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Monitoring the impact of changes in weather on the activity of bee communities in the five regions of the Republic of Croatia

Praćenje utjecaja promjena vremenskih prilika na aktivnost pčelinjih zajednica u pet regija Republike Hrvatske

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ABSTRACT

The paper examines climate variations in three climatic regions of the Republic of Croatia and their impact on bee colonies, monitored in the period from 2019 to 2023. The research was conducted in five regions of the Republic of Croatia. One city was selected from each region to be the centre of the research. The selected regions are: Central Croatia (Križevci), Eastern Croatia (Osijek), Highlands (Gospić), Northern Croatian Littoral (Pula), Southern Croatian Littoral (Split). By monitoring the average annual dry-bulb temperatures, precipitation amounts, the number of clear days and the number of days with precipitation over the past five years in the Republic of Croatia, insight was gained into year-to-year climatic changes, including increasingly frequent dry periods, milder winters, and warmer summers. All of this ultimately has a negative impact on bee colonies, which is primarily reflected in reduced honey yields, weaker bee colonies, weaker bee resistance to diseases, a changed flowering calendar of honey plants, more difficult adaptation of conventional beekeeping technology to the newly created climate conditions, and the increasingly frequent occurrence of extreme weather that destroy honey plants (the main bee pasture). We cannot influence extreme weather, but we can respond in a timely manner if we include new digital technologies to predict critical situations and make decisions to avoid them. Therefore, the education of beekeepers in the application of new digital technologies could result in timely decisions to avoid the negative impact of climate variation on the activity of bees in and outside the hives.

Keywords: climate variation, bee colonies, honey plants, digital technologies

SAŽETAK

Rad se bavi razmatranjem klimatskih varijacija na tri klimatska područja Republike Hrvatske (RH) i njihov utjecaj na pčelinje zajednice, praćeno u razdoblju od 2019. do 2023. godine. Istraživanje je provedeno u pet regija RH. Iz svake regije odabran je po jedan grad koji će biti središte istraživanja. Odabrane regije su: Središnja Hrvatska (Križevci), Istočna (Osijek), Gorska (Gospić), Sjeverno hrvatsko primorje (Pula) i Južno hrvatsko primorje (Split). Praćenjem srednjih godišnjih temperatura suhog termometra, količine oborina, broja vedrih dana i broja dana s oborinama unazad pet godina na području RH, dobiven je uvid u to kako se klima iz godine u godinu mijenja, kako su sušna razdoblja sve češća, zime sve blaže, a ljeta sa sve većim temperaturama zraka. No sve to u konačnici ima negativan utjecaj na pčelinje zajednice koji se ponajprije ogleda u smanjenim prinosima meda, slabijim pčelinjim zajednicama, slabijoj otpornosti pčela na bolesti, promijenjenom kalendaru cvatnje medonosnih biljaka, težoj prilagodbi konvencionalne tehnologije pčelarenja novonastalim klimatskim uvjetima te sve češćoj pojavi nepogoda koje uništavaju medonosne biljke (glavnu pčelinju pašu). Na prirodne nepogode ne možemo utjecati, ali možemo pravovremeno reagirati ukoliko uključimo nove digitalne tehnologije radi predviđanja kritičnih situacija i donošenja odluka o njihovom izbjegavanju. Stoga bi edukacija pčelara za primjenu novih digitalnih tehnologija mogla rezultirati pravovremenim odlukama u izbjegavanju negativnog utjecaja klimatske varijacije na aktivnost pčela u košnicama i izvan njih..

Ključne riječi: klimatske varijacije, pčelinje zajednice, medonosne biljke, digitalne tehnologije

INTRODUCTION

The climate of the Republic of Croatia reflects its location within the temperate latitudes (around 45° north latitude), a parallel halfway between the equator and the North Pole (Opačić, 2016). Due to this location, the climate is moderate, without any temperature extremes, so there is a regular change of four seasons: winter, spring, summer, and autumn. However, today we are witnessing the emergence of weather extremes and the loss of this regular seasonal pattern. There are three main climatic zones in the Republic of Croatia: Adriatic or Mediterranean, mountain-valley, and Continental-Pannonian (Croatian Meteorological and Hydrological Service – DHMZ, 2024), which have conditioned the development of specific honey plants and diverse bee pastures within the influence of these climatic zones. This has contributed to the development of migratory beekeeping on selected bee pastures for the purpose of obtaining varietal honey (honey from black locust, chestnut, linden, sunflower, citrus, lavender, sage, etc.). This paper aims to determine the impact of weather changes on the development and activity of bee colonies, particularly the impact of temperature extremes, which were monitored from 2019 to 2023. The research was conducted in five regions of the Republic of Croatia. One city was selected from each region to be the centre of the research. At the end of the research, insight will be gained into how changes in temperature and precipitation affect bee activity and their overall survival. The results of the paper will also include reports from the Croatian Meteorological and Hydrological Service (DHMZ) on temperature and precipitation fluctuations in individual regions of Croatia. It is known that bees in the Republic of Croatia are exposed to the consequences of weather changes, such as irregularities in plant flowering, extreme weather conditions (most often sudden changes in environmental temperature), the spread of disease agents, and reduced water availability. All of this leads to stress and, consequently, to increased sensitivity of bees to various pathogens.

MATERIAL AND METHODS

This paper used secondary documentation (original documentation from beekeepers – records of work inside the apiary related to hive management and beekeeper behaviour for traceability of the product from the apiary to the consumer – and documentation from the Croatian Meteorological and Hydrological Service). The data required for this analysis were collected from publicly available sources and are based on monitoring and keeping records of the occurrence of weather conditions within five years (from 2019 to 2023) and the state of bee colonies within the five observed regions of the Republic of Croatia. The selected regions are: Central Croatia (Križevci), East (Osijek), Highlands (Gospić), Northern Croatian Littoral (Pula), Southern Croatian Littoral (Split). One city was selected from each region to be the centre of the research, as stated. The goal is to primarily focus on the Koprivnica-Križevci County, specifically Križevci, as the starting region where Križevci University of Applied Sciences is located (Figure 1). The collected data on the state of bee colonies within the five observed regions are presented graphically and explained in text.

