MISAR in Enhancing Agricultural Resilience: A Comprehensive Approach to Climate Change Risk Management for Mango Farms in Sicily, Italy

Mohsen Pourmohammad Shahvar[1], Dario Scuderi [2], Davide Valenti[1], Alfonso Collura[3], Salvatore Micciché[1], Vittorio Farina [2], and Giovanni Marsella[1]

[1] Dipartimento di Fisica e Chimica "E. Segrè", Università degli Studi di Palermo, Italy.
[2] Dipartimento di Scienze Agrarie, Alimentari e Forestali, Università degli Studi di Palermo, Italy.
[3] Istituto Nazionale di Astrofisica, Osservatorio Astronomico di Palermo, Italy

ABSTRACT

Agriculture plays a crucial role in the economy of Italy, particularly in the region of Sicily where it serves as a primary source of income. To ensure high yields, it is essential to enhance farmers' knowledge and awareness, especially in mitigating potential risks and damages caused by climate change and managing farming processes such as soil and water preparation, fertilizer, and pesticide management. To follow the MISAR (Climate Change Risk Management by Improving the Individual and Social Awareness of Risk in Sicily) targets, this paper focuses on the importance of Information and communication technologies (ICT) in the "Mango Farms Risk Management Plan" to foster stronger connections between stakeholders and farmers in Messina. Climate change poses various hazards such as temperature fluctuations, extreme events, soil salinity, and irregular rainfall, which are expected to increase in the future. Effective decision-making for stakeholders and farmers requires efficient analytical tools, particularly for handling large datasets. The paper introduces a new architecture called ADM, which combines Decision Support Systems (DSS), Agent-Based Modelling (ABM), and Machine Learning (ML) methods to develop a comprehensive risk plan for future agricultural challenges. The ADM model in MISAR incorporates empirical information collected during the ML phase, including the reactions of Mango plants to risks and determining factors like extreme temperature changes. To promote and safeguard mango cultivation and production, changes in temperature are estimated using advanced techniques such as Random Forest and Feed-Forward Neural Networks. Weather stations equipped with meteorological sensors are strategically placed within farms, providing direct measurements of hazards. Each station has its own credentials, allowing farmers access to the data. Furthermore, historical data analysis considers data from municipal meteorological stations and satellite sources. The model facilitates mutual communication between decision-makers and farmers, enabling farmers to monitor forecasts and report unexpected events in their respective farm areas.
Keywords: MISAR, Machine Learning, Artificial Intelligence, Mango, Agriculture, Decision Support System, Agent-based Modelling, Random Forest, Feed-forward neural network.

INTRODUCTION

The MISAR (Climate Change Risk Management by improving the Individual and Social Awareness of Risk in Sicily) project is built upon a comprehensive research framework, utilizing the latest advancements in risk analysis, modelling techniques, behavioural theories, and social sciences. Its main aim is to enhance resilience against climate change impacts. This objective is well-articulated by Shahvar et al. (2022).

Central to the MISAR project is a deep understanding of how climatic variables affect crop growth and yield, as discussed by Normand et al. (2015). The threat of rapid climate change is significant, with potential repercussions for both society and the natural environment, underscored by Shahvar et al. (2022). Given the agricultural sector's vulnerability to climatic shifts, it's crucial to address these looming challenges proactively.

Mango, prized for its economic and nutritional value (FAO, 2022, 2023), emerges as a crucial crop within this context. *Statista's*[1] data for 2021 ranks mango as the sixth most-produced fruit globally, accentuating its significance in the agricultural landscape. Sicily, with its unique climatic conditions, including an average temperature that rarely dips below 10 °C for eight months a year and minimal lows of 6 °C during the coldest periods (Gugliuzza et al., 2023), is home to approximately 55 hectares of mango orchards along its coastal regions ("Department of Sicilian Agriculture," 2017). These areas benefit from well-draining soils and natural windbreaks like cypress trees, creating an ideal environment for mango cultivation. Various mango varieties, such as *Kensington Pride, Keitt, Glenn, Maya, and Tommy Atkins*, thrive in this setting, displaying a wide range of fruit weights (Farina et al., 2013; Gentile et al., 2019).

