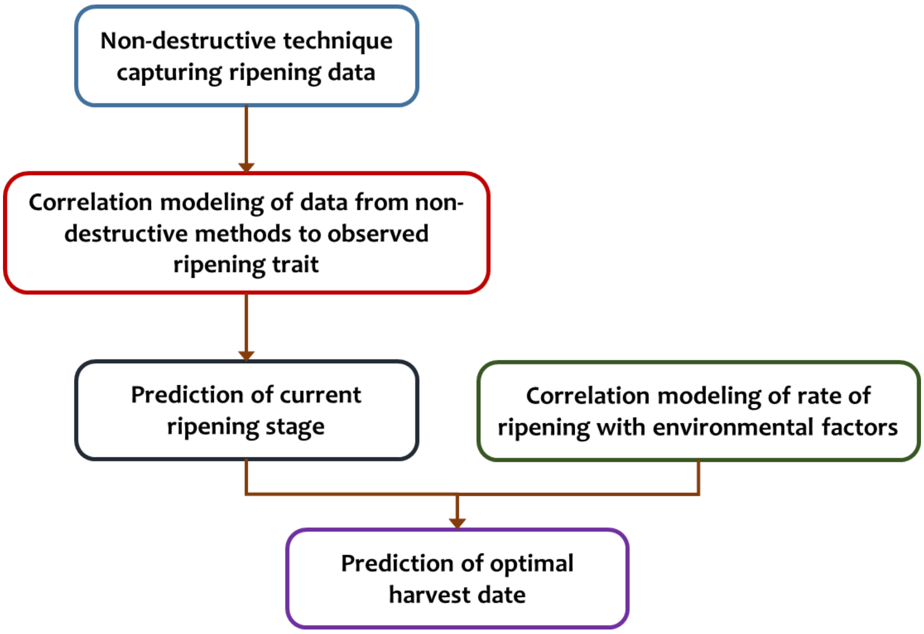

Figure 4: A scheme of the overall workflow for the prediction of the optimal harvest data [21]

The experimental farm of 8ha is located at Tighboula village, Ksiba locality and Bni Mellal Province, at 32°37′35.8″ N, 6°00′17.7″ W. shows the olives field planted 6 years ago and equipped with drip irrigation system. The trees (Picholine Marocaine), which most adapted to the national agricultural context, are distributed in lines separated by 7m and 5m between trees. Figure 6 shows the days when the data collection campaign for biometric, chemical measurements and drone investigations were performed.

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Figure 5: Experimental area localization (Farm).

50Kg of olives were collected during each visit to the plot, i.e. 350Kg for all 7 field visits. These samples were used for the evaluation of the quality and maturity of the olives (maturity index and specific weight) and for the chemical and sensory analysis of the extracted olive oil.

The work period was spread out between October 18 and December 2, 2022, that is to say 7 successive weeks, three of which concerned the shooting of the orchard by drone.

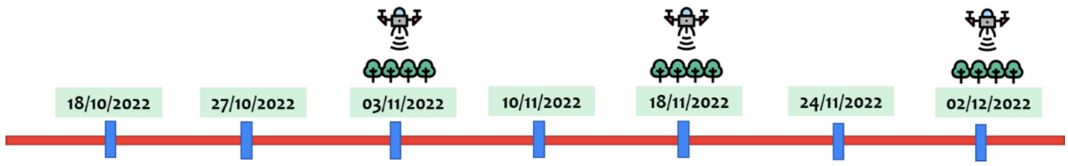

Figure 6: Working schedule during the different stages of maturity of the olives

Stakeholders and regional partners:

- National School of Agriculture of Meknes (ENAM);
- Provincial Directorate of Agriculture (DPA Beni Mellal);
- GIE Dir Beni Mellal (Olive associations group) (GIE);
- National Office of the Agricultural Council (ONCA).

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The tasks focus on three main pillars namely:

1. Conduct on-farm experiments for the detection of the optimal time of olive harvesting and the development of a harvesting program based on the maturity parameters of the olives.
2. Development and implementation of a solution for advising on optimal olive harvest time using precision sensing techniques and a mobile application on smartphones.
3. Support and training of farmers in the use of the mobile application designed for harvest quality and scheduling of olive harvesting.

2.1.3 Drone description

- Phantom 4 Pro multispectral RTK

Technical specifications:

- Diagonal (without helix): 350 mm
- Max. Ascent Speed: 6 m/s (automatic flight); 5 m/s (manual control)
- Max. speed 50 km/h (31mph) (P-mode); 58 km/h (36mph) (A-mode)
- Operating temperature: 0 to 40°C (32 to 104°F)
- Transmitter power (EIRP): 2.4 GHz: < 20 dBm (CE/MIC/KCC): 5.8 GHz: < 26 dBm (FCC/SRRC/NCC)
- Image Position Compensation: The relative positions of the CMOS center of the six cameras and the phase center of the integrated D-RTK antenna calibrated and recorded in the EXIF data of each image.