Beekeeping in the Republic of Croatia

In the Republic of Croatia (RH), most beekeepers are organised into local beekeeping associations. The organisation that brings together most beekeeping associations and beekeepers in the territory of the Republic of Croatia is the Croatian Beekeeping Association (Hrvatski pčelarski savez, HPS).

Figure 1. Monitored regions of the Republic of Croatia with their associated centres (cities)

The registered number of beekeepers in 2018 was 7,283, and they owned 372,002 bee colonies (MPRH, 2018). During 2018, the largest number of beekeepers and beehives was recorded in Split-Dalmatia County, and 779 (10.7%) beekeepers owned 37,191 (10%) beehives. The smallest number of beekeepers and beehives was recorded in Lika-Senj County, where 157 (2.16%) beekeepers owned 7,434 (2.0%) beehives. The estimate of annual honey production is based on data on average honey production per hive according to a survey conducted by HPS. The production of honey per bee colony largely depends on the weather and the composition of the plant cover, and it is estimated that the yield per hive averaged 20 kg of honey during 2017 and 2018. Total production in 2017 is estimated at 8,128 t, while production in 2018 was 7,440 t of honey.

In Croatia in 2022, 9,190 beekeepers engaged in beekeeping (2.7% more than in 2021) and 460,827 hives were registered. The number of bee colonies is ten per cent higher compared with the average of the five years from 2017 to 2021 (MPRH, 2022).

Almost 41% of beekeepers have up to 30 hives, and together they own 13.5% of the total number of hives. More than half of the registered beekeepers (5,100 or 55.5%) own between 31 and 150 colonies, or approximately 70% of all hives. More than 150 bee colonies are owned by 323 registered beekeepers (3.5% of them).

According to the data of the Croatian Bureau of Statistics (MPRH, 2023), honey production in 2022 amounted to 8,295 t, which is 77.5% more than in 2021. Self-sufficiency in honey production in 2021 was 72.8%. Net imports of honey in 2022 amounted to 2,352 t.

Figure 2 shows the state of beekeeping in the Republic of Croatia in the period from 2017 to 2022.

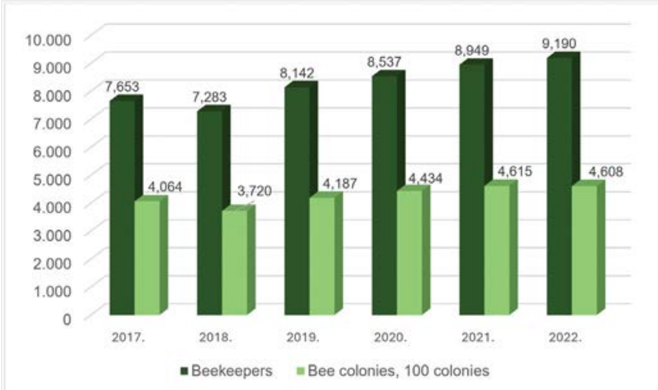

Figure 2. Number of beekeepers and bee colonies

(Source: Croatian Beekeeping Association; Processed by Ministry of Agriculture, 2023)

The placement of honey on the market depends on the size of the bee farm. Beekeepers with fewer hives predominantly sell through one of the forms of direct sales at the place of production or at local markets. About 75% of beekeepers market bee products through direct sales, while 25% of beekeepers participate in wholesale sales. Sales in retail chains and supermarkets are covered by large honey suppliers and packers. According to the Ministry of Agriculture, 24 honey buyers/packers are registered in Croatia.

Honey plants by climatic zones of the Republic of Croatia

The existing beekeeping resources of the Pannonian part of Croatia include orchards, meadows, and pastures, which constitute the main pasture in early spring. After the spring development, the first strong pastures of oilseed rape and black locust follow, which represent the main, abundant and short-term pasture for beekeepers. After the flowering of black locust pastures of amorpha, chestnut, and linden follow, species that bloom relatively briefly, so that in most cases the pasture-free period begins at the end of June. Beekeepers in Slavonia rely on sunflower pastures at the end of June and in July, from which bees can also collect significant amounts of nectar. At the end of summer, the flowering of goldenrod begins, a plant species that is a rich source of nectar and pollen for bees, especially during the dry season. A similar situation occurs in the Primorje region, but if the sage and bramble pastures fail, the pasture-free period begins as early as May, so beekeepers are forced to move their bee colonies, most often to Lika, hoping for meadow pasture. In late April and early May, the tangerine pasture, which is one of the most honey-producing plants, begins in the Neretva valleys. In June, honeydew may appear on Montpellier maple (*Acer monspessulanum* L.) and field maple (*Acer campestre*) in certain locations in the Dalmatian hinterland. If the summer months are not very dry, in August, white and red heather (*Satureja montana* and *Satureja subspicata*) pastures can be expected, and beekeepers on the Pelješac peninsula and the southern Dalmatian islands can hope for heather pastures in September and October. In the mountainous part of Croatia, the spring development of the bee colony is delayed due to the specific climate of that area, so in normal years, bees begin to develop more intensively at the end of April and in May. After the developmental grazing on mountain maple, wild cherry and plants of the ground forest layer (spring grasses), coniferous honeydew appears at the end of June, especially on fir, which is also the main grazing for some beekeepers in the area. Grazing on fir is very interesting but also specific because honey production does not occur regularly or abundantly every year or in all locations at the same time. With favourable weather conditions, aphids, especially green and brown aphids, play the main role. Thanks to its climatic diversity and the large number of honey plant species (Table 1), Croatia has great potential to produce varietal honey. However, in recent years, these natural resources have often not been used to any great extent, primarily due to the influence of weather conditions precisely at the time of flowering of honey plants. Climate change in an area should be distinguished from variations within a certain climatic period; variations refer to differences within much shorter periods, for example from one year to another (Prđun, 2017), as will be seen in this paper. Thus, we can see that two consecutive winters are not the same: one can be noticeably colder (or warmer) than the other.

