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Effects of air temperatures on acacia and chestnut honey yields: case study in Italy

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Abstract. Global honey production is increasing.In Italy, the two predominant monovarietal honey types are acacia and chestnut . Climate change, with an increase in extreme weather events (including droughts, heat waves and late frosts), impacts both the phenology of melliferous species andhoneybee activity. The aim of this study was to correlate the honey yields of acacia and chestnut in five Italian climatic sub-regions with the thermal extremes during the flowering phases of the two melliferous species. The objective was to understand the impact that these parameters have on yields.The results highlighted differing impacts of thermal extremes on honey yields for acacia and chestnut, respectively . In the acacia, temperature below 4.3C° in the flowering period had a negative impact particularly in the North-West ($P<0.01$). Instead temperatures above 17.5C° impacted positively in North Italy. In contrast, for chestnut, temperatures above 23.5C° negatively affected honey yields in the North-West. Understanding the interaction between climate, melliferous species and bees is useful for beekeepers towards developing adaptation strategies to climate change with the aim of protecting the yields, income, animal welfare and ecosystem services.

Keywords: bees, climate change, agrometeorology, plant phenology, ERA5 land.

1. INTRODUCTION

Honey production is rising on a global level with an 85 % increase in the number of managed honeybee colonies reported for the 1961-2017 period (Phiri et al. 2022). In Italy honey production was 0.026Mt in 2021 and according to ISMEA (2020), the increase in the last 10 years was attributable to the growth in the number of professional and amateur beekeepers. In 2022 the recorded number of beekeepers was 72020 (Report Osservatorio nazionale del miele 2022) with 60 monovarietal honey types. However, annual production is strongly influenced by the weather conditions (Rahimi_2021, Delgado et al. 2012, Olvera et al. 2023). Acacia (*Robinia pseudoacacia L.*) and chestnut (*Castanea sativa L.*) honeys in Italy represent the two main monovarietal types spread over almost the national territory (Parri et al. 2014). From both observational and experimental studies, it is well established that climate change has been associated with an alteration of phenological cycles, resulting in an earlier onset of vegetation activity in spring with effects on the related leaf-out and flowering dates (Piao et al. 2019). Strong relationships were found between phenological events and early spring weather (Sparks and Carey 1995, Linderholm 2006, Richardson et al. 2013) with vegetal species respond to a rise in temperature by coming into leaf or/and flowering earlier. It is projected that in the future, leaf and flowering dates will to be 3-4 weeks earlier than present (IPCC 2023, Simpson et al. 2023). In Italy there are insufficient studies investigating the impact of meteo-climate conditions on honeybee production. Nonetheless, there have been research reports correlating the activity of bees, phenological period and resultant honey production with climatic factors (Wyver et al. 2023a, Wyver et al. 2023b, Blasi et al. 2023). It has been found (Medina 2018) from simulated bee stress conditions in the laboratory thatf high temperatures (<= 40°C) influenced on the phenotype and behavior of honey bees under heat stress, with potential consequences for colony fitness (Medina 2018). In two sites in Portugal, Fernandes et al. (2015) in Portugal showed that high rainfall and low temperatures advanced vegetative growth and early flowering in the northern study site, whereas high temperatures with no rainfall advanced growth and ripening phase of fruits in the southern site. Previous work demonstrated that the increase in average temperatures in winter and early spring accelerated the phenological development of plants by interacting with the activity of pollinators in the various ecosystems (Hung e al 2018, Villagomez et al. 2021, Hunichen et al. 2021, Mashilingi et al. 2022,). A decrease in honey production under extreme drought conditions was also observed in a case study in Cordoba, Spain (Flores et al. 2019). Zhao et al. (2021) highlighted two temperature values, 5°C and 10°C of daily minimum values, which determined the optimal start of bee activity inside and outside the hive, respectively In China an increase in temperatures and a reduction in rainfall, respectively, was shown to alter the phenology of plants in general but more specifically honey plants (Guo et al. 2013). The growing season expanded by 4.3 days per decade in Beijing region with the first flowering was advanced by high temperatures between January and June, but delayed by warm conditions during the chill accumulation phase.

