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IMPACT OF CLIMATE CHANGE OF AIR TEMPERATURE ON VITAL ACTIVITY OF THE BEE FAMILIES

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Abstract

The purpose of this paper was to determine the correlation between the monthly average atmospheric air temperature values at different periods of the year and the evolution of the valuie morpho-productive characters of the bee families, thereby elucidating the impact of climate change on the vital activity of bee colonies Apis mellifera. The scientific researches were carried out at the experimental apiary of the Institute of Zoology of the Academy of Sciences of Moldova, located in the central part of Moldavian Codri. Research results have demonstrated that there are positive correlations between the atmospheric air temperature in October of the last year and January of this year and the wintering resistance of the bees colonies (r_{xy} = 0.469 and 0.768). High temperatures of atmospheric air in July, August and September have a negative impact on the wintering resistance of bee families in the next year (r_{xy} = -0.479; -0.699 and -0.494). The prolificity of queens is positively influenced by January temperatures (r_{xy} = 0.464 ± 0.076; t_r = 6.11; P <0.001). Air temperature in February, April and June correlates negatively with the prolificity of queens, estimated in June (r_{xy} = -0.594; -0.795 and -0.461). High temperatures in July and September negatively influence the prolificity of queens in the following year (r_{xy} = -0.531 and -0.711). Colony strength, evaluated in June, is negatively influenced by air temperatures in April and June (r_{xy} = -0.603; -0.691), also correlated with air temperature in September of the last year (r_{xy} = - 0.60; t_r = 2.71; P <0.01), as well as positive one with October of the same year (r_{xy} = 0.517; t_r = 2.00; P <0.05). The viability of the bee brood is positively influenced by the January and February air temperatures (r_{xy} = 0.495 and 0.511), and - negative in the May (r_{xy} = -0.548, t_r = 2.22, P <0.05). Overall, the annual average air temperature positively influence the viability of the brood (r_{xy} = 0.833; t_r = 7.71; P <0.001). Honey production, appreciated at the end of June, tends to be positively influenced by the atmospheric air temperature in January (r_{xy} = 0.488; t_r = 1.81; P <0.1) and, negatively, by the temperature in June (r_{xy} = -0.497; t_r = 1.87; P <0.1). Atmospheric air temperatures in July and September have a negative impact on honey production in the next year (r_{xy} = -0.548 and -0.684; t_r = 2.22 and 3.64; P <0.05 and <0.001); but in October has a positive impact on this production (r_{xy} = 0.513; t_r = 2.00; P <0.05).

Key words: *bees, climate change, temperature, air, correlations, characters, morpho-productive.*

INTRODUCTION

In the last decades of the XX century and the beginning of the XXI century, human society exerts a growing influence on the climate, in particular on Earth's temperature, by burning fossil fuels, deforestation and intensive farming livestock. This adds enormous amounts of greenhouse gases to those naturally occurring in the atmosphere, increasing the greenhouse effect and global warming.

According to a report of the European Commission (Causes of climate change, 2018), the current global average temperature on Earth is 0.85ºC higher than it was in the late 19th century. Each of the past three decades has been warmer than any preceding decade.

Another European source (Consequences of Climate Change, 2018) mentioned that climate change on Earth already have an impact on human health. There has been an increase in the number of heat-related deaths in some regions and we are already seeing changes in the distribution of some water-borne illnesses and disease vectors.

The most affected economic sectors of society are: agriculture, forestry, energy and tourism. Global climate change is happening so fast that the survival of many plant and animal species is threatened.

Many terrestrial, freshwater and marine species have already migrated. Some plant and animal species will be at increased risk of extinction if global average temperatures continue to rise unchecked, according to Paris Agreement - UN Framework Convention on Climate Change (2016) and Council Decision (EU) 2016/1841 (2016).

In Technical Report of Greenpeace Research Laboratories (2013) it was mentioned that: „climate change, such as increasing temperatures, changes in rainfall patterns and more erratic or extreme weather events, will have impacts on pollinator populations. Some of these changes could affect pollinators individually and ultimately their communities, becoming reflected in higher extinction rates of pollinator species”.

For example, in Poland it has been documented that honeybees reacts to climate change by making their first cleansing flight (spring cleaning) earlier than normal, which coincides with the phenomenon commonly known as "seasonal change".