Table 1. Flowering time of honey plants in the Republic of Croatia-main bee pasture

Climatic areas of Croatia	Plant name	Flowering time/month	Plant name	Flowering time/month
Continental Croatia	Hazel (*Corylus avellana* L.)	I.-III.	Willow (*Salix caprea* L.)	III. i IV.
	Oilseed rape (*Brassica napus* var. oleifera DC.)	IV. (spring in VI.)	Black locust (*Robinia pseudacacia* L.)	Early V.
	Fruit trees	III.-V.	Amorpha (*Amorpha fruticosa* L.)	Early VI.
	Sweet chestnut (*Castanea sativa* Mill.)	VI.	Linden (*Tilia* spp.)	VI. – early VII.
	Lavender (*Lavandula* spp.)	VI. i VII.	Sunflower (*Helianthus annuus* L.)	VII.
	Evodia (*Tetradium daniellii*)	VII. i VIII.	Giant goldenrod (*Solidago gigantea* Aiton.)	VI.-IX.
	Common goldenrod (*Solidago virgaaurea* L.)	VII.-IX.	Ivy (*Hedera helix* L.)	VIII.-XI.

Continued. Table 1

Climatic areas of Croatia	Plant name	Flowering time/month	Plant name	Flowering time/month
Mountain and coastal Croatia	Almond (*Amygdalus communis* L.)	I.-III.	Bay leaf (*Laurus nobilis* L.)	II. - end of IV.
	Laurustinus (*Viburnum tinus* L.)	I.-VI.*	Yellow goldenrod (*Asphodeline lutea* L.)	III.-V.
	Cypress (*Cupressus sempervirens* L.)	III.-V.	Broadleaf boxwood (*Phillyrea latifolia* L.)	III.-V.
	Rosemary (*Rosmarinus ofjicinalis* L.)	III.-V.	Sharp-needle juniper (*Juniperus oxycedrus* L.)	III.-IV.
	Turkish cherry (*Prunus mahaleb* L.)	Early IV.	Oak (*Quercus ilex* L.)	IV.
	Aleppo pine (*Pinus halepensis* Mill.)	IV.-V.	Fir (*Abies alba*)	IV.-V.
	Aurinia (*Aurinia sinuata* L.)	III.-VI.	Snapdragon (*Antirrhinum majus* L.)	III.-XI.
	Dalamtian laburnum (*Petteria ramentacea Sieber*)	IV.	Montpellier maple (*Acer monspessulanum* L.)	IV.-V.
	Rowan (*Sorbus domestica* L.)	IV.-V.	Christ's thorn (*Euphorbia milii*)	IV.-VI.
	Stinker (*Pistacia terebinthus* L.)	IV.-VII.	Mediterranean immortelle (*Helichrysum italicum* G.Don f.)	IV.-VII.
	Saber carpobrot (*Carpobrotus acinaciformis* L.)	IV.-X.	Sea blackberry (*Rubus ulmifolius* L.)	IV.-X.
	The sticky oman (*Dittrichia viscosa* L.)	IV.-XII.	Black pine (*Pinus nigra* Arnold)	V.
	Mountain maple (*Acer obtusalum* Kit.)	V.	Scorzonera (*Scorzonera villosa* Scop.)	V.-VI.
	Smoke tree (*Cotinus coggygria* Scop.)	V.-VI.	Olive (*Olea europaea* L.)	V.-VI.
	Meadow sage (*Salvia pratensis* L.)	V.-VII.	Myrtle (*Myrtus communis* L.)	V.-VIII.
Mountain and coastal Croatia	Pithospora (*Pittosporum tobira* Thunb. W. T. Aiton)	V.-IX.	Honey oak (*Quercus pubescens* Willd.)	VI.
	Dalmatian sharp leaf (*Onosma echioides* subsp. Dalmatica L.)	VI.-VII.	Lavender (*Lavandula* spp.)	VI.-VIII.
	Drypis spinosa (*Drypis spinosa* subsp. jacquiniana Murb. & Wettst.)	VI.-VIII.	Rue (*Ruta angustifolia* Pers.)	VI.-VIII.
	Great Yellow Gentian (*Gentiana lutea* L.)	VI.-IX.	Willow grass (*Teucrium montanum* L.)	VI.-IX.
	Sea wormwood (*Artemisia caerulescens* L.)	VI.-IX.	Wooly broom (*Cirsium eriophorum* L.)	VI.-X.
	Waldstein's belflower (*Campanula waldsteiniana*)	VII.-VIII.	Chaste tree (*Vitex agnus castus*)	VII.-IX.
	Coastal savory (*Satureja montana* L.)	VII.-IX.	White lettuce (*Marrubium incanum* Desr.)	VII.-IX.
	Catnip (*Nepeta cataria* L.)	VII.-IX.	Coastal dogwood (*Crithmum maritimum* L.)	VIII.-IX.
	Carob (*Ceratonia siliqua* L.)	VIII.-X.	Strawberry tree (*Arbutus unedo* L.)	X.-XII.

Note: * depending on terrain
Sources: Bučar (2008); Bučar (2018); Rađa (2024); Srečec and Erhatić (2021)

RESULTS AND DISCUSSION

Impact of variations within the climate period (2019–2023) on the flowering of honey plants in continental Croatia

A brief overview of the impact of weather conditions on the main bee pastures in continental Croatia and on bee activity is shown in Figures 3, 11, 16 and in Figures 4, 5, 7-10, 12-15, 17, 18, with special emphasis on central Croatia (City of Križevci).

Figure 3. Impact of variations within the monitored climatic period on the main honey-bearing pastures of continental Croatia (central Croatia – City of Križevci) and bee activity

Central Croatia: Križevci 2019–2023 – impact of weather conditions on the main bee pastures and activity of bee colonies

In 2019, spring grazing began at the start of spring (temperatures were favourable for flowering, as shown in Figure 4).

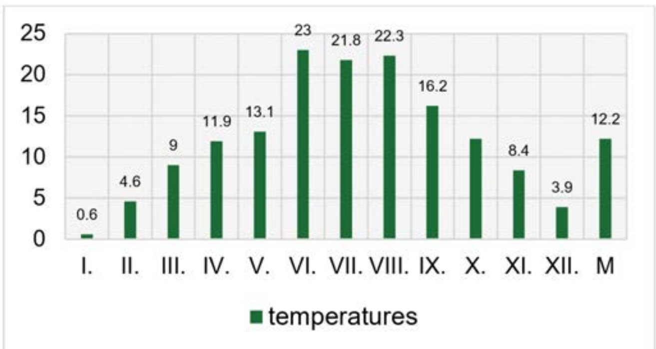

Figure 4. Average monthly dry-bulb temperature (°C) – Križevci 2019 (DHMZ, 2019-2023)

In 2019, the highest amount of precipitation occurred in May, with 24 rainy days and only 2 clear days (the main black locust (*Robinia pseudoacacia* L.) pasture was very weak, as shown in Figure 5). Heavy rainfall during the spring pasture and the acacia pasture favoured the development of *Varroa*. After the black locust, the chestnut (*Castanea sativa*) and linden (*Tilia*) pastures follow.

