

Objective

To determine the best time for hops harvesting using IoT and smart technologies

Introduction

- Hop chemistry is ever changing with variations also during hops ripening
- Internet of Things (IoT) and smart farming technologies to be employed in agriculture to collect and process data from the field
- Very limited applications to detect hop ripeness

Material and Methods

- Three growing season monitored: **2021, 2022, 2023**
- Hops harvesting at different ripening times
- Chemical characterization** of hop cones for each maturation stage:
 - Bitter acids content (HPLC-UV)
 - Essential oil extraction (hydro distillation)
- Morphological measurements** of hop cones
- Different types of **IoT devices** (environmental sensors, soil sensors, leaf sensors...) sending data once a day
- Data collection **platform** for data analysis and calculation of indexes (e.g., Growing Degree Days, GDD)
- Different Artificial Intelligence (AI) models for harvesting quality assessment:
 - Forecasting: **Multi-output Linear Regression**
 - Classification: **Decision Tree Classifier**

Results

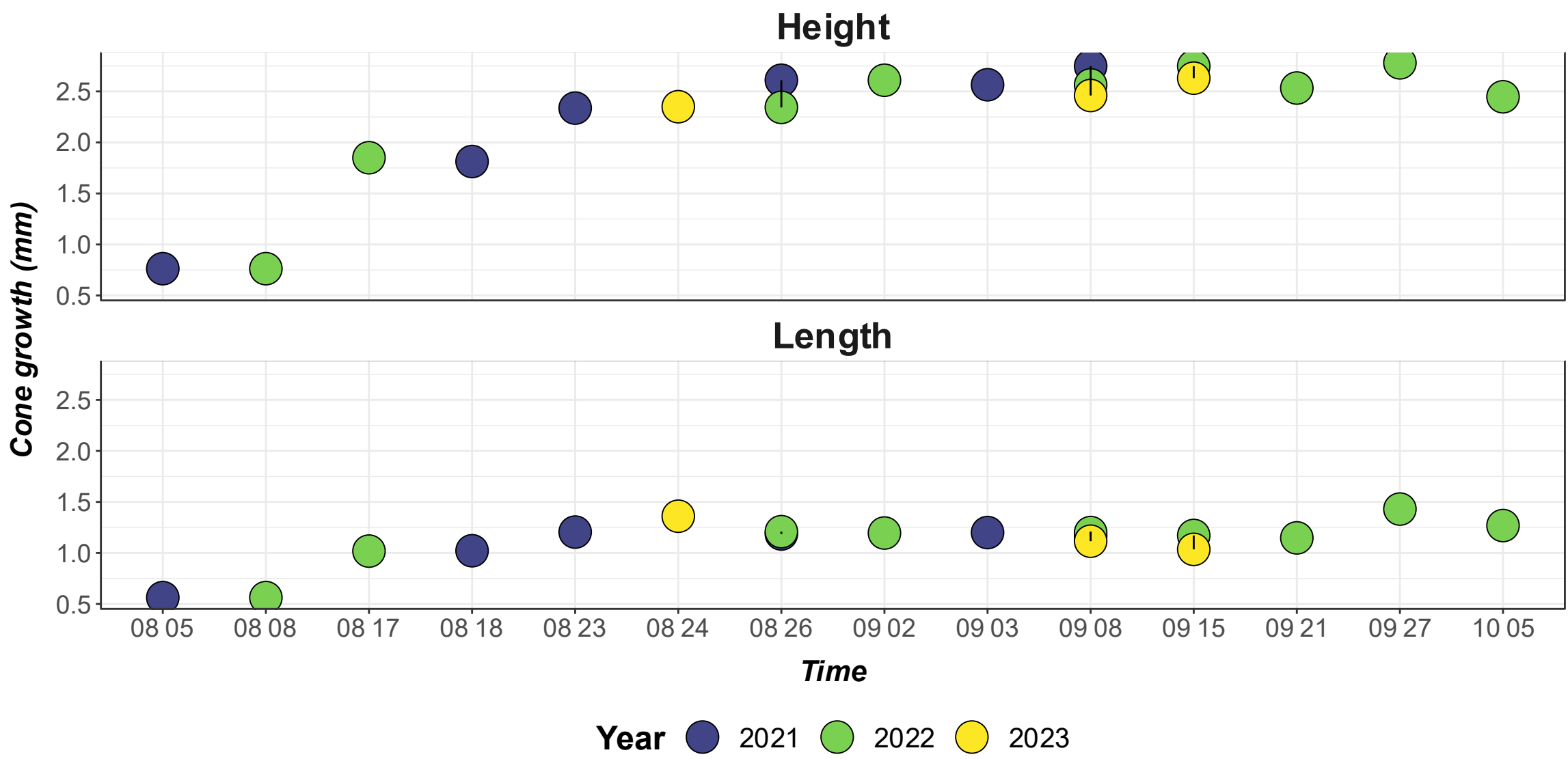


Fig. 1 Growth parameters evolution in 2021, 2022 and 2023

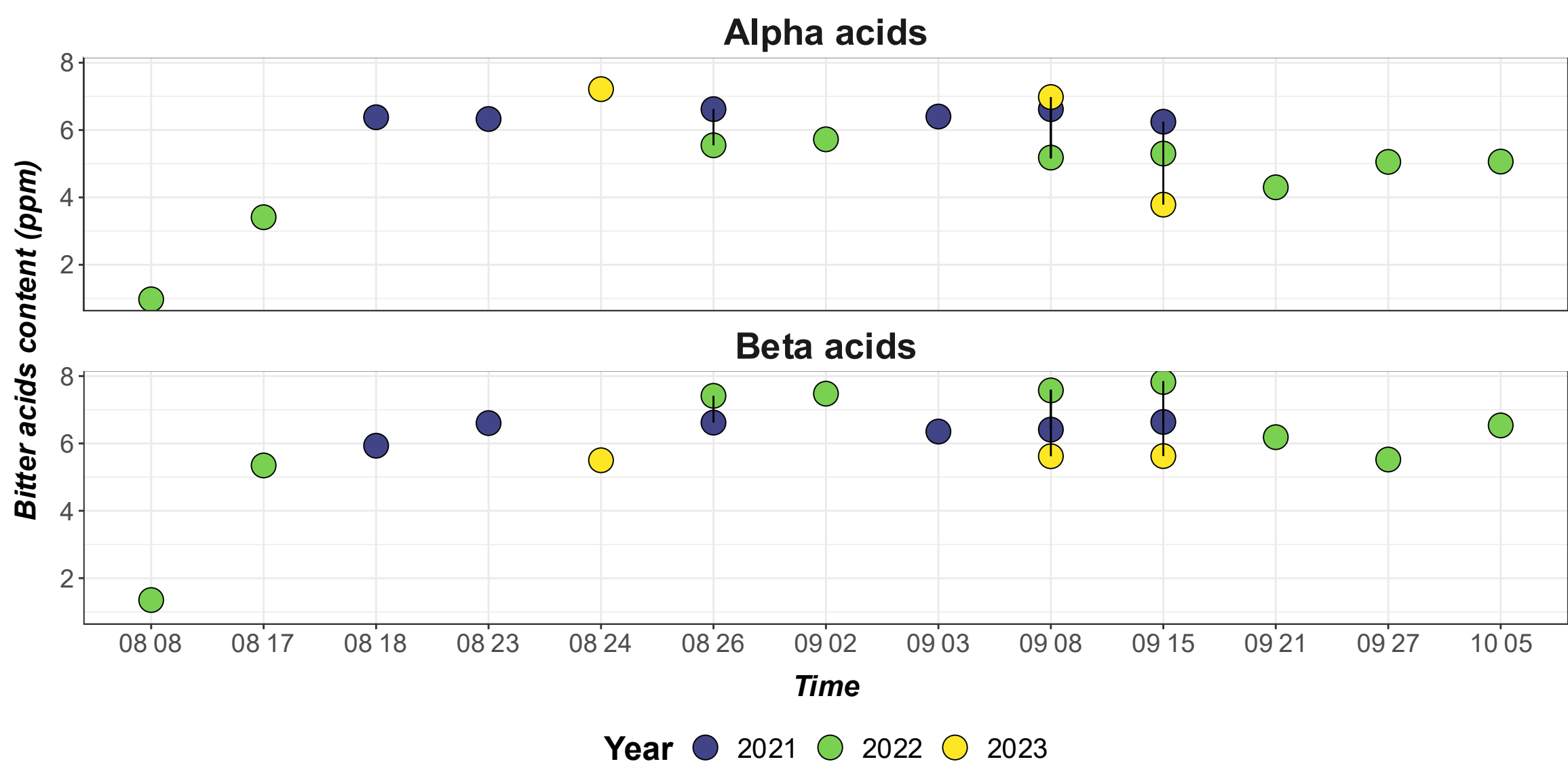


Fig. 2 Bitter acids content in 2021, 2022 and 2023

	Oil %	Alpha-acid	Beta-acid	Moisture %	Height	Lenght
GDD	0,850734	-0,1068607	0,3563867	-0,857563	0,6804395	0,580259
Air temperature	-0,680784	0,05738431	-0,157546	0,53648352	-0,371386	-0,26628
Dew point temperature	-0,548007	-0,2752959	-0,093774	0,34038158	-0,296827	-0,24789
Soil moisture (upper)	-0,201682	0,59294226	0,4775698	0,51737316	-0,149014	-0,14151
Soil moisture (lower)	-0,258	0,52516238	0,2679661	0,55277062	-0,285476	-0,24078
Soil temperature (upper)	-0,817889	-0,0137531	-0,268154	0,48451502	-0,438602	-0,40175
Soil temperature (lower)	-0,758845	-0,1390189	-0,303966	0,41873147	-0,412516	-0,39819