MANGO CULTIVATION MANAGEMENT BY USING ICT

Mango cultivation along coastal regions faces a multitude of challenges, primarily stemming from the dynamic and ever-changing climate conditions that originate from both land and sea (Farina et al., 2020). To effectively address these challenges and optimize mango cultivation, the integration of cutting-edge Information and Communication Technology (ICT) solutions has become a game-changer in this field.

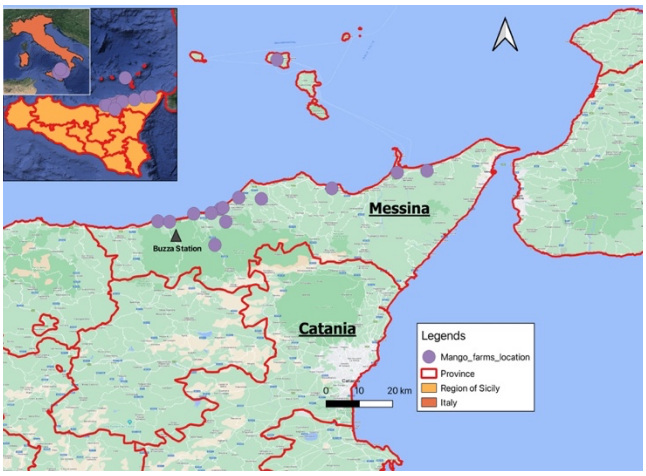

Figure 2 Case Study Area

Figure 1 Risk Map

CHALLENGES OF COASTAL MANGO CULTIVATION

1. Saltwater Intrusion

Rising sea levels due to climate change have led to saltwater intrusion into the soil, posing a direct threat to land quality (Tarolli et al., 2023). Mango trees are highly sensitive to high salinity levels, which can impede their growth and productivity (Gentile et al., 2019).

2. Storm Surges and Flooding

Coastal areas are more vulnerable to storm surges and flooding (Saleh et al., 2022), both of which can cause significant damage to mango orchards and uproot trees. The increasing frequency and intensity of storms due to climate change amplify the risks faced by mango cultivation in these regions (Asare-Nuamah et al., 2022).

3. Strong Winds

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[1] https://www.statista.com/statistics/264001/worldwide-production-of-fruit-by-variety/

Coastal areas are often subjected to strong winds that can break branches or uproot mango trees. With climate change contributing to more severe weather events, the risk of wind damage to mango orchards is on the rise (Farina et al., 2017).

4. Increased Temperatures

Climate change can result in higher temperatures that may exceed the optimal range for mango cultivation. Extended periods of extreme heat can stress the trees, negatively impacting fruit development and yield (Gugliuzza et al., 2023).

Figure 3. Cupitur Orchard: Thriving amidst the Coastal Challenges in Messina

LEVERAGING INFORMATION AND COMMUNICATION TECHNOLOGY (ICT)

ICT solutions offer a robust approach to address the challenges of coastal mango cultivation, enabling efficient management and mitigation strategies.

1. Real-time Monitoring

Through the use of sensors and data analytics, ICT allows for real-time monitoring of weather conditions, salinity levels, and other environmental parameters (Akhter & Sofi, 2022).

2. Early Warning Systems

ICT can provide early warning systems that alert farmers to impending storms, floods, or strong winds (UNDRR, 2020).

3. Precision Irrigation

ICT-driven precision irrigation systems help manage water resources efficiently, combatting the problems of soil salinity and waterlogging (Zeynoddin et al., 2023).

4. Climate-Resilient Varieties

Using ICT, farmers can access information about climate-resilient mango varieties that can thrive in changing conditions (Acevedo et al., 2020).

Farms like "Cupitur" have demonstrated success in providing high water quality and wind protection. To enhance resilience, farmers can consider implementing coastal barriers or windbreaks, using elevated planting beds, and employing advanced drainage systems to mitigate the effects of storm surges and flooding.

RISK MAPPING AND ASSESSMENT:

Our approach uses advanced geospatial technology and QGIS to create detailed risk maps from Digital Elevation Models (DEM) and satellite land use data, classifying areas exposed to coastal proximity and artificial structures, especially up to 200 meters above sea level, into high, mid, and low-risk categories to systematically assess and mitigate climate-related risks to mango crops.