Camera:

- Format(s): JPEG photo (visible light imagery) + TIFF (multi-spectral Imagery).
- Operating Temperature: 0 to 40°C (32 to 104°F)
- Max image size: 1600x1300 (4:3.25)
- Shutter speed 1/100 -1/20000 s (visible light imagery): 1/100 -1/10000 s (multi-spectral imagery)

2.2 Result

The first preliminary results obtained concern the analysis of data from the harvested olive samples in order to evaluate the maturity index and specific weight according to the methodology presented above. The results concerning the quality of the extracted oil and the analysis of the data from the UAVs will be carried out in the coming months.

Maturity index

The calculation of the maturity index of olives according to the method of Ferreira [17] has noted that it has increased from 0.3 between the first tour of 18/10/2022 which means that the majority of olives are still green to 4.3 on 02/12/2022 which implies a high maturity of olives.

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Figure 7: Olives simples used for maturity index and specific weight calculation.

The following graph shows the distribution of the sample of 100 olives between the 8 predefined classes. We can clearly see the evolution of the maturity of the olives from the dominance of the dark green class at the beginning of the period to the almost absence of this class at the end of the period (02/12/2022) to find black olives in majority in the last week of harvest. According to the results, we can define the optimal period of harvest according to the index of Ferreira during the last two weeks of November. This is not necessarily the case over several years because the environmental conditions change and can influence the period of maturity in relation to the temperature and rainfall of each year.

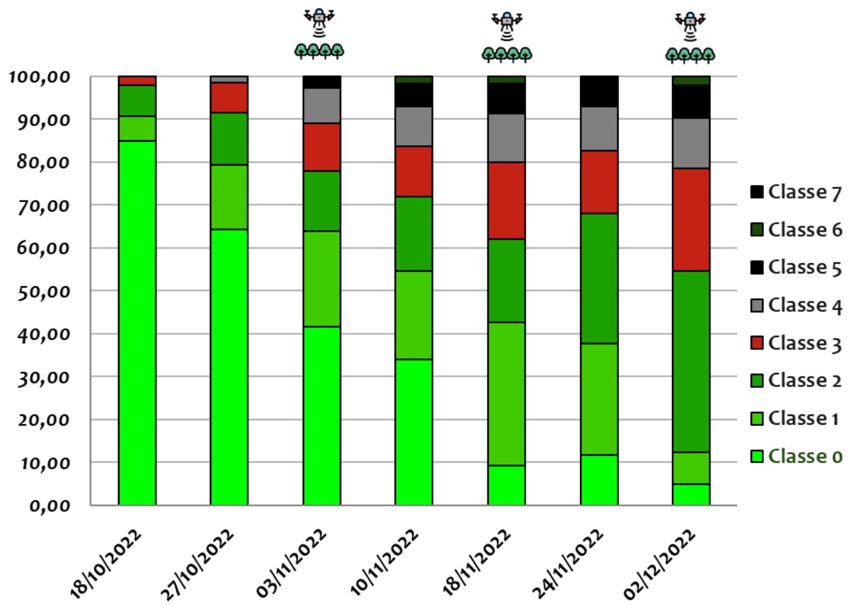

Figure 8: Olives classes evolution at different stages of maturity from 18/10 to 02/12/2022

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Specific weight

Concerning the specific weight or the evolution of the weight of the olives according to the age, we used the same sample to measure the weight of 100 olives for the 7 weeks studied. The results show a significant evolution of the weight of the olives during the first 3 weeks to pass from 254g for the first week, that is to say the 18/10/2022 to 348g during the last week of 02/12/2022, that is to say an increase of 37% of the specific weight. These results show the importance of this phase in the maturity of olives and allows to link the maturity of the fruit to its size. Indeed, according to the graph below we note that the specific weight of olives to increase significantly during the first four weeks of harvesting samples until 10/11/2022 to stabilize around 348g/100olives during the next 3 weeks.