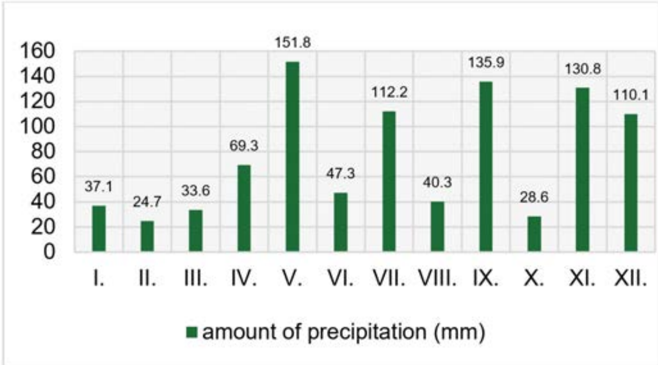

Figure 5. Monthly precipitation (mm) – Križevci 2019 (DHMZ, 2019-2023)

During the linden pasture (June) there was not much precipitation (10 clear days and 8 rainy days), which provided good conditions for bees to fly out of the hives. Chestnut pasture occurred in mid-June during sunny days. Flowering progressed well until July (17 rainy days, as shown in Figure 7). Bee activity in 2019 is shown in Figure 6.

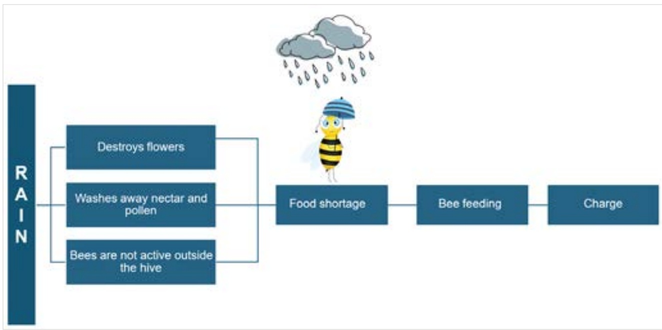

Figure 6. Bee activity in 2019

In 2020, temperatures at the beginning of the year were favourable for beekeepers (as shown in Figure 8). During the black locust season, there was no rain, only light drizzle (which increases nectar production). In August, high temperatures and a dry period occurred, requiring earlier feeding (shown in Figure 7).

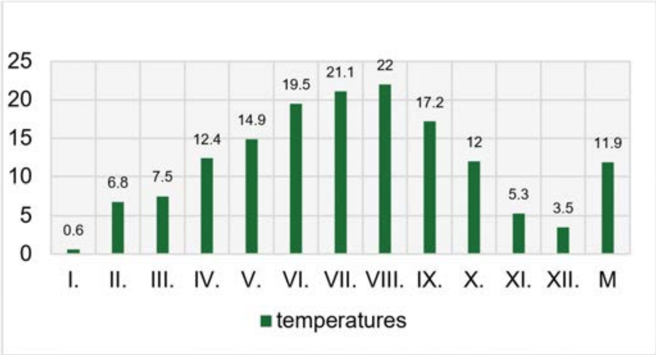

Figure 7. Average monthly dry-bulb temperature (°C) – Križevci 2020 (DHMZ, 2019-2023)

In 2020, rainfall in July caused a decline in linden and chestnut flowering, resulting in poorer pasture (shown in Figure 8). Rain in October affected colony treatments for *Varroa* (shown in Figure 8).

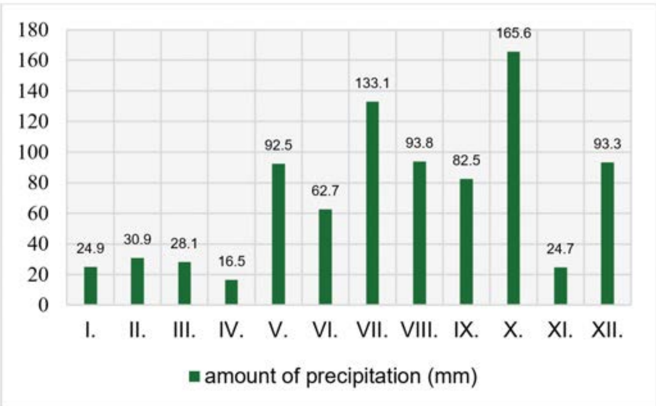

Figure 8. Monthly precipitation (mm) – Križevci 2020 (DHMZ, 2019-2023)

In 2021, the winter was mild (no hibernation for bees) (shown in Figure 10). The queen laying eggs leads to high food consumption. Spring grazing was supported by suitable temperatures, resulting in good yields. June was dry (weak linden and chestnut grazing). Honey production was low for the rest of the summer. Additional feeding was required (shown in Figure 9).

In 2021, May had 20 rainy days and strong winds, resulting in poor black locust grazing (shown in Figure 10). Rainy days meant no hive departures and, therefore, higher food consumption. Bee activity in 2021 is shown in Figure 11.

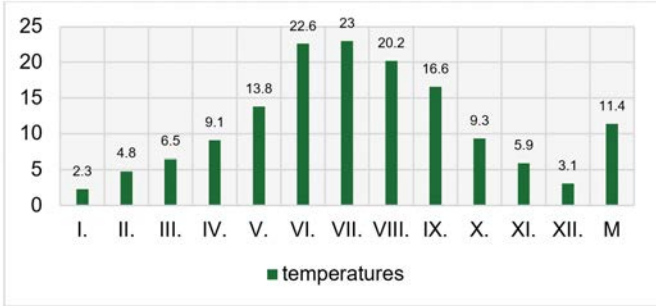

Figure 9. Average monthly dry-bulb temperature (°C) – Križevci 2021 (DHMZ, 2019-2023)