INTRODUCING METEOSENSE 4.0[2]:

Central to our strategy is the advanced MeteoSense 4.0 station, an agrometeorological tool providing reliable, precise sensor measurements and seamless integration with agronomic models in our Decision Support System (DSS). The real-time data it collects is accessible via the Cloud Live Data portal, enabling stakeholders to access critical information from smartphones, notebooks, and desktops. By monitoring key meteorological parameters like temperature, humidity, wind velocity, and precipitation, the MeteoSense 4.0 station revolutionizes mango cultivation management, empowering farmers and decision-makers to make informed decisions and implement protective measures promptly in response to adverse weather events or climate changes.

Figure 4. MeteoSense 4.0 station

EMPOWERING DATA-DRIVEN DECISION-MAKING:

Our approach places data-driven decision-making at the forefront. Armed with real-time weather data and the insightful risk map generated through geospatial analysis, stakeholders involved in mango cultivation are better equipped to thrive in an environment of dynamic climate challenges. They can proactively adapt planting and harvesting schedules, safeguarding crops from temperature extremes, strong winds, and precipitation events.

METHODOLOGY

Agent-Based Modelling Framework:

In our research, we explore climate change, agriculture, and decision-making by constructing an agent-based model (ABM) where meteorological factors act as dynamic agents. Temperature, crucial for mango cultivation, affects all stages from flowering to harvest, with extremes below 5°C and above 40°C causing significant damage. Our research also considers climate risks like strong winds and heavy precipitation. To manage this complex landscape, our agents use simple heuristics for decision-making.

The ADM (Agent-Based + Decision Support + Machine Learning) Architecture:

The ADM (Agent-Based + Decision Support + Machine Learning) architecture integrates agent-based modelling, decision support systems, and machine learning techniques. This architecture predicts temperature, a critical variable for mango cultivation, using machine learning methods like Random Forest and Feed Forward Network models. These models are fed with environmental data, including soil moisture, water volume, leaf age, branch rest time, and wind velocity. This comprehensive approach enables responsible corporations and decision-makers to make informed choices to protect mango plants.

[2] https://www.netsens.it/en/

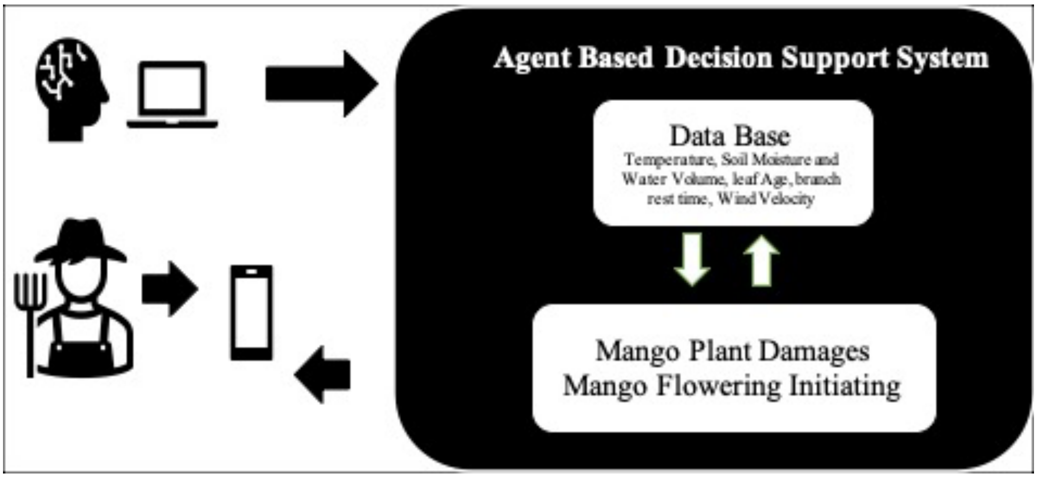

Figure 5. ADM Architecture

Leveraging ICT for Real-Time Collaboration:

Leveraging ICT for real-time collaboration in agriculture facilitates seamless information sharing and decision support between decision-makers and farmers. A dedicated website or application enables farmers to monitor weather changes and communicate swiftly about unexpected field circumstances.

Data Collection and Pre-Processing:

Our analysis is based on meticulously collected data from the primary meteorological website of the Sicilian region, covering 2009 to 2021. These datasets include various climate-related variables such as temperature, humidity, albedo, solar irradiance, air pressure, wind velocity and direction, and precipitation, forming the basis for our predictive models.