Moreover, it was reported that from 1956 to 2010, the budding of many honey plants, was progressively brought forward, up to 13.5 days, with impacts on the subsequent phenological stages of many honey species (Juknys et al. 2011). This was corroborated by Visser and Both (2005), demonstrating an advance from 3 to 11 days in the manifestation of many phenological phases of cultivated species during the end of winter and the beginning of spring. Also Dalla Marta_et al. (2010) showed that the phenology of Montepulciano vine progressively advances for one day every 2 years in the budding and flowering phases. Back in 2005 (Peat amd Goulson 2005)attention was already drawn to the effects of climate change. Those authors pointed out that climate change modifies the quality and quantity of available nectar and/or pollen, limiting its collection by pollinating insects. Southern European countries, including Italy, are among the most critically affected by climate change in Europe and the situation is expected to worsen in the coming decades with an impact both temperatures and precipitation distribution (IPCC 2021). A variation in the distribution of precipitation regimes and temperatures in different Italian areas were evidenced (Brunetti et al. 2006) These variations were also highlighted by studies on a regional scale (Bartolini et al. 2014) with a decrease in precipitation during winter and spring, especially in northwestern areas. Regarding temperatures, an increase was observed during all months of the year, also associated with an increase in heat waves. More recently, Bartolini et al. (2021) demonstrated both spatial and temporal changes in dry spells in Central Italy during the 1955–2017 period. Given the climate changes and impacts on the phenology of honeybee species, the aim of the present study is to correlate the honey yields of acacia and chestnut with the thermal extremes during the flowering phases of the two species, within five Italian climatic sub-regions, in order to understand the impact of these environmental parameters on yields.

2. MATERIALS AND METHODS

2.1. Climatological dataset (Era5 Land)

Climatological data was obtained by the ERA5 reanalysis dataset from 1950 at a 0.1° resolution.The data wasstored in a tridimensional hypercube data store where the first two dimensions represented spatial dimensions (Longitude and Latitude) and the third, a time dimension. Taking into account the high heterogeneity in climate (Martinelli and Matzarakis 2017), Italy divided into 5 climatic sub-regions (North West, NW; North East, NE; Northern Central Tyrrhenian, NCT; Central Adriatic, CA; South, S) (Figure 1), each describing the different climatic zones in the April-July period. Recently a simi-

Figure 1. Italian climatic sub-regions used in the study. North West, NW; North East, NE; Northern Central Tyrrhenian, NCT; Central Adriatic, CA; South, S.

lar approach was used in studies investigating the impact of atmospheric circulations on the crop yields in specific Italian sub-areas (Central and North-East Italy) (Salinger et al. 2020, Salinger et al. 2022).

2.2. Honey production

The production of acacia and chestnut honey was obtained from the National Honey Observatory annual reports (https://www.informamiele.it/). The database reports the average production in kg/hive on a regional scale for the period 2015-2022. For each climatic sub-area, an average was calculated (Figure 2).

2.3. Phenological data

Phenological data for chestnut and acacia were acquired from the Italian PHEnology Network (IPHEN) database, a national system of monitoring based on comprehensive phenological observations for some plant species. IPHEN is a cooperative project that started in 2006 with theaim of producing nationwide maps analysis maps and forecasts for the phenological stages of plants of interest to agriculture, health, and environmental care. More details about the IPHEN dataset have been described by Mariani et al. (2012).

For acacia and chestnut, weekly IPHEN phenological maps shows the BBCH phenological stadium (Meier 2001, Meier 2018) for each vegetative season. The Day Of the Year (DOY) when 50% of flowering occurs in most of the domain was estimated for each of the Italian climatic sub-regions. DOY was considered as the Annual Zonal Peak Flowering (AZPF) in the present study. Starting from the AZPF, a temporal flowering window (FW) of 16 days (Figure 3) was derived, The FW ranges from 7 days before the AZPF to 7 days after.

2.4. Data processing and statistical analysis

For each macro-climatic area, average daily temperature data was obtained from each pixel (0.1° x 0.1°, Lat/Lon). During FW, the number of days (occurrence) for different thermal extremes were calculated. These extremes were identified with the following percentile classes: 2,10,15, 25, 75, 80, 85, 90 and 98 respectively. The occurrence was calculated during the period 1950-2022. The data obtained was than related to the honey production for the two melliferous species using a linear correlation.

Statistical analyses were carried out in the Conda 4.2 open source, using the Python 3.8 programming language, related temporal and statistical analysis (XArray, SciPy, Statistics, Numpy, Pandas) and visualization (Matplotlib) modules.

3. RESULTS AND DISCUSSION

3.1. Effects of low temperature on honey production

The effect of low temperature anomalies had a significant negative impact only on acacia honey yields in Northern Italy (Table 1).

The NW Italian area showed the highest significance ($p<0.01$) with a negative impact of low temperatures for all percentile classes except for the most extreme one (2th).