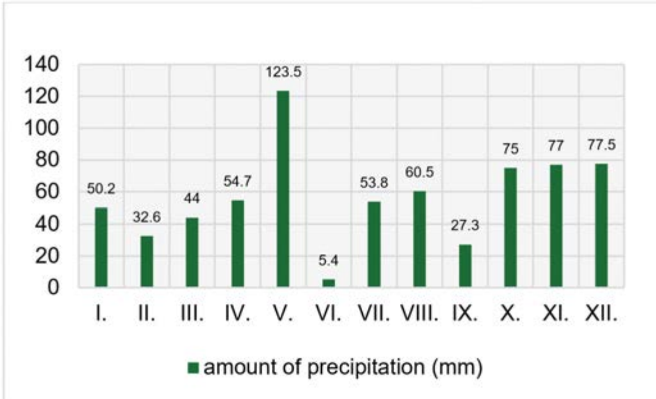

Figure 10. Monthly precipitation (mm) – Križevci 2021 (DHMZ, 2019-2023)

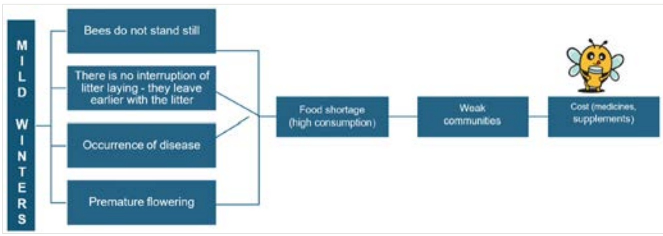

Figure 11. Bee activity in 2021

In 2022, the winter was mild (shown in Figure 12). It was one of the more favourable years for beekeepers, with high-yielding pastures. Warm February temperatures caused early flowering of spring crops and fruit trees. In late March and early April, frost resulted in a poor first spring pasture and damage to spring crops and many fruit trees.

In 2022, high temperatures in summer led to hive ventilation, great effort for the bees, increased water intake into the hives, and a high demand for water. There was little precipitation in the summer months (shown in Figure 13).

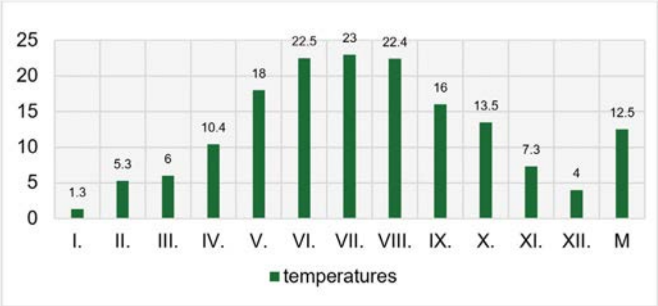

Figure 12. Average monthly dry-bulb temperature (°C) – Križevci 2022 (DHMZ, 2019-2023)

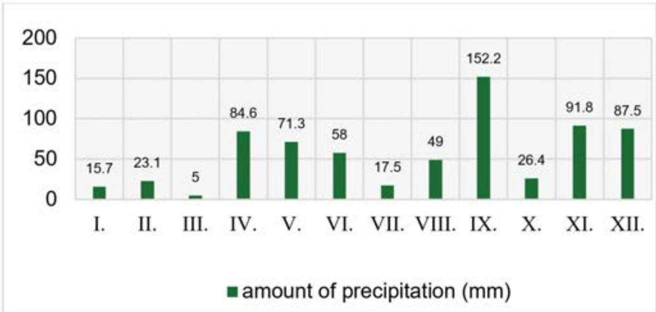

Figure 13. Monthly precipitation (mm) – Križevci 2022 (DHMZ, 2019-2023)

Honey production from black locust was excellent (good yields in the hive). Linden and chestnut grazing also produced good yields.

In 2023, rainfall was the highest of the monitored period, and temperatures were very high (Figures 14 and 15). Bees require feeding (high costs). Flowering of spring crops and fruit trees was delayed (fruit trees were two to three weeks late – a shock to nature). Oilseed rape and acacia flowered simultaneously (making the honey variety questionable). Frost also occurred.

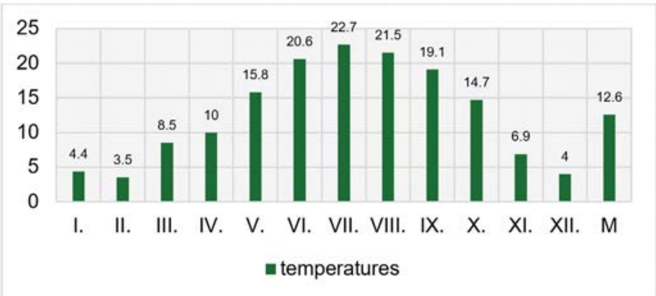

Figure 14. Average monthly dry-bulb temperature (°C) – Križevci 2023 (DHMZ, 2019-2023)

In 2023, January was very rainy, and February was cold (delayed first cleansing flight of bees, leading to the occurrence of nosemosis and treatment of colonies). Rain in summer resulted in poor yields and high feeding costs. *Varroa* was present. Bad weather in summer (strong stormy wind accompanied by rain and hail) is shown in Figure 15. Bee activity in 2023 is shown in Figure 16.

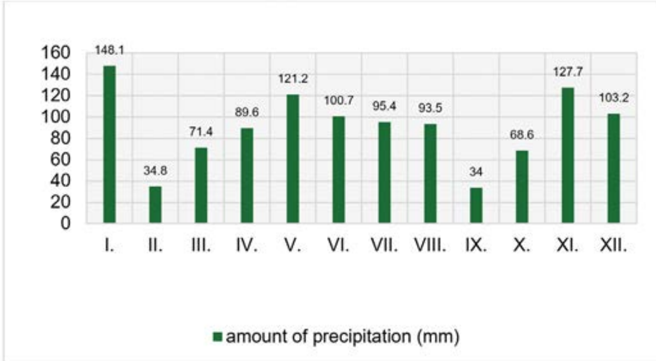

Figure 15. Monthly precipitation (mm) – Križevci 2023 (DHMZ, 2019-2023)

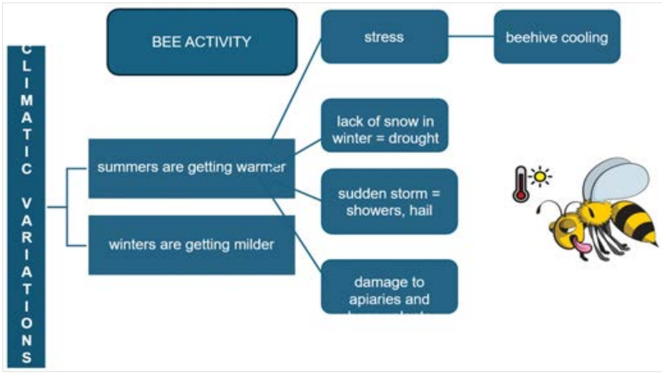

Figure 16. Bee activity in 2023

Consideration of climate parameters for Križevci in the period from 2019 to 2023

Temperature variations show a tendency to increase from year to year. Winters are becoming warmer (weaker bee colonies). Summers are becoming warmer with long dry periods (thunderstorms), leading to reduced nectar intake into hives and increased stress for bees (shown in Figures 17 and 18). The development of diseases, lack of food, and weakening of bee colonies are observed. Changes in the flowering calendar of honey plants also occur (premature or simultaneous flowering).

