Romanian Journal of Ecology & Environmental Chemistry, 5(2), 2023
https://doi.org/10.21698/rjeec.2023.213

Proceedings of the 26th International Symposium "The Environment and the Industry" (SIMI 2023), 27-29 September 2023

Minimizing food loss and repurposing waste within the viticulture industry

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Received:	Accepted:	Published:
31.08.2023	18.12.2023	20.12.2023

Abstract
The global issue of Food Loss and Waste (FLW) is gaining increased attention from both academic and policy circles. This challenge is progressively spreading, particularly in less developed and developing nations. This article aims to address the FLW concern within grape cultivation, proposing solutions for repurposing leftover materials from the crop. The paper will depict the current understanding of FLW, outline the supply and value chain of grape crops, and conduct an intricate analysis of production quantities, imports, exports, and processing. The study draws from the IPSUS project's research, which explores techniques for reclaiming plant and seaweed proteins through recycling raw materials. Additionally, it will explore the potential for upcycling and assess the quantity and quality of FLW at various points along the value chain. To evaluate FLW in viticulture, an IoT system will measure environmental parameters like air temperature, humidity, soil moisture, and precipitation. These measurements will help estimate harvest quality and quantity, pivotal aspects within the context of food loss and waste. The outcomes of this research will underscore the significance of repurposing grape crops, opening novel avenues for agricultural advancement in Romania.

Keywords: *FLW, grape crop, recycled plant, supply chain, value chain*

INTRODUCTION

According to the Food and Agriculture Organization of the United Nations (FAO), about 32% of global food production in recent years has been either lost or wasted. This translates to roughly 24% of the world's food output being lost or wasted when measured in terms of calories. Consequently, only one out of every four calories in food intended for human consumption is actually ingested.
The FAO provides a definition for food loss, which pertains to a reduction in the quality or quantity of food due to the functioning of the food production and distribution system, as well as its institutional and legal framework. Within this framework, the FAO distinguishes food waste as a specific aspect of food loss. Qualitative Food Loss and Waste (FLW) denotes changes in food characteristics that diminish its suitability for its intended purpose, whereas quantitative FLW pertains to food that is lost within the food supply chain. Food losses are typically observed across the entirety of the food supply chain, from the point of harvest up until but excluding the point of sale. Conversely, food waste takes place at the stages of sale and consumption [1].
The incentives, economic context, and fundamental drivers of stakeholders within the food supply chain differ when addressing the matter of food waste as opposed to unintended food loss. It's possible to differentiate between preventable and inevitable food waste. Preventable food waste encompasses items that are disposed of due to surpassing the labeled "best before" date. Inevitable food waste pertains to the disposal of inedible components of various foods, such as peels of fruits and vegetables, eggshells, and the bones of fish and animals [2].