This result can be explained by the fact that during the acacia flowering period (May) the low air temperatures impacted negatively on bee activity. The present work corroborated a recent study carried out on Rho-

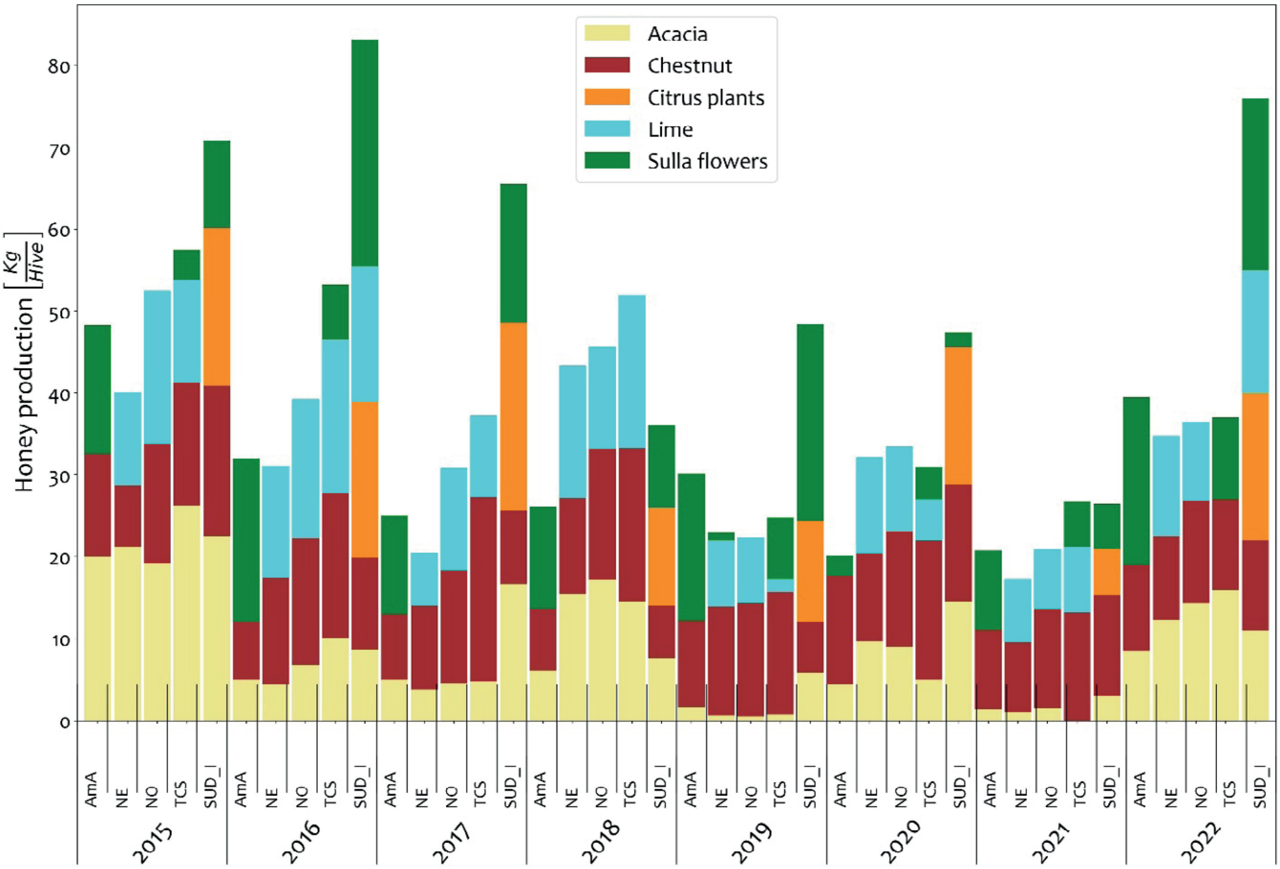

Figure 2. Production in kg/hive for each climatic sub-area in the period 2015-2022.

des Island, from 2015 to 2019, showing a link between wildflower honey production and the main microclimatic parameters (air temperature and humidity). The results showed that the optimal temperature values for the daily production of honey in spring were around 17°C, while below 14°C the balance between the honey produced and consumed became negative (Gounari et al. 2022). This was also confirmed in an earlier study demonstrating that bee foraging activity was reduced to the point of cessation at 6.5°C (Oshi and Joshi 2010). Instead, foraging activity was shown to increase at higher temperatures reaching a maximum peak around 20°C (Tan et al. 2012).