Geographic Information System (GIS) Integration:

Our research integrates Geographic Information System (GIS) data, including Digital Elevation and Land Use Cover satellite images from the Copernicus website. Using QGIS software, we process and vectorize these images, classifying data based on agricultural areas, green spaces, and elevations prone to inundation and landslides to construct a comprehensive risk map. This spatial analysis enhances our understanding of localized climate risks in mango cultivation regions.

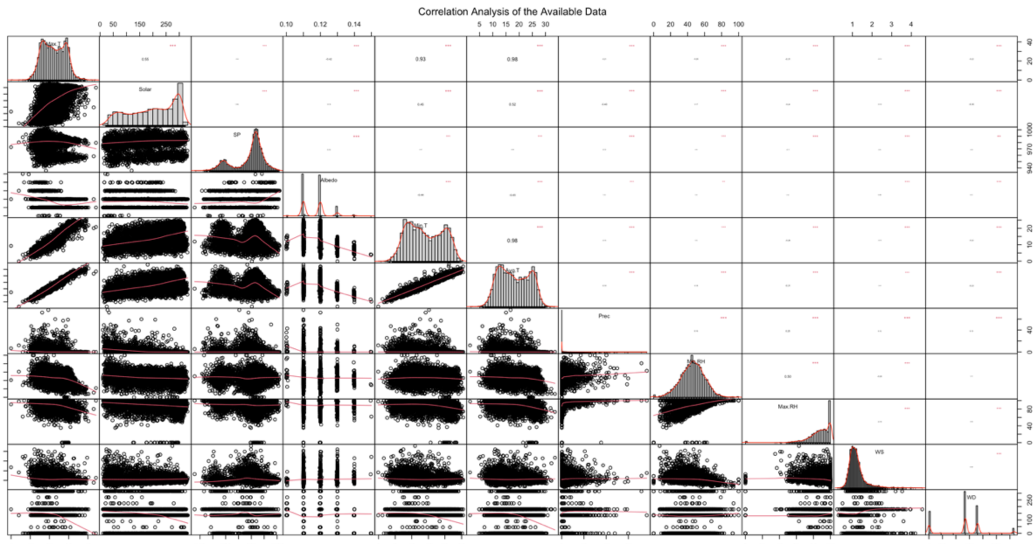

Figure 6. Correlation Analysis, Maximum Temperature Vs. other variables

Correlation Analysis:

To streamline model complexity, we perform a correlation analysis to exclude highly correlated variables, simplifying our machine learning (ML) and artificial neural network (ANN) models. We use daily maximum and minimum relative humidity, albedo, solar irradiance, surface air pressure, wind velocity, and precipitation quantity for temperature prediction in the Random Forest and Feed-Forward Neural Network models.

RESULTS AND DISCUSSION

Random Forest Model:

In our pursuit of predicting future temperatures, the Random Forest (RF) algorithm emerges as a powerful tool. The RF model consists of an ensemble of decision trees that collectively make predictions. In our study, we divide the dataset into a training set comprising daily temperature readings from January 2009 to December 2020, and a test set containing temperature data for the entire year 2021. After training the RF model using the training set, we apply it to forecast temperatures for the year 2022.