The problem of food loss is a significant global concern. About 815 million individuals lack adequate food to fulfill their daily nutritional requirements, which accounts for approximately one-eighth of the current global population. Roughly one-third of all food produced for human consumption is lost or squandered annually. Food waste is garnering increasing attention from policymakers at the European, national, and local levels, as well as from a range of international organizations, non-governmental organizations (NGOs), and scholars across diverse disciplines [3].
Food loss and waste give rise to diverse adverse effects on both the economy and the ecosystem. They represent an economically inefficient expenditure that could lower farmers' earnings and increase expenses for consumers. Furthermore, food loss and waste exert several detrimental influences on the environment, encompassing insignificant emissions of greenhouse gases and inefficient utilization of water and land resources. Over time, these repercussions can lead to the degradation of natural habitats and the degradation of the services they offer [4].
A frequently mentioned approximation suggests that approximately one-third of the world's total food production is either lost or wasted. The anticipated economic impact of global Food Loss and Waste (FLW) exceeds $1 trillion annually. These figures highlight significant inefficiencies within the global food network, leading to substantial environmental, economic, and societal consequences, despite ongoing discussions surrounding the theories, methodologies, and data supporting these approximations [5].
The process of food production consumes a substantial share of resources, utilizing 20% of the Earth's surface, 70% of the planet's freshwater resources, 32% of the global energy supply, in addition to other necessary inputs. This production also generates solid waste, emissions of greenhouse gases (GHGs), and various pollutants. Consequently, minimizing Food Loss and Waste (FLW) presents significant benefits. The heightened attention on FLW has been fuelled by persistent concerns regarding global food security, which have been exacerbated by increasing food demand and the potential disruptions to the food supply due to the impacts of climate change [6].
This paper is grounded in the research conducted as part of the IPSUS project (Climate-smart food innovation using plant and seaweed proteins from upcycled sources). This project focuses on exploring methods to extract plant and seaweed proteins from repurposed raw materials that would otherwise contribute to the approximately 1.6 billion tonnes of annual global food loss and waste. The study investigates six protein sources (pumpkin, grape, brewer's spent grain, potato, hazelnut, and seaweeds). Within these supply chains, the examination encompasses the volume, quality, and potential for upcycling of food loss and waste. Additionally, the work of this paper has been influenced by the U-GARDEN project, which promotes the incorporation of urban gardens and agroforestry experiences as fundamental elements within the strategic framework for sustainable urban development in European cities.
As this paper further unfolds, it's noteworthy that the wine industry presents a notable example of waste generation, prompting exploration into sustainable solutions such as composting. The following discussion will delve into the environmental and agricultural benefits of composting wine production residues, especially within vineyards that grapple with challenges like soil degradation, biodiversity loss, and water scarcity in the context of climate change.
The High-Level Panel of Experts on Food Security and Nutrition takes a unique approach to distinguish between food loss and waste. Food waste is associated with consumer behaviours and practices, while food losses can occur at any stage prior to reaching the consumer. Therefore, the concept of 'food loss and waste' encompasses the entire spectrum, from harvesting through consumption or removal from the food distribution system [7].
The wine sector produces a substantial volume of waste material. Utilizing composting as a method to recycle the remnants resulting from the wine production process offers advantages both in terms of agricultural productivity and environmental impact. Particularly in Mediterranean regions, vineyards encounter notable threats to soil health, including the depletion of organic matter, biodiversity decline, erosion, contamination from fertilizers, and compaction. Additionally, the looming impact of climate change signifies reduced water availability, which will exacerbate the occurrence of heightened heat and drought conditions within vineyards [8].

The quality of wine is influenced by the nature of the soil in which the vineyard is situated. Contemporary investigations have explored the potential of integrating compost into vineyards to mitigate the vulnerabilities posed by extended drought periods and soil degradation. Numerous research endeavors have delved into the outcomes of compost application to grape pomace and stalks. The findings of these studies have demonstrated that composting contributed to a reduction in bulk density, a metric indicative of soil compaction, with recorded decreases ranging from 2% to 10% [9].

The rise in consciousness regarding Food Loss and Waste (FLW) commenced with a handful of publications that elevated the significance of the issue. A byproduct known as grape pomace emerges predominantly during wine production. Within this byproduct, essential nutrients are found, and it has been effectively incorporated into diverse food items spanning plant-based, meat, fish, and dairy products. Grape pomace is particularly rich in dietary fibber and polyphenols, constituting the principal bioactive components. These compounds serve as fortification elements when integrated into food products. Incorporating grape pomace into various foods led to an elevation in overall polyphenolic content, yet it also resulted in modifications to the color of the fortified items. The fortification of food with grape pomace further boosted oxidative stability and extended the shelf life, particularly evident in meat and fish products. Nevertheless, heightened concentrations of grape pomace negatively impacted the texture and sensory attributes of the fortified foods. The review reasserts the favourable influence of grape pomace on a range of food items, though it underscores the necessity of conducting distinct sensory assessments for each specific food product before implementing fortification [10].

The main ways for reusing grape pomace are covered in a recent publication. These include the use of grape pomace in traditional methods (such as ensuring distillates, feed for animals, soil fertilizer), as a technological support in various industrial processes (such as adsorption, immobilization, cosmetics), added to food products, with potential effects on the physicochemical, functional, and sensory qualities of these products, and as a raw material for the production of bioenergy [11].

Various techniques are employed by the grape pomace processing industries, including the extraction of anthocyanins for use as food colouring agents and the extraction of grape seed oil using organic solvents. The obtained products are utilized in the food, pharmaceutical, and cosmetics industries for various technological applications or as functional ingredients [12, 13].