Furthermore, as is well-documented, air temperature is a determining factor of the plant species phenology (Alilla et al. 2022). *Robinia pseudacacia* was shown to be particularly damaged by late frosts which negatively impact young leaves, shoots and flowers thereby reducing the availability of food for the bee (Vítková et al. 2017). Of note, it is important to take into consideration that the low percentiles in northern Italy had lower values than the temperatures obtained in central and southern Italy.

As far as the chestnut honey yields are concerned, the analysis did not show statistical significance as regards the low temperatures. The chesnut flowering period (June) occurrs one month later than Acacia, and for this reason low temperatures are not conditioning chesnut flowering.

3.2. *Effects of high temperature on honey production*

The effect of positive temperature anomalies on acacia honey yields was positive in most macro-areas (Table 2) with statistical significance in NW, NE, NCT, CA.

In North Italy and in NCT, the greatest significance occurred in the less extreme percentiles. The highest significances (P<0.001) were observed in North Italy in the 75th percentile class.

The positive effect of high temperature is in agreement with that shown by Tan et al. (2012) who identified that the maximum bee foraging activity occurred

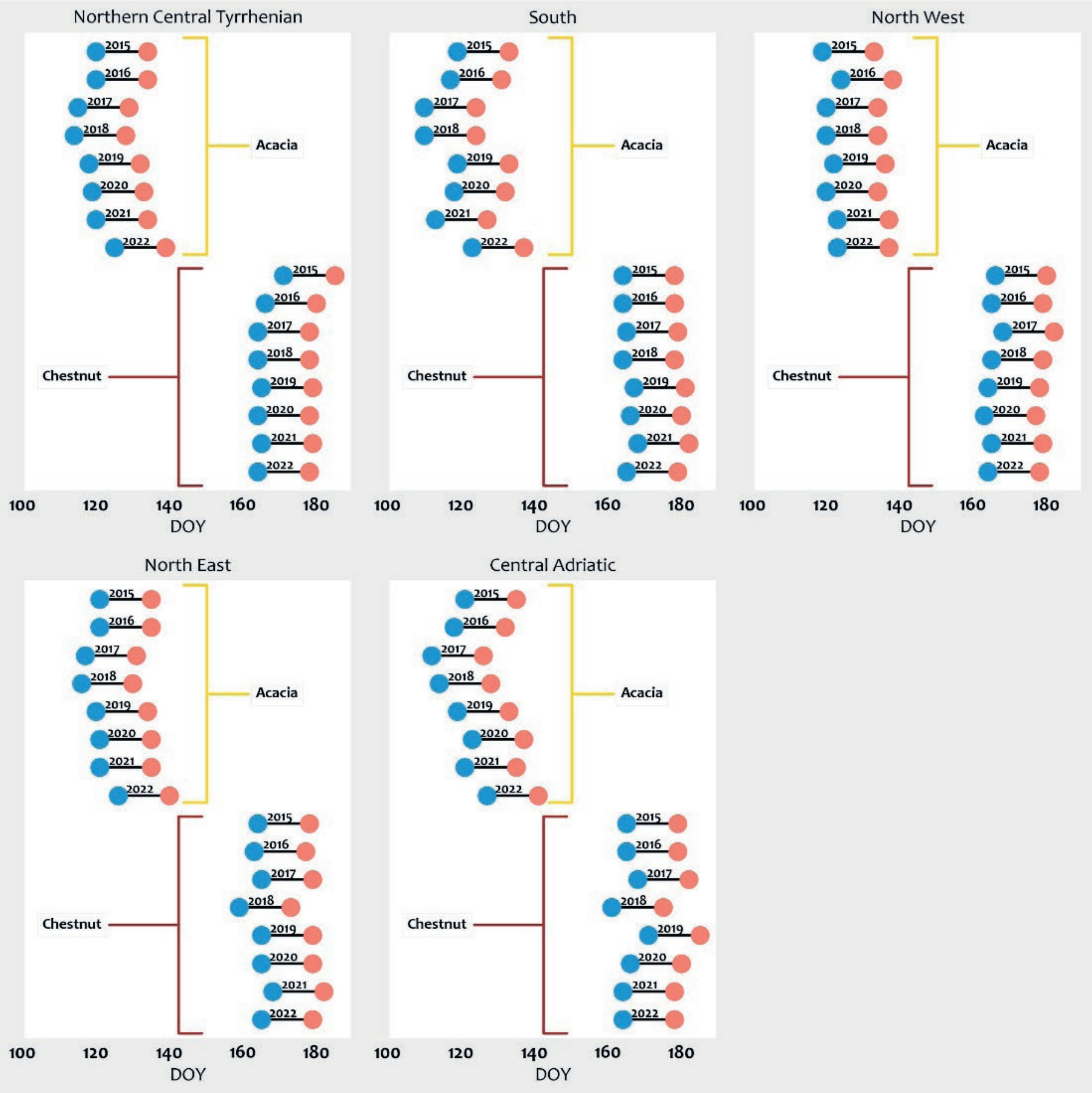

Figure 3. Acacia and chestnut flowering windows for each Italian climatic sub-region.

in the spring with temperatures close to 20°C. This temperature also has a positive effect on the nectar characteristics which becomes more available to the insects and contained a higher sugar content (Bertsch 1983, Kim et al. 2020). Furthermore, Alilla et al. (2022) found a greater nectar quantity in the advanced stages of flowering in *Robinia pseudacacia* a greater nectar quantity with maximum availability starting from the second week. The higher temperatures were also shown to allow a faster opening of the inflorescences, reducing the time period needed by the bees to obtain nectar (Giovannetti et al. 2013).

In Southern Italy, high temperatures did not have a significant effect on honey yields.