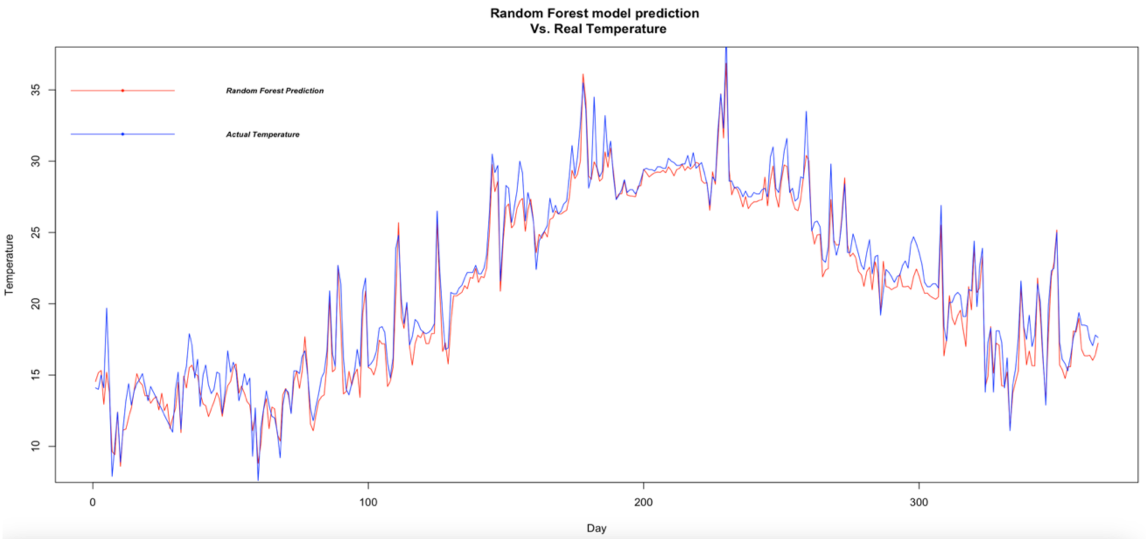

Figure 7. Max Temperature Prediction for year 2022

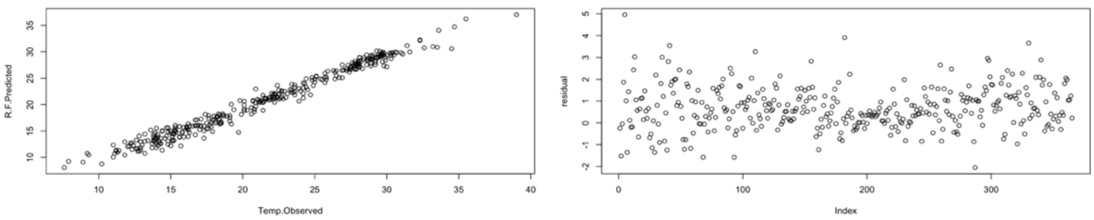

Figure 8. Residual Plots for Max Temperature Prediction in RF model

To assess the accuracy of the model on the test set, we compare the predicted temperatures with the actual temperatures. We visualize the performance of the RF model by plotting the predicted temperatures against the actual temperatures as depicted in Figure 8. Furthermore, we analyse the residuals as its illustrated in Figure 9, which are the differences between the observed and predicted values. The residuals provide insight into the model's accuracy and any patterns or deviations present in the predictions.

Neural Network (Feed Forward) Model:

In tandem with the RF model, we employ the Feed Forward Neural Network (FNN) for temperature prediction. The FNN consists of multiple layers of interconnected neurons that process information and make predictions. The flow of information is unidirectional, starting from the input layer, passing through hidden layers, and culminating in the output layer.

Similar to the RF model, the FNN's performance is evaluated using the RMSE metric. The RMSE is calculated as described earlier, providing a measure of the differences between predicted and actual values. The results obtained from the FNN model align with the expectations set by the RF model. The

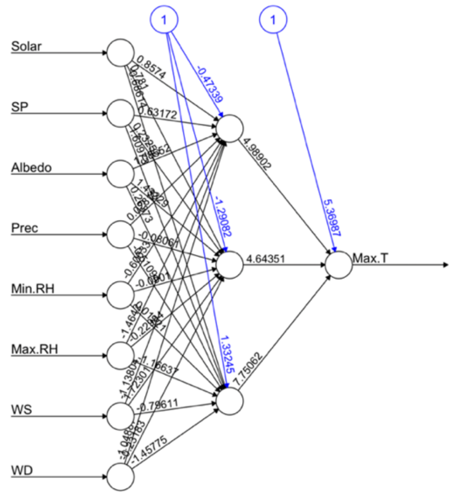

Figure 9. FeedForward Network Design

low RMSE value, coupled with the absence of any discernible pattern in the residual analysis, highlights the accuracy and reliability of this forecasting approach.