Additionally, grape pomace is a polluted waste that is usually thrown away in landfills, where it contaminates water and prevents plant growth. The goal of a current study was to use white-rot fungus and a solid-state fermentation bioprocess to transform this abundant biomass into a feed that is suitable for ruminants. Research results demonstrated that lignin and condensed tannin content were decreased and crude protein and mineral content were increased when grape pomace was fermented with white-rot fungi [14].

MATERIALS AND METHODS

Biomass stands as the planet's most prolific renewable asset, encompassing all organic material resulting from the metabolic activities of living organisms. Since the inception of fire, biomass has served as humanity's earliest energy source [15].

The forms of biomass energy recovery currently used are:

- Chemical conversion of vegetable oil-type biomass by treatment with alcohol and generation of esters, e.g. methyl esters (biodiesel) and glycerol. Purified biodiesel can be burned in diesel engines.
- Pyrolysis combustion with the generation of syngas (CO + H2)
- Enzymatic degradation of biomass to ethanol or biodiesel. Cellulose can be enzymatically degraded to its monomers, carbohydrate derivatives, which can then be fermented to ethanol.

- Fermentation, with the generation of biogas (CH_4) or bioethanol (CH_3-CH_2-OH), in the case of fermentation of sugar products. Biogas can be burned directly and bioethanol, mixed with petrol, can be used in internal combustion engines.
- Direct combustion with heat generation

Biomass extraction varies based on the origin of the organic material and its intended application. It can be sourced from primary remnants of agricultural harvests or timber products, secondary leftovers emerging once a biomass product is utilized, or residual elements from forests that are no longer viable for industrial or commercial use.

As a result, repurposing grape pomace serves a dual purpose: generating methane gas and mitigating the potential contamination of soil, surface water, and groundwater by leachate. Grape pomace, a byproduct stemming from grape processing in winemaking (see Figure 1), is a prime example of this practice.