In contrast, for Chestnut honey yields, the positive temperature anomalies were generally shown to have a negative impact, significant in the NW climatic sub-region, with a reduction especially for the 85th and 90th percentile (Table 3).

Table 1. Correlation coefficient (r) and significance (sig) of the correlations between low temperatures and Acacia honey production. NS Not significant; * P<0.05; ** P < 0.01; *** = P<0.001%; NW = North West; NE = Nord East; NCT = Northern Central Tyrrhenian; CA = Central Adriatic; S =South. tt= average temperature of the percentile for each Italian climatic sub-regions.

Acacia		Climatic sub-regions														
		NW			NE			NCT			CA			S		
		r	sig	tt	r	sig	tt	r	sig	tt	r	sig	tt	r	sig	tt
percentile	2	-0.49	NS	1.0	0.00	NS	1.3	0.00	NS	4.4	0.00	NS	2.2	0.00	NS	5.2
	10	-0.70	**	2.7	-0.51	NS	3.2	-0.49	NS	6.0	-0.38	NS	4.0	-0.38	NS	6.4
	15	-0.82	**	3.3	-0.61	NS	3.8	-0.49	NS	6.4	-0.35	NS	4.5	-0.55	NS	6.9
	20	-0.79	**	3.9	-0.63	NS	4.4	-0.51	NS	6.9	-0.47	NS	5.0	-0.51	NS	7.3
	25	-0.88	***	4.3	-0.67	*	4.8	-0.60	NS	7.2	-0.58	NS	5.5	-0.56	NS	7.7

Table 2. Correlation coefficient (r) and significance (sig) of the correlations between high temperatures and Acacia honey yields. NT Not significant; * P<0.05; ** P < 0.01; *** = P<0.001%; NW = North West; NE = Nord East; NCT = Northern Central Tyrrhenian; CA = Central Adriatic; S =South. tt= average temperature of the percentile for each Italian climatic sub-region.

Acacia		Climatic sub-regions														
		NW			NE			NCT			CA			S		
		r	sig	tt	r	sig	tt	r	sig	tt	r	sig	tt	r	sig	tt
percentile	75	0.89	***	17.5	0.93	***	18.0	0.76	*	20.2	0.66	*	19.4	0.23	NS	20.4
	80	0.84	**	18.0	0.92	***	18.5	0.83	**	20.6	0.74	*	20.0	0.16	NS	20.9
	85	0.71	*	18.5	0.89	***	19.0	0.83	**	21.0	0.69	*	20.5	0.15	NS	21.5
	90	0.78	*	19.2	0.86	**	19.7	0.84	**	21.6	0.73	*	21.2	0.01	NS	22.3
	98	0.76	*	21.2	0.63	NS	21.5	0.86	**	23.8	0.63	NS	23.4	0.08	NS	24.7

Table 3. Correlation coefficient (r) and significance (sig) of the correlations between high temperatures and Chestnut honey yields. NE = Not significant ; * P<0.05; ** P < 0.01; *** = P<0.001%; NW = North West; NE = Nord East; NCT = Northern Central Tyrrhenian; CA = Central Adriatic; S =South. tt= average temperature of the percentile for each Italian climatic sub-region.