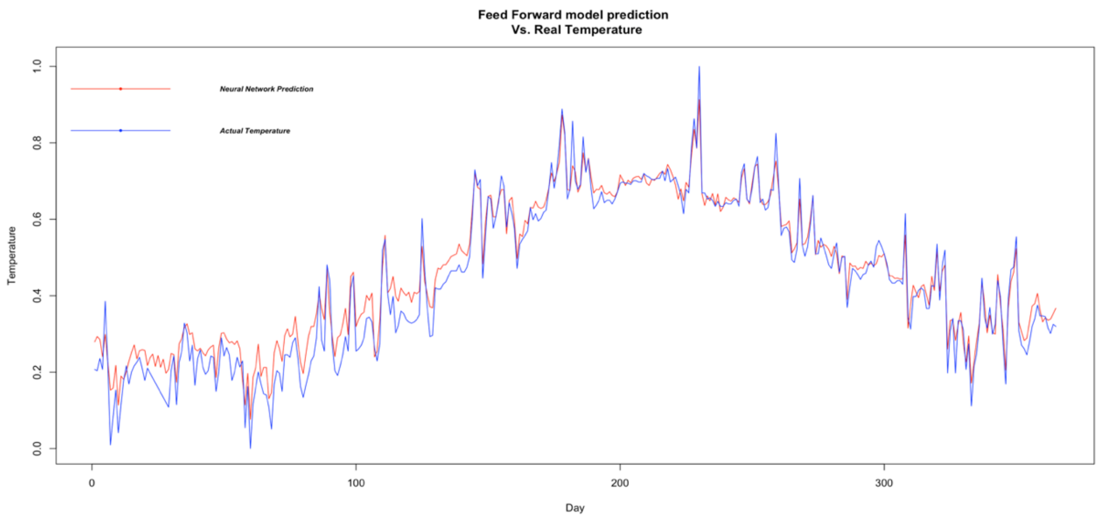

Figure 11. Residual Plot for FNN model

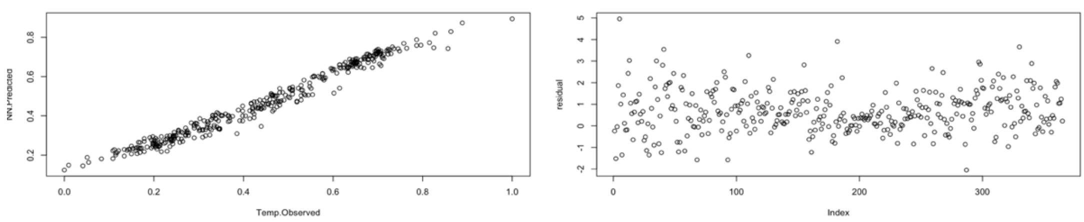

Figure 10. Feedforward prediction for Max Temperature Year 2022

CONCLUSIONS

Our MISAR project focuses on managing climate change risks in agriculture, specifically for mango farms in Sicily. By leveraging advanced Information and Communication Technologies (ICT), we've developed a "Mango Farms Risk Management Plan" to enhance connections between stakeholders and farmers in the Messina region. A key innovation is our ADM (Agent-Based + Decision Support + Machine Learning) architecture, which predicts temperature variations and helps protect mango crops. This approach supports both environmental and economic sustainability in rural areas. Our interdisciplinary methods, combining agent-based modeling, machine learning, geospatial analysis, and ICT, empower farmers and decision-makers with data-driven tools to handle changing climate conditions. While we've made significant strides, further research with more comprehensive data and additional meteorological variables is needed to improve predictive accuracy.

In summary, the MISAR project provides valuable academic and practical solutions to climate change challenges in agriculture. We aim to enhance agricultural resilience and remain committed to improving our models and expanding data sources.

References

Acevedo, M., Pixley, K., Zinyengere, N., Meng, S., Tufan, H., Cichy, K., Bizikova, L., Isaacs, K., Ghezzi-Kopel, K., & Porciello, J. (2020). A scoping review of adoption of climate-resilient crops by small-scale producers in low- and middle-income countries. *Nature Plants*, *6*(10), 1231–1241. https://doi.org/10.1038/s41477-020-00783-z

Akhter, R., & Sofi, S. A. (2022). Precision agriculture using IoT data analytics and machine learning. *Journal of King Saud University - Computer and Information Sciences*, *34*(8), 5602–5618. https://doi.org/10.1016/j.jksuci.2021.05.013

Asare-Nuamah, P., Antwi-Agyei, P., & Dick-Sagoe, C. (2022). Mitigating the risks of climate variability and change on mango seedlings in Ghana: Evidence from mango seedlings producers in the Yilo Krobo Municipality. *Environmental Challenges*, *8*, 100594. https://doi.org/10.1016/j.envc.2022.100594