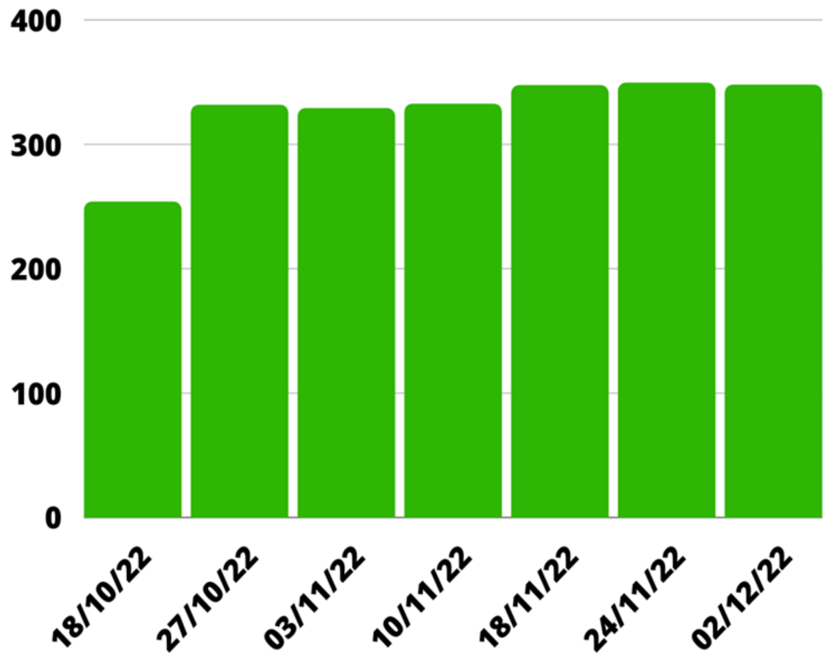

Figure 9: Average weight of 100 Olives at different stages of maturity from 18/10 to 2/12/2022

The results obtained in this part, combined with the results of chemical and sensory analysis of olive oil obtained for the 50Kg harvested for each period, will serve as a basis for the calibration of the model for assessing the maturity of olives through drone images. Below is a picture of the drone collecting a scene between the lines of the experimental orchard.

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Figure 10: Drone collecting data between olives trees lines at the experimental field.

2.3 Main results

a. Improving the production of olive oil in quality and quantity by less than 20% compared to the current situation, taking into account the possibilities of reducing the losses of olives at harvest. Improvement of farmers' income through the production of a better quality olive oil in relation to the maturity of the olives.
.
b. Cost reduction of the production and more sustainability of regional agriculture considering resources scarcity and climate changes effects. Increase of farmer's income.

3. Risks and mitigation measures

The main risk is related to the use of the smartphone and the interpretation of the recommendations provided to farmers on optimal harvest period (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 harvest period.

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:

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- Reduction of the olive harvesting losses by 10-15% and improvement of the quality of the olive oil produced: as far as the applied technology is concerned, it is expected that the knowledge and ability of the farmers to detect the optimal olive harvesting period through the use of the mobile application will be improved.

At the overall regional level, it is expected that the olive tree will be better valued as an important crop for the area and that it will be better integrated into the regional agricultural production system. For the quality component, the improvement in the quality of olive oil should result in better availability for the end consumer.

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

- PPI-LT: 10% increase of small farmers and SMEs' income through increase in production quality (average).

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

5. Objectives and description of the innovation

A fruit picker has been designed. Materials were selected based on the expected prototype properties, processing, design and intended environment. The fruit picker will be light enough and adjustment to pick the fruit while maintaining their quality. The pole will be flexible to be connected in series and adjustable to allow harvesting/picking of fruits at various tree height. The safety of farmer will be a priority consideration. The tool shall be simple to use and move around while in operation.

The overall objective is to design and fabricate a safe fruit picker that maintains the fruit quality.

The specific objectives are to:

i. Design and fabricate a fruit picker.
ii. Demonstrate the operation of the fruit picker in Kitui Food Hub;
iii. Assess technology acceptance of the fruit picker in Kitui Food Hub; and
iv. Analyse the economics of investing in a business for commercial production of the fruit picker.

The fruit picker has the following components:

1. Fang like hook for dislodging the fruit from the branch 20 cm in length, hook cut on one up to 5cm, welded at 10cm - 13cm, holes drilled at 14cm and 18cm for fastening nuts and bolts. Bolts and nuts will be used for easy operation and maintenance
2. Ring to hold the fang hook, handle and support tunnel tube with the following parameters: Diameter: 15cm, Circumference = 47.14cm and rounding upwards to 50cm
3. Adjustable handle to be able to reach the whole tree irrespective of its height
4. Backpack with substantial volume to hold the fruit as it's harvested before it's packaged. The recommended weight of the full backpack is 15% - 25% of a person’s body weight.