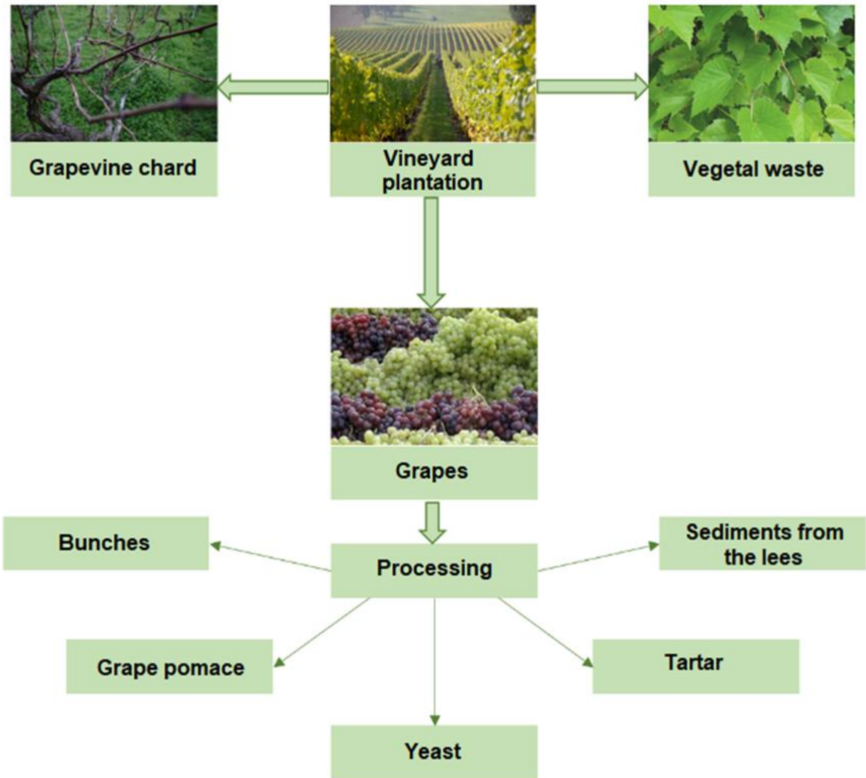

Fig. 1. Food losses in the winemaking process

Grape pomace is a heterogeneous solid amalgamation predominantly comprised of skins (constituting 63%), seeds (comprising 33%), as well as other fractions and remnants of pulp. For every 6 litres of wine produced, it is estimated that one kilogram of grape marc is generated, which can be further used to produce other alcoholic drinks. Grape pomace holds the potential for various applications, such as the extraction of oil, antioxidants, and antimicrobial agents. Notably, its key constituents are polyphenolic compounds. These bioactive elements lingering within plant tissues encompass phenolic acids, diverse flavonoids, flavonols (like catechin, epicatechin, and epigallocatechin), and other phenolic compounds such as proanthocyanidins or condensed tannins.

Red grape variety grape pomace has found application in anthocyanidin recovery, which is sanctioned for use as food colorants. Owing to its valuable chemical composition, grape pomace offers diverse avenues for exploitation, encompassing the creation of animal feed, the generation of composts and bio-posts to enrich organic soil, the extraction of bioactive compounds for deployment in the pharmaceutical and cosmetics sectors, the development of energizing dietary supplements for young athletes, and more. The polyphenolic potential harbored within grape pomace is contingent upon various factors, including the inherent qualities of the grape variety, the geographical production locale, the vintage year, and the techniques employed in grape processing.

The market for grape seed oil, derived from the recuperation of wine-related waste, is comparatively narrower than that of "conventional" oils like sunflower and olive oils. To produce a sole bottle of wine, approximately 1 kilogram of grapes is required. After processing, a quarter of the weight transforms into waste material, while grape pomace has limited applications, being mainly used as agricultural fertiliser, animal feed or disposed of as food waste [16].
Waste generated during the winemaking process has the potential to significantly impact the environment, particularly due to the fermentation procedures it goes through. Contrarily, a distinctive scenario unfolds in grape processing facilities, where endeavours are directed towards recycling wine-related waste. However, this endeavour is hampered by the substantial volume of waste generated. Upon careful examination of this challenge, a decision was reached to explore an alternative approach for managing grape pomace – specifically, the extraction of grape seed oil.
The grape seed oil production process is divided into three stages.

- The initial phase involves the collection of grapes from the vineyards and their subsequent processing to extract the essential juice required for wine production. Following the extraction of juice, the residual pomace becomes the focal point of the subsequent stage.
- The subsequent phase encompasses the drying of the marc and the meticulous sorting of the retained grape seeds.
- In the final phase, the emphasis shifts to extracting and refining oil from the previously dried and sorted grape seeds.

Once the oil extraction process concludes, the resultant oil undergoes storage, bottling, and extensive examination in multiple laboratories to ensure its quality meets the requisite standards. Following the processing of approximately 35 tonnes of pomace, the outcome yields approximately 260 kilograms of oil, equivalent to 20,000 bottles. The residual materials remaining post-oil extraction are repurposed and distributed to livestock farmers as supplementary feed [17, 18]
In this study, our fundamental objective is to develop effective strategies to reduce food loss and waste in the wine industry. To this end, we adopted an innovative technological approach by implementing an IoT (Internet of Things) system for vineyard monitoring. This advanced system aims to help significantly reduce Food Loss and Waste (FLW) by providing accurate, real-time data to enable informed decision-making and optimization of the entire viticultural process.
By integrating IoT technology into viticulture, we aim to quickly identify and address critical factors that lead to food loss and waste. The IoT monitoring system collects and analyses essential data related to climatic conditions, soil moisture, plant development stage and other key parameters (Figure 2). This information, when properly collected and interpreted, provides a deeper understanding of viticultural processes and potential FLW vulnerabilities.
An essential component of our IoT system is sensors placed at various critical points on the vine. These sensors provide real-time data about the state of the plants and the surrounding conditions.
The structure proposed in this work was designed to be modular, opening the way for future improvements and expansion without requiring substantial modifications to existing elements. The proposal manages to successfully integrate hardware components with corresponding software, resulting in outstanding performance in terms of transferring sensor-captured data to the real-time visualization platform.
The architecture of the platform involves the use of remote monitoring and sensing devices to gather information about vineyard crops. These devices include sensors that monitor soil temperature and humidity, solar radiation and key weather parameters.
To facilitate communication between the sensing devices and the other components of the platform, network devices such as communication modules and the Gateway are used. These allow data to be transferred over variable distances, whether short or long. To ensure efficient data transmission, communication technologies such as Wi-Fi and 3G/4G are used and the transmission process is optimised through software routines.