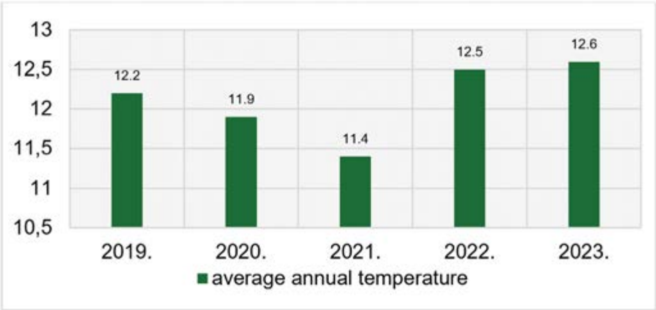

Figure 17. Average annual dry-bulb temperatures (°C) – Križevci 2019–2023 (DHMZ, 2019-2023)

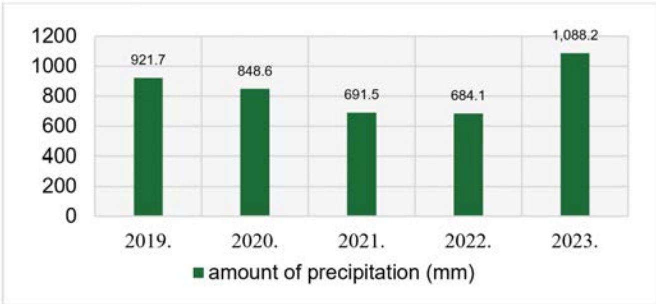

Figure 18. Total precipitation (mm) – Križevci 2019–2023 (DHMZ, 2019-2023)

Eastern Croatia: Osijek 2019–2023 – the impact of weather conditions on the main bee pastures and bee colony activity

A general overview of the impact of weather conditions on the main bee pastures of continental Croatia and bee activity is shown in Figure 19 and in Figures 20 and 21, with special reference to eastern Croatia (City of Osijek).

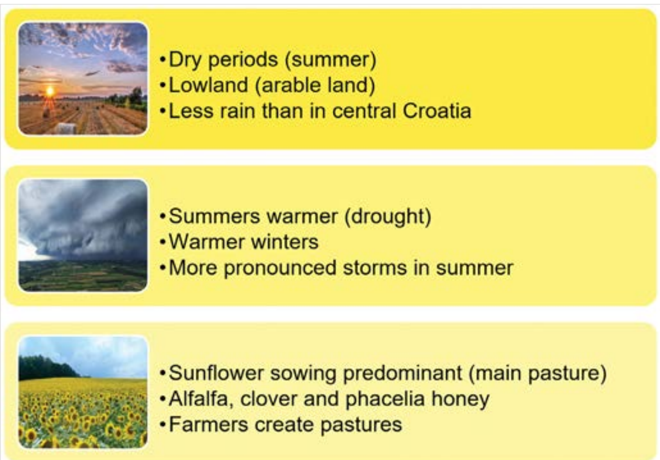

Figure 19. Impact of variations within the monitored climatic period on the main honey-bearing pastures of continental Croatia (eastern Croatia – City of Osijek) and on bee activity

Consideration of climate parameters for Osijek in the period from 2019 to 2023

Affected by droughts and dry periods. Dry summers with little water (shown in Figures 20 and 21). Sunflower (*Helianthus annuus* L.) is one of the main pastures for bees.

Advantage: Farmers help beekeepers by sowing crops, thereby creating new pastures.

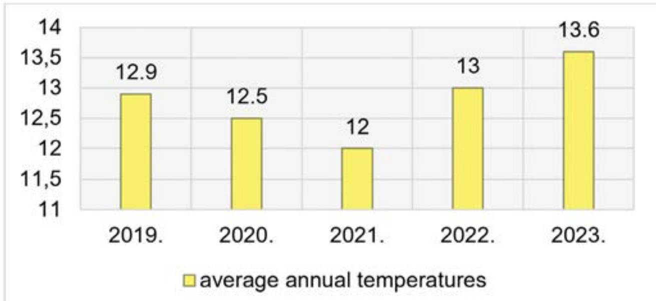

Figure 20. Average annual dry-bulb temperatures (°C) - Osijek 2019-2023 (DHMZ, 2019-2023)

PRECIPITATION: Less than Križevci. Unexpected occurrence of storms (strong wind and hail).

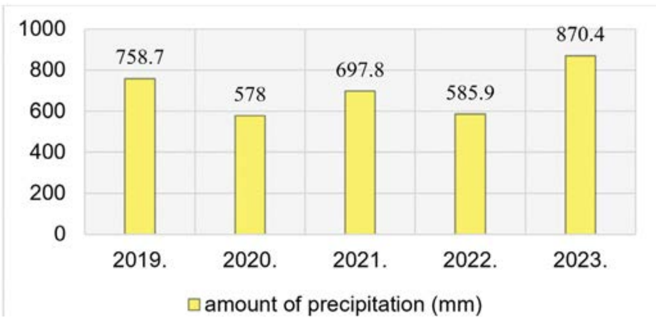

Figure 21. Annual precipitation (mm) – Osijek 2019–2023 (DHMZ, 2019-2023)

The impact of variations within the climatic period (2019–2023) on the flowering of honey plants in coastal and mountainous Croatia

A brief overview of the impact of weather conditions on the main bee pastures of coastal and mountainous Croatia and bee activity is shown in Figures 22, 23, 26 and in Figures 24, 25, 27 to 30, with special emphasis on the northern Croatian coast (City of Pula), mountainous Croatia (City of Gospić), and the southern Croatian coast (City of Split).