“Department of Sicilian Agriculture.” (2017). Statistical Data on Tropical Fruits. *Viale Regione Siciliana n.2771, Palermo, Italy.*

FAO. (2022). *Major Tropical Fruits: Preliminary results 2021. Rome*. https://doi.org/https://www.fao.org/3/cb9412en/cb9412en.pdf

FAO. (2023). *Major Tropical Fruits Market Review – Preliminary results 2022. Rome*. https://doi.org/https://www.fao.org/3/cc3939en/cc3939en.pdf

Farina, V., Corona, O., Mineo, V., D’Asaro, A., & Barone, F. (2013). Qualitative characteristics of Mango fruits (Mangifera indica L.), which have undergone preservation. *Acta Italus Hortus*, *12*, 70–73.

Farina, V., Gentile, C., Sortino, G., Gianguzzi, G., Palazzolo, E., & Mazzaglia, A. (2020). Tree-Ripe Mango Fruit: Physicochemical Characterization, Antioxidant Properties and Sensory Profile of Six Mediterranean-Grown Cultivars. *Agronomy*, *10*(6), 884. https://doi.org/10.3390/agronomy10060884

Farina, V., Tripodo, L., Gianguzzi, G., Sortino, G., Giuffrè, D., Cicero, U. L., Candia, R., & Collura, A. (2017). Innovative Techniques to Reduce Chilling Injuries in Mango (Mangifera Indica L.) Trees under Mediterranean Climate. *Chemical Engineering Transactions*. https://doi.org/https://doi.org/10.3303/CET1758138

Gentile, C., Di Gregorio, E., Di Stefano, V., Mannino, G., Perrone, A., Avellone, G., Sortino, G., Inglese, P., & Farina, V. (2019). Food quality and nutraceutical value of nine cultivars of mango (Mangifera indica L.) fruits grown in Mediterranean subtropical environment. *Food Chemistry*, *277*, 471–479. https://doi.org/10.1016/j.foodchem.2018.10.109

Gugliuzza, G., Scuderi, D., & Farina, V. (2023). Fruit quality and photosynthetic response of three cultivars of mango (Mangifera indica L.) in a greenhouse in south of Italy. *Acta Horticulturae*, *1372*, 259–266. https://doi.org/10.17660/ActaHortic.2023.1372.34

Normand, F., Lauri, P.-E., & Legave, J.-M. (2015). CLIMATE CHANGE AND ITS PROBABLE EFFECTS ON MANGO PRODUCTION AND CULTIVATION. *Acta Horticulturae*, *1075*, 21–31. https://doi.org/10.17660/ActaHortic.2015.1075.1

Saleh, E., Jolis, G., Osman, N. F., Sentian, J., Joseph, J., Jomitol, J., & Adin, N. (2022). Beach erosion: Threat and adaptation measures of communities in the Tun Mustapha Park (TMP), Sabah, Malaysia. *IOP Conference Series: Earth and Environmental Science*, *1103*(1), 012034. https://doi.org/10.1088/1755-1315/1103/1/012034

Shahvar, M. ., Buscemi, M., Incardona, S., Tripodo, G., & Marsella, G. (2022). MISAR: Proposal for “Climate Change Risk Management by improving the Individual and Social Awareness of Risk in Sicily.” *GARR-Conf22*, 31. https://doi.org/https://doi.org/10.26314/GARR-Conf22-proceedings-05

Tarolli, P., Luo, J., Straffelini, E., Liou, Y.-A., Nguyen, K.-A., Laurenti, R., Masin, R., & D’Agostino, V. (2023). Saltwater intrusion and climate change impact on coastal agriculture. *PLOS Water*, *2*(4), e0000121. https://doi.org/10.1371/journal.pwat.0000121

UNDRR. (2020). Hazard Definition & classification review. *Hazard Definition & Classification Reviewazard Definition & Classification Review*.

Zeynoddin, M., Gumiere, S. J., & Bonakdari, H. (2023). Enhancing water use efficiency in precision irrigation: data-driven

approaches for addressing data gaps in time series. *Frontiers in Water*, *5*.
https://doi.org/10.3389/frwa.2023.1237592