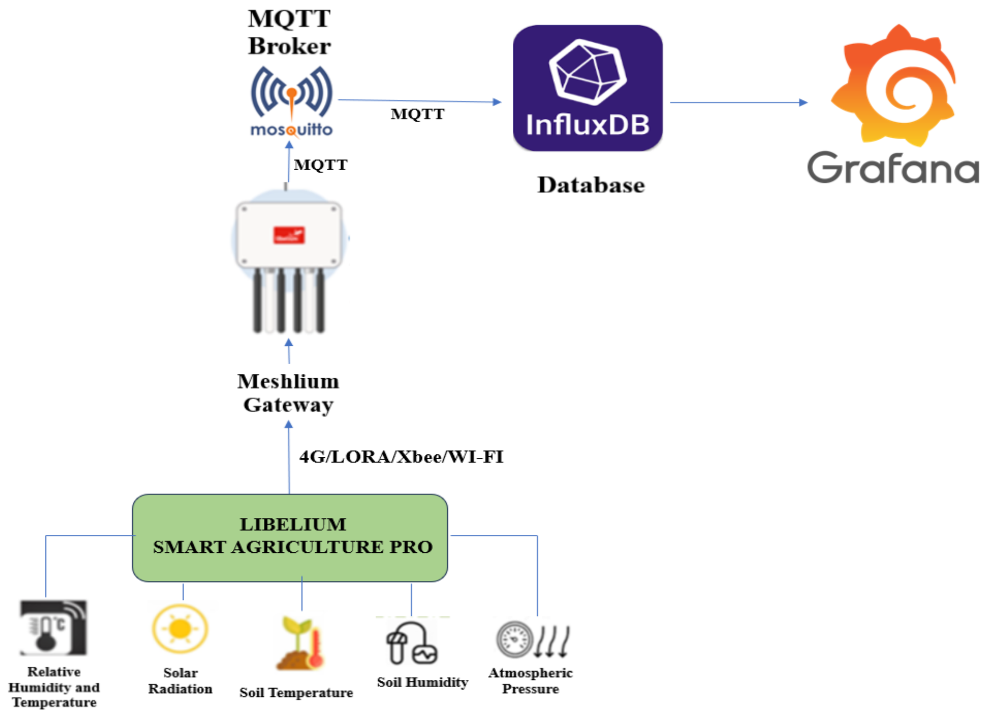

Fig. 2. IoT system architecture

Data captured by sensors is routed to a central unit via a network protocol called MQTT (Message Queuing Telemetry Transport). Here, this data is stored in a database and processed for further use. The choice of the MQTT protocol, characterised by simplicity and efficiency, allows data to be transferred without requiring significant resources from the IoT platform [19].

Within this presented system, InfluxDB was the optimal choice to serve as a database, motivated by the multiple advantages it offers. This system is specifically optimised for storing time series data, with outstanding performance in both writing and reading information. In addition, it offers efficient horizontal scalability and supports advanced queries. These fundamental features ensure effective management of Internet of Things (IoT) data, facilitating successful development, monitoring and analysis of the entire solution.

The visualisation platform created allows users to access data in graphs or tables, apply mathematical formulas to graphs and set up alerts. In this context, the choice of the Grafana platform was justified. With this platform, data can be extracted from the database and analysed in terms of its evolution over time (Figure 3).