Figure 22. The influence of variations within the monitored climatic period on the main honey pastures of mountainous and coastal Croatia

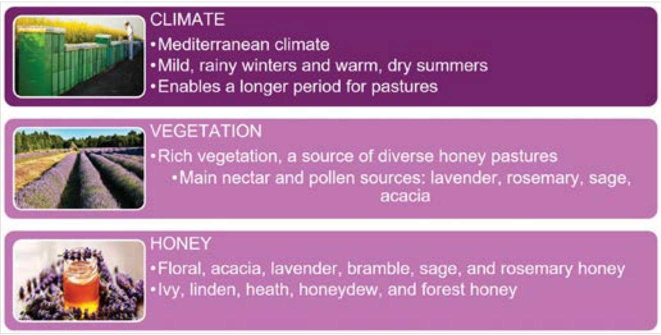

Figure 23. The impact of variations within the monitored climatic period on the main honey-bearing pastures of mountainous Croatia (City of Gospić) and on bee activity

Consideration of climate parameters for Pula 2019–2023

In the years 2019–2023, winters have been getting warmer: in 2019 (January 5.2 °C), in 2023 (January 8.2 °C) – warming (shown in Figure 24).

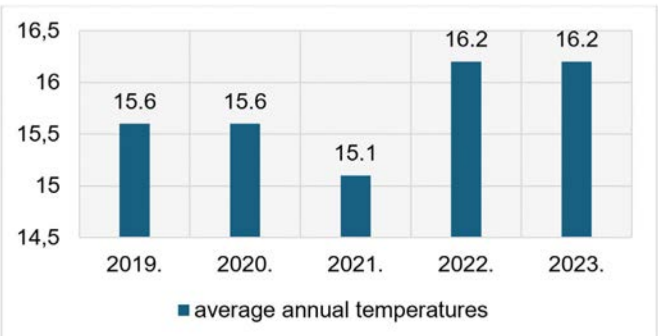

Figure 24. Average annual dry-bulb temperatures (°C) – Pula 2019–2023 (DHMZ, 2019-2023)

In the years 2019–2023, light rains and local showers (short-lived) occurred; drought periods (reduced nectar quantity and longer periods without water); bramble pasture (significant in southern Istria); and ivy (suitable because it blooms late) are shown in Figure 25.

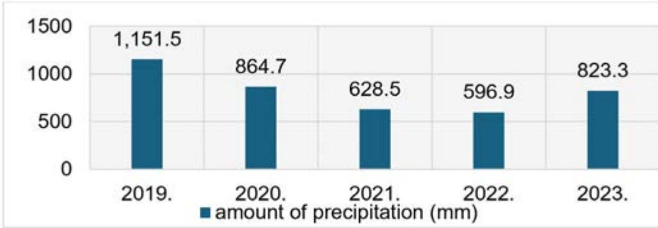

Figure 25. Annual precipitation (mm) – Pula 2019–2023 (DHMZ, 2019-2023)

Figure 26. The impact of variations within the monitored climatic period on the main honey-bearing pastures of the southern Croatian coast (City of Split) and on bee activity

Consideration of climate parameters for Gospić 2019–2023

In the years 2019–2023, temperatures increased (shown in Figure 27), with heat waves, mild winters, reduced snow cover and changes in seasonal precipitation.

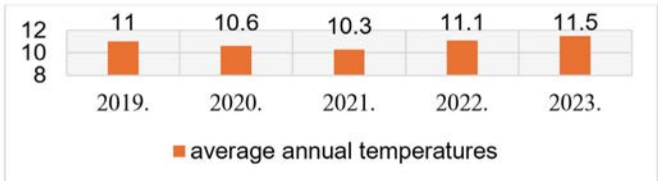

Figure 27. Average annual dry-bulb temperatures (°C) – Gospić 2019–2023 (DHMZ, 2019-2023)

Strong storms and long-term droughts occurred (hive migration to Lonjsko polje and the Sava River area). Hive migration was required during the large and main grazing periods.

In the years 2019–2023, heavy rains also occurred; in 2023, there were 150 days with precipitation. Hive control was required (parasites and diseases); humid and warm weather resulted in *Varroa* infestation (treatment required), as shown in Figure 28.

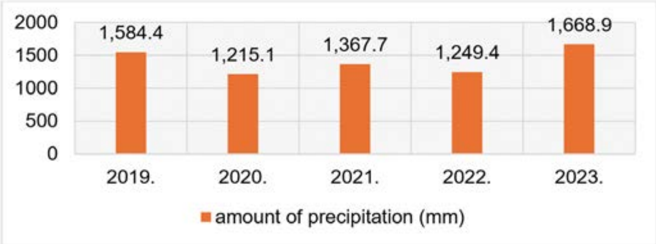

Figure 28. Annual precipitation (mm) – Gospić 2019–2023 (DHMZ, 2019-2023)

Future: Rainfall will decrease, and summers will become warmer, with more frequent migration and more regular inspections (timely response and treatment of hives).

Consideration of climate parameters for Split 2019–2023

In the years 2019–2023, drought periods became longer, reducing the number of honey-bearing plants. Mild winters and earlier springs can extend the growing season (longer activity period and more opportunities to collect nectar). Stress increases (too little rest; lower disease resistance), requiring hive relocation. Temperatures are rising, winters are mild, and droughts are becoming more frequent (shown in Figure 29).

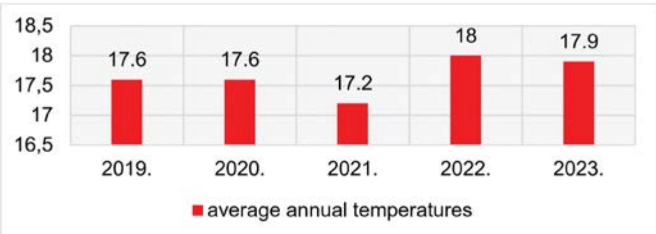

Figure 29. Average annual dry-bulb temperatures (°C) – Split 2019–2023 (DHMZ, 2019-2023)

In the years 2019–2023, unexpected rains became an increasingly frequent phenomenon (shown in Figure 30).