Chestnut		Climatic sub-regions														
		NW			NE			NCT			CA			S		
		r	sig	tt	r	sig	tt	r	sig	tt	r	sig	tt	r	sig	tt
percentile	75	-0.73	*	23.5	0.19	NS	24.2	-0.26	NS	27.1	-0.19	NS	26.2	-0.25	NS	28.3
	80	-0.72	*	24.1	0.23	NS	24.8	-0.26	NS	27.5	-0.15	NS	26.9	-0.19	NS	28.9
	85	-0.84	**	24.8	0.07	NS	25.4	-0.30	NS	28.1	-0.14	NS	27.5	-0.12	NS	29.6
	90	-0.79	**	25.6	-0.05	NS	26.2	-0.23	NS	28.8	-0.13	NS	28.4	-0.01	NS	30.3
	98	-0.508	NS	27.9	0.333	NS	28.2	-0.679	*	30.8	-0.01	NS	30.6	0.11	NS	32.7

This result can probably be explained by the change in nectar characteristics with air temperature. In a recent study on *Castanea sativa*, it has highlighted that a higher sugar content was present in the nectar with average daily air temperatures between about 22 and 25°C but that the sugar content tended to rapidly decrease with higher air temperatures (Kim et al. 2020).

In addition, studies have highlighted a positive role of high air humidity levels in the nectar characteristics. In particular, an increase in the sugar content produced by numerous herbaceous flowers, shrubby and tree species with high air humidity was reported Corbet et al. (1979). Therefore, if we consider that over the last few decades, the northern Italian areas have experienced negative rainfall anomalies (Caloiero et al. 2021) and an increase in drought episodes (Baronetti et al. 2020), the decrease in honey production could also be explained by low air humidity.

However, this result cannot be generalized to all melliferous species. In fact, a study on the evaluation of the sugar content in the nectar of *Epilobium angustifolium* (Bertsch 1983) did not show significant differences at different air humidity rates (50%, 78%, 94%).

The main strength of the present study was to draw cognitive awareness to the complex interaction of plant, insect, man and climate. To date, correlation studies between honey production and meteorological parameters are still scarce, especially in the Mediterranean Basin.However, these correlation studies can provide a very useful tool for beekeepers to understand production dynamics. Furthermore, the use of ERA5 Land spatialized data can also be very useful in instances where ground meteorological stations are not sufficiently near apiaries.

This preliminary study must is to be considered as a starting point for understanding the dynamics correlating climate with bee activity and phenology of melliferous species. However, some limitations were shown to exist. The first limitation was the represented by the limited sample size. The number of years of production is in fact rather limited and does not allow for a sufficient comparison with the thermal extremes. Furthermore, the climatic data was calculated as an average of the macro-area, also including information from pixels of areas not suitable for the two honey species. Probably, a comparison with the Corine Land Cover could help in better defining the thermal characteristics of the areas.

Future studies are aimed at increasing the sample size, extending the study to other honey types, thereby including other melliferous species. This would also make it possible to increase the honey production window to the entire summer. In addition, overwintering conditions, effects of pests on hive health conditions should be taken into account in future studies.

Furthermore, the correlation analysis could also be extended to other meteorological parameters (e.g. wind, air humidity), which which also may play an important role in both bee activity and nectar availability. For this reason, a cross-disciplinary research in environmental sciences that make available long historical series of climatic-environmental data (for example Itineris Project,Italian Integrated Environmental Research Infrastructures System), colud be very useful in order to improve this type of research by including case studies on honey yields in specific sites.

4. CONCLUSION

Our study showed that air temperature was able to describe the trend of acacia and chestnut honey yields in Italy under many situations. Above all, high temperatures (higher percentiles) were shown to exert a positive impact on the spring acacia honey yields, especially in the more northern latitudes (North and central Italy) where cold spells are generally more likely during the spring. In contrast, the chestnut honey yields seemed to be negatively influenced by the higher air temperature which impacted on both honeybee activity and on the phenology of the melliferous species. These results, especially in the contest of climate change, could be very useful in understanding the mechanisms of interaction between climate, melliferous species and bees. In particular, the integration of the results obtained using models for estimating honey production as a function of the expected climatic conditions could allow for an early estimation of honey production in the various Italian climatic macro-areas. Moreover, the use of seasonal forecasts assist beekeepers in choosing the locations in which to carry out nomadism. The study was performed with a view to provide to beekeepers a tool that allows to adopt adaptation strategies to counteract climate change effects and consequently to protect production, income, animal welfare and ecosystem services.

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