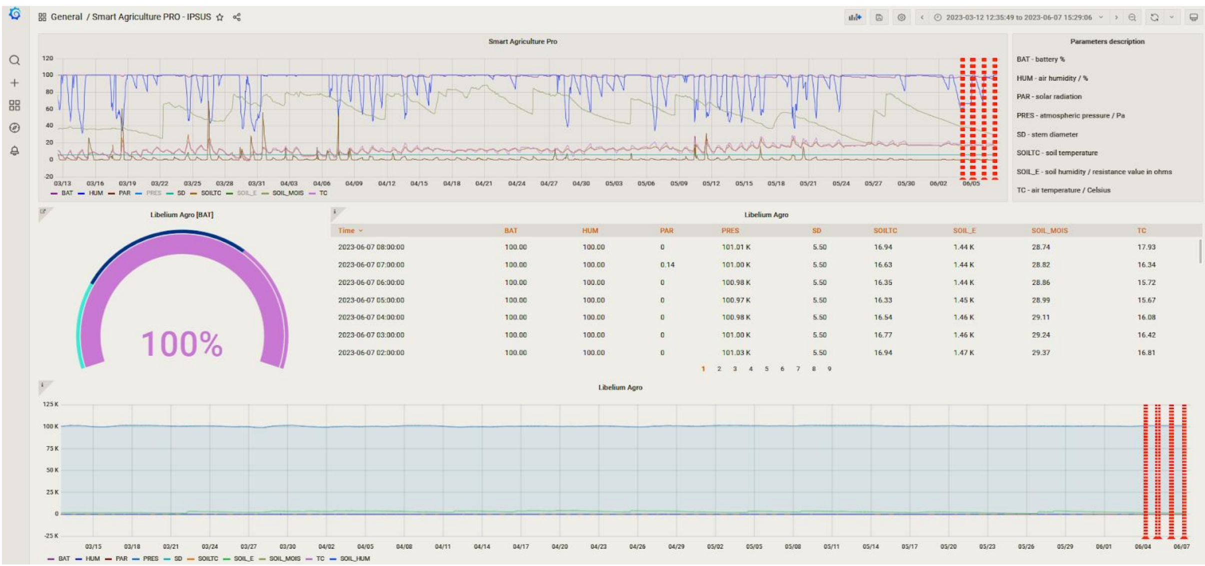

Fig. 3. Grafana dashboard

RESULTS AND DISCUSSION

In 2020, Romania produced 3.8 million hectolitres of wine. The total area of vineyards cultivated at national level continued to decrease in 2021, reaching 179.3 thousand ha (Figure 4). Vineyards underwent restructuring and reconversion processes, assisted with European funds from the national support programme allocated to Romania (€47.5 million, annually, in budget year 2019-2023)