Table 1 Pearson's correlation values between sensors data and chemical characterization of hop cones

- Identification of the seven sensory parameters highly correlated with cone's chemical information
- Sensors' information **prediction** using a Multi-output Linear Regression algorithm with a **one-week** time horizon
 - Average accuracy: 0.96
- Maturation's state **classification** into 3 classes (*IMMATURE*, *MATURE*, *OVERRIPE*) using a Decision Tree Classifier
 - Accuracy: 0.95
- Combination of the two models (prediction and classification) to find the **optimal harvest** period for hop

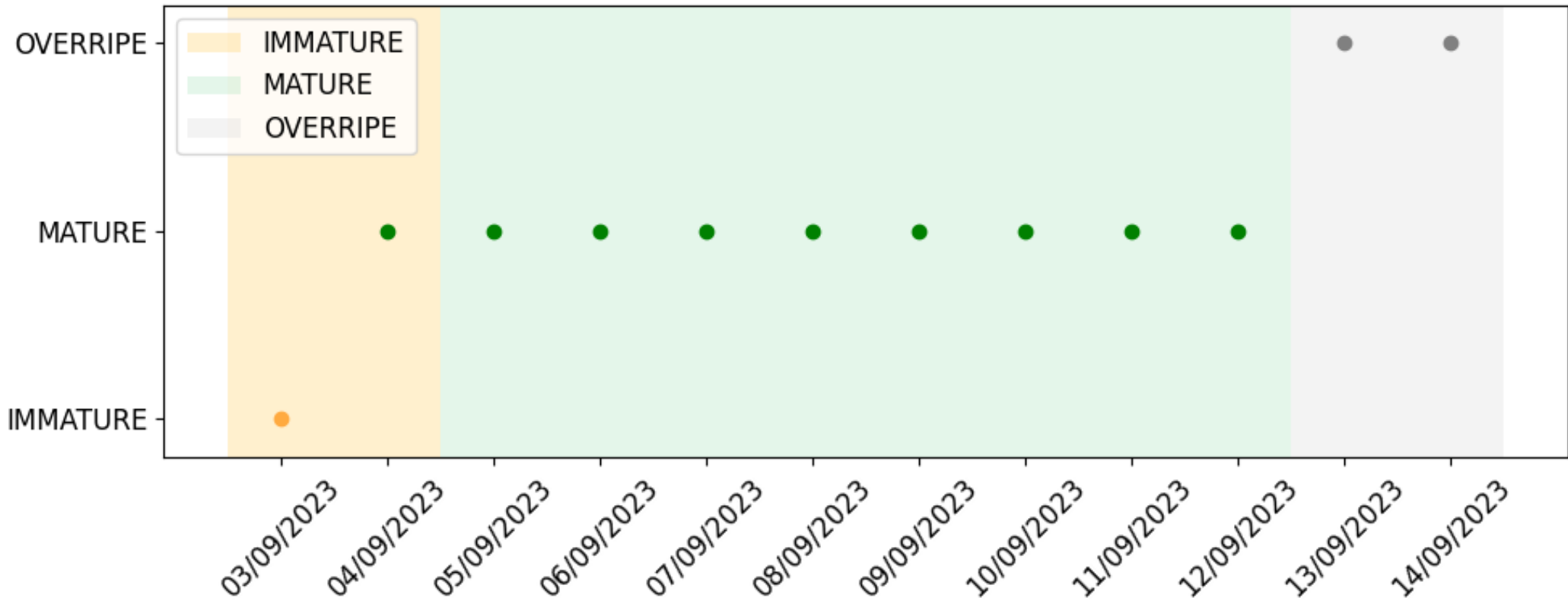


Fig. 3 Results of forecasting and classification using ML algorithms on 2023 data

Conclusions and Future Works

- The optimal harvest period is highly dependent on seasonality
- Cone growth rate, and bitter acids and essential oils contents suggest the optimal ripening and harvesting period for hop cones
- The combination of a Multi-output Linear Regression algorithm and a Decision Tree Classifier can suggest, with a one-week time horizon, the optimal harvest period and identify the overripe status
- For future developments, the importance of other parameters can be investigated, such as the evolution of hop cone size (height and length) in relation to the parameters monitored by IoT sensors