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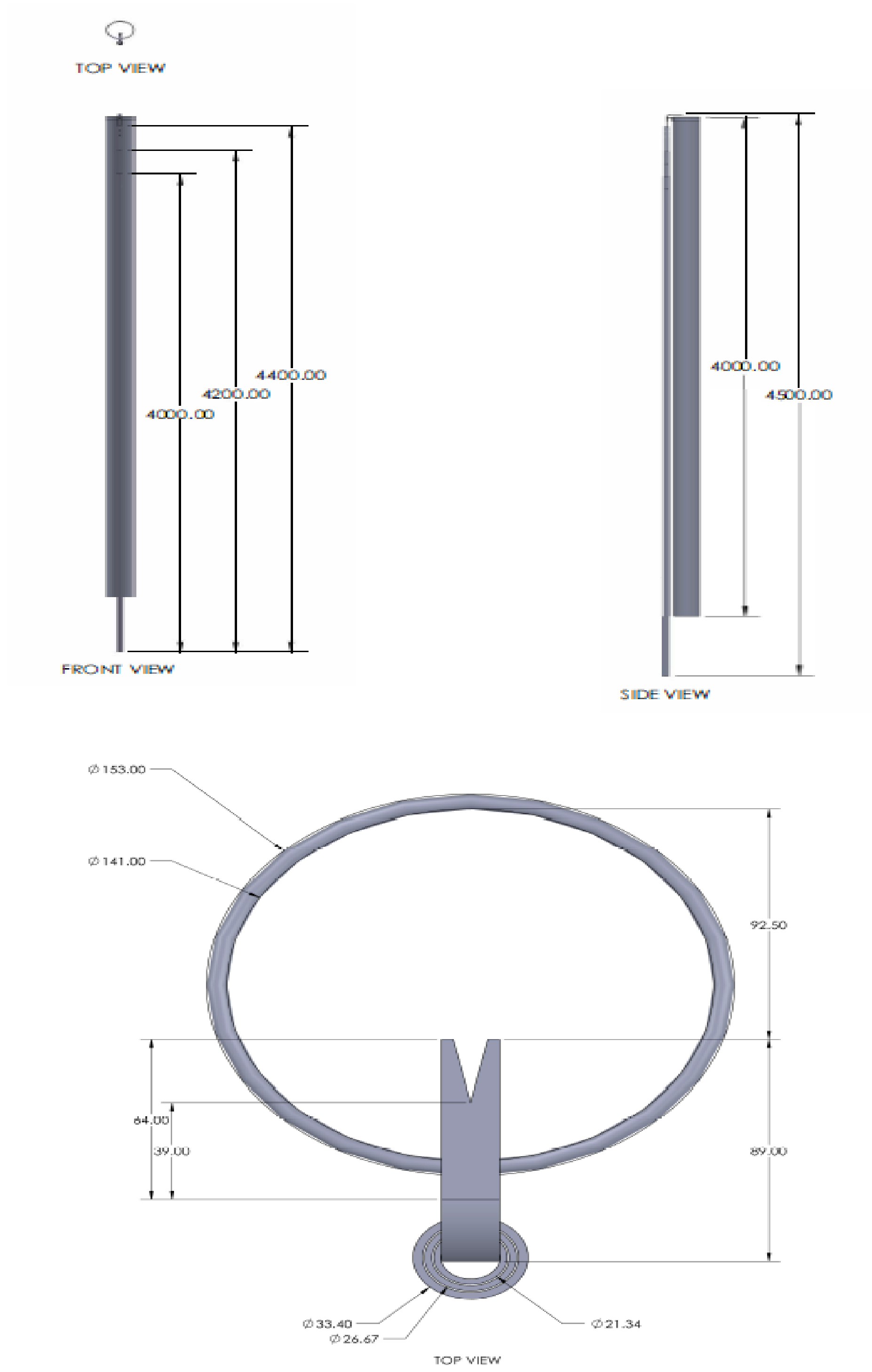

Figure 11: Fruit Picker (Dimensions are in mm)

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6. First Field Tests

Small scale field test shall be carried out. The current methods of harvesting fruits from trees which include; manually shaking the trees, climbing the trees, and employing makeshift pickers constructed from scrap materials will be used. The constructed fruit picker will be used to harvest fruits and compared in terms of physical quality and ease of harvesting.

7. Design Consideration for Fruit Picker

The design of this equipment was necessitated by these challenges. The following specifications for the final design were discussed during brainstorming sessions as well as literature review:

- The fruit picker should be light in weight.
- Mobility; the tool should be simple to use and move around while in operation
- Simplicity; the picker should be simple to operate,
- Safety elements should be incorporated into the design.
- Durability: The equipment should be able to survive challenging circumstances like weather, age, and incorrect use.
- Cost: It ought to be reasonably priced

8. Technology and Production Key Performance Indicators to be gathered

- Design of the Fruit Picker;
- Construction of the Fruit Picker prototype;
- Demonstrated good performance in fruit picking;
- Technology acceptance in Kitui Food Hub; and
- Profitability of investing in an enterprise producing the fruit picker.

9. Work plan

Activity No.	Activity	2023				2024				Comment (If any)
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
1	Construction & Testing of Fruit Picker									
3	Validation activities									SME and Kitui Food Hub

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4	Economic analysis									

10. Risks and Mitigation Measures

The risk is unavailability of fruits when field work is supposed to be done. The mitigation measure is to plan for validation work only when the targeted fruits (mangoes) are in season.

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