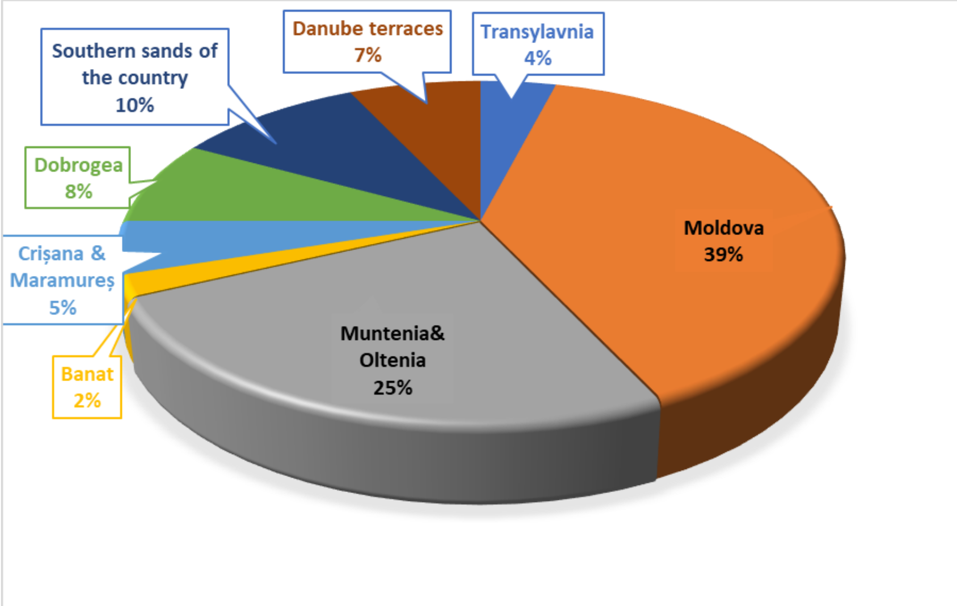

Fig. 4. Wine-growing area in 2021

Exploring the variety of ecoclimatic conditions in Romania, we observe a significant diversity in the ripening period of grapes. These differences are profoundly influenced by ecoclimatic factors such as altitude, sun exposure, land slope and even available water resources. For example, a similar grape variety can reach maturity up to 4÷5 weeks earlier in Giurgiu County compared to Cluj County [20]. These ecopedological variations can lead to early or late ripening of grapes. However, despite these discrepancies, the specific ecological conditions, the cultivated varieties, the technologies used and the quantity and quality of grapes vary substantially between the different viticultural regions. However, in general terms, each wine-growing region can be considered as a distinct habitat with similar characteristics in terms of ecological conditions, variety assortment and vine care and wine production techniques.

Moving from the eco-climatic to the technological field, we enter the sphere of innovative solutions brought by Internet of Things (IoT) technology to the wine industry. Our IoT vineyard monitoring system, equipped with a variety of environmental sensors, is an effective response to Food Loss and Waste (FLW) challenges. Collecting data from these sensors provides an in-depth understanding of the vineyard environment, which underpins informed decisions to reduce food loss and waste. Constant monitoring and detailed analysis of this data forms the basis of a proactive approach to mitigating yield losses and increasing the efficiency of the entire viticultural process.

Therefore, by constantly monitoring air and soil temperature and humidity, we can identify significant variations that could indicate the risk of disease or plant stress (Figure 5). This allows growers to intervene quickly by applying appropriate treatments or adjusting irrigation levels, thus preventing significant damage and reducing production.

Soil moisture and soil temperature are of crucial importance in proper irrigation management (Figure 6). By monitoring soil moisture, we can avoid over-irrigation or under-irrigation, both of which can cause significant yield losses. Soil temperatures can also affect plant roots and therefore plant growth. Adjusting temperatures can help maintain an optimal growing environment for plants.

Solar radiation information can influence the optimal time for harvesting and handling grapes (Figure 7). Excess or lack of exposure to solar radiation can affect the ripeness and composition of the grapes, with a direct impact on the quality of the wine produced.