Beekeeping is threatened, and it is high time to take measures to protect it, because if there are no bees, human survival is questionable.

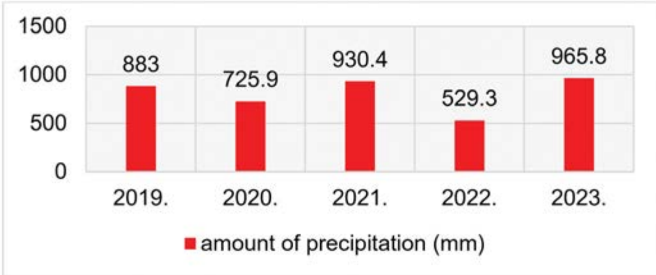

Figure 30. Annual precipitation (mm) – Split 2019–2023 (DHMZ, 2019-2023)

Five-year monitoring of climate variations in three climatic regions of the Republic of Croatia and their impact on plant cover, bee forage sources, and bee colony biology can be summarised in Figure 31. Warming (increased air temperature and reduced precipitation) has a negative impact on honey plants, and consequently on bee biology.

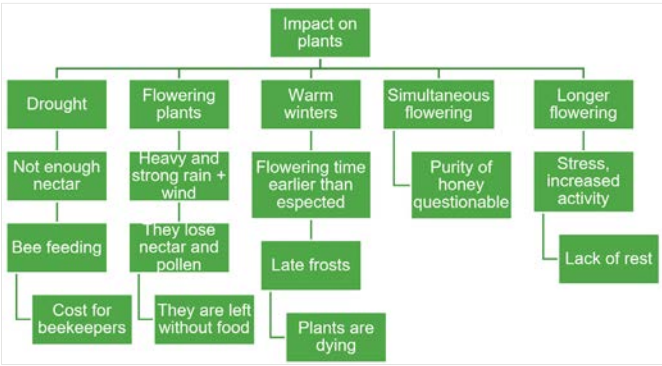

Figure 31. Summary of the impact of climate variations over five years in three climatic areas, monitored in five regions of the Republic of Croatia, on honey plants and the life cycle of bees

Apis mellifera subspecies are found in a wide range of climates, from hot and dry to tropical and temperate (Abou-Shaara et al., 2017). In the Republic of Croatia, the most widespread bee is the subspecies *Apis mellifera* var. *carnica*. The results show that temperature and relative humidity, wind speed, precipitation, and light intensity (day length, number of sunny days) affect bee activity in nectar and pollen collection and pollination activities.

Foraging occurs in a wide range of temperatures, from 10 °C to 40 °C (Jiang et al., 2016; Abou-Shaara et al., 2017) reported that bees are not active on rainy days when the relative humidity is higher than 80%. Honeybees can predict future precipitation by increasing their foraging activity. He et al. (2016), using radio frequency identification (RFID) tracking, showed that forager bees work more intensively on days preceding rain than on days following a sunny day.

During long, windy periods, bees refrain from foraging and honey production stops because flying in such conditions is energetically expensive (increased food consumption, while supply is simultaneously reduced due to reduced intake). Hennessy et al. (2020) found that a wind speed of only 2.75 m/s results in a 37% reduction in flower visits. Therefore, the choice of a bee-foraging location must ensure leeward conditions, as wind is a strong climatic factor that limits honey production. The ambient temperature interferes with colony life; when the temperature is too high or too low compared with the hive temperature of 35 °C, which guarantees brood development, bees must invest additional energy to cool or heat the hive. However, according to Stabentheiner et al. (2012), thermoregulation in the hive was absent at ambient temperatures ranging from 13 – 30 °C. Bees inside the hive regulate microclimate conditions suitable for brood development and daily colony activity. Bees have exceptional thermoregulatory power; this physiological function allows them to stabilise body heat according to environmental conditions and different needs, enabling colonies to survive throughout the year (Southwick and Heldmaier, 1987). Thus, worker bees actively produce heat by shivering their flight muscles to maintain the temperature of the winter brood ball above ambient temperature (Nürnberger et al., 2018). In this way, during the winter months, honeybees use all their strength to warm the hive and preserve the future generation of bees. Therefore, monitoring climate conditions is crucial for maintaining bee health. Beekeepers can inspect the hive only during the day, without rain, and when the ambient temperature is in the range of 15–38 °C (Zacepins et al., 2016). New technologies from the domain of digital agriculture would provide significant help in monitoring the biological status of bees in hives, as well as climate variations. However, beekeepers are usually reluctant to invest in digital solutions. The main reason is uncertainty about the economic benefits that such systems could provide (Robustillo et al., 2022). To reduce costs, only a fraction of the hives in an apiary could be equipped with sensors, assuming that different colonies in the same environment are in similar conditions (Hadjur et al., 2022).

CONCLUSIONS

Climate variations in the three climatic regions of the Republic of Croatia are manifested in the prevalence of mild winters, the earlier arrival of spring, dry and warm summers (warming from year to year), unexpected occurrences of storms and frost, and large amounts of precipitation in 2019 and 2023, but in less expected months (January and May). The occurrence of aseasonality is increasingly common in the monitored years compared with the introductory definition of the temperate climatic region of the Republic of Croatia, which implies a regular change of seasons. Thus, climate variations monitored in five regions of the Republic of Croatia have a negative impact on the phenological phases of honey plants and on bee biology. Therefore, the introduction of young queens is necessary to reduce the effects of stress and maintain the strength of bee colonies under the newly created climatic conditions. One of the preventive measures in beekeeping technology would be the sowing of honey crops near apiaries (black cumin, *Nigella sativa* L.; the related species wild fennel flower, *Nigella arvensis*, an extremely honey-producing plant that thrives in arid areas) to avoid critical climatic influences on bee activity when they fly to distant pastures. We cannot influence natural disasters, but we can react in a timely manner if we include new digital technologies (a set of theories and techniques that enable the practical use of scientific knowledge) to predict critical situations and make decisions to avoid them. Therefore, educating beekeepers in the application of new digital technologies could result in timely decisions to avoid the negative impact of climate variation on bee activity in and outside the hives. Additional work should be done on the commercialisation of digital equipment, for example, for the wider application of RFID sensors for precision beekeeping. All the mentioned activities in beekeeping technology could help reduce the negative impact of climate variations on the biological activity of bees.

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