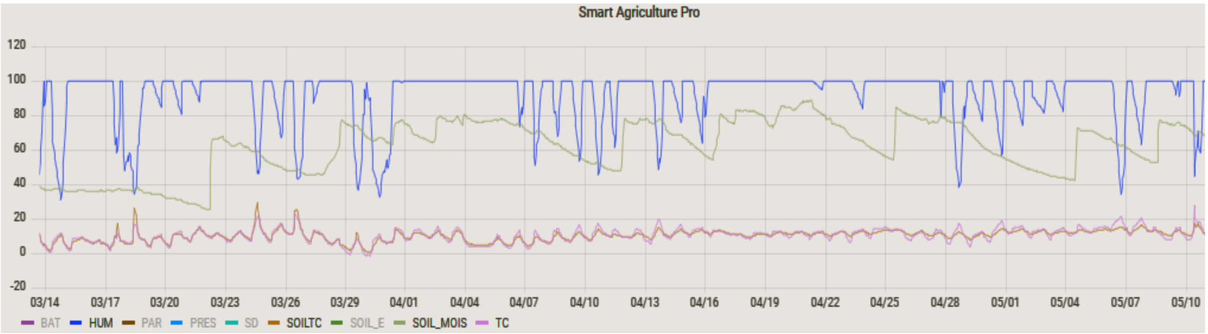

Fig. 5. Air and soil monitoring

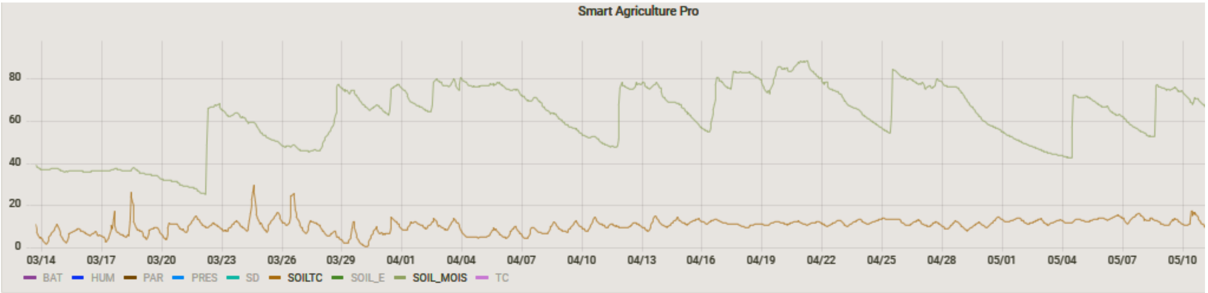

Fig. 6. Soil moisture and temperature monitoring

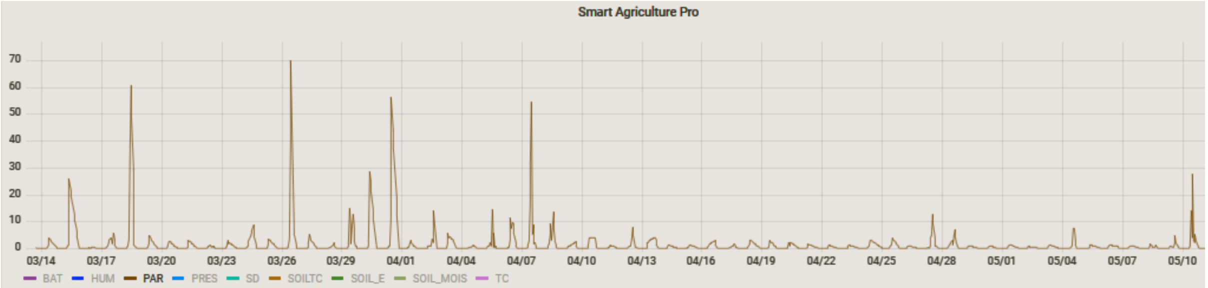

Fig. 7. Solar radiation monitoring

By analysing these parameters in real time, growers can make more informed and faster decisions, preventing situations that can lead to FLW. For example, adjusting irrigation according to soil moisture levels or applying treatments at the right time to prevent the development of diseases can significantly contribute to reducing crop losses.

CONCLUSIONS

Food Loss and Waste poses a global predicament that is rapidly proliferating, with its repercussions more pronounced in less developed nations. This article is specifically centered on addressing Food Loss and Waste within the viticulture sector, proposing solutions for repurposing the byproducts of the wine production process.

Biomass, the planet's most abundant renewable asset, is currently subject to diverse forms of energy reclamation. Within this context, reutilizing grape pomace emerges as a method to generate methane gas and mitigate pollution risks. Grape pomace boasts a versatile spectrum of applications, encompassing the generation of animal feed, the acquisition of composts and bio-posts for enriching organic soil, the extraction of bioactive compounds for use in pharmaceuticals and cosmetics, and the production of dietary supplements.

While waste stemming from winemaking can significantly jeopardize the environment, the extraction of grape seed oil emerges as an alternate means of grape pomace processing. Furthermore, grape pomace can function as a substrate for the generation of microbial protein, emerging as an alternative protein source for animal feed or human consumption. In sum, the research outlined in this paper underscores the vital significance of biomass repurposing and introduces fresh avenues for progress within Romania's agricultural sector.

In this context, Internet of Things (IoT) technology is proving to be a powerful ally in the fight against food loss and waste. Our IoT vineyard monitoring system, equipped with diversified environmental sensors, provides the necessary tools for detailed understanding of vineyard environmental conditions. This data provides the foundation for informed decisions, resulting in a significant reduction in food loss and waste. By taking a proactive approach and carefully analyzing the data collected, it paves the way for more sustainable and efficient wine production.

ACKNOWLEDGEMENTS
This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI – UEFISCDI, project number 302/2022 for IPSUS and project number 294/2022 for U-GARDEN.

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Citation: Streche, R., Orza, O., Bosoc, S., Dobre, C., Danila, A., Carp, L., Suciu, G., Minimizing food loss and repurposing waste within the viticulture industry, *Rom. J. Ecol. Environ. Chem.*, **2023**, 5, no. 2, pp. 128-137.