The cleansing flight took place one month earlier, compared to the average during the 25-years observation period, which was attributed to the temperature rises (Sparks et al., 2010).

Climate change can lead to the changing of flowering patterns, shifting the flowering period of honey plants that are a major food source for bees, or seasonal change, in which case the flowering period no longer corresponds to the moment of spring awakening of bees (Kremen et al., 2007).

Because of changes in times and patterns of flowering in plants, climate change also affects the interaction between pollinators and their sources of food.

Thus, the researchers (Memmott et al., 2007) demonstrates the reducing of available floral resources to 17-50% of all pollinator species, depending on model of climat change that cause the modification in flowering patterns of plants.

The authors anticipates that the predicted result of these disruptions is the extinction of pollinators, plants and their crucial interactions.

In the abovementioned bibliographic sources, besides the general conclusions made by the authors, concrete information about the influence of climate change on evolution of the morpho-productive characters of bee families is lacking.

At the same time, the above-mentioned bibliographic sources, besides the general conclusions made by the authors, lack information about the concrete influence of climate change on the evolution of morpho-productive characters of bee families.

In this context, the purpose of this paper was to determine the correlation between the parameters of the average monthly atmospheric air temperature values at different periods of the year and the evolution of the morpho-productive characters of the bee families, thereby elucidating the impact of climate change on the vital activity of bee colonies *Apis mellifera*.

MATERIALS AND METHODS

The scientific researches were carried out on bee families *Apis mellifera Carpatica,* at the experimental apiary of the Institute of Zoology of the Academy of Sciences of Moldova, located in the central part of Moldavian Codri, Forest District Ghidighici, Canton no. 8, Forest Sector no. 21. At the apiary there were a total of 50 bee families. Every bee colony were evaluated for the main morpho-productive reproductive and developmental characters (queen prolificity, family strength), wintering and disease resistance, brood viability, as well as productivity of honey accumulated in nest, according to our methods (Cebotari et al., 2010) described in the Zootechnical norme regarding breeding of bee families, the growth and certification of genitor beekeeping material, approved by Government Decision no. 306 of 28.04.2011 (Official Journal of the Republic of Moldova, 2011). Then the average value of each evaluated morpho-productive characters per apiary was calculated.

To study the impact of climate change on the vital activity of bee families, monthly and annual average of atmosferic air temperature data in the last 8 years (2010-2017), from the nearest hydrometeorological station in Bravicea, Calaras, at a distance of 27 km from the apiary, were used. During this period, for each month, Pirson's linear correlation coefficients were calculated between the monthly average of atmospheric air temperature and the average values per apiary of each of the 6 main morphoproductive characters of bee families, such as: queen prolificity, families strength, wintering colony resistance, disease resistance, brood viability and honey production of bee families. For the first half of the year, correlation coefficients were calculated between atmospheric air temperature and values of morpho-productive characters, evaluated in the same year at the end of June, with the exception of wintering resistance, which was assessed at the end of March. Given that in the second half of the year the climatic factors don't influence the morpho-productive characters, already evaluated in this year, the atmospheric air temperature variable in July-December was calculated in correlation with the value of the morpho-productive characters of the bee families from next year. The same correlation coefficients were also calculated for the average annual temperature of the atmospheric air and the average values per apiary of the above-mentioned in this 6 morpho-productive characters. For each correlation coefficient (r_{xy}) the criterion of certainty of the correlation (t_r) and the certainty threshold (P) after Student was calculated in part.

The obtained in experience data were statistically processed using computer software "STATISTICA - 12" and evaluated their certainty, according to variation biometric statistics, by methods of Плохинский Н.А. (1989).

RESULTS AND DISCUSSIONS

The results of the research have shown that the global warming phenomenon has been manifested also in the area of Bravicea Hydrometeorological Station, located near the site where the experimental apiary is situated. Moreover, in this area the effects of global warming were more evident, compared to data from the European Commission Report (2018). We found that the average annual air temperature rose from 10.4°C in 2010 to 10.9°C in 2017, i.e. by 0.5°C. If we compare the average air temperature during the first three years (2010-2012) of the research period with the average of the last three years (2015-2017), we find significant increase from 9.6°C to 11.1oC, or 1.5°C, which is very much and worrying. Because of this, during the relatively short research period of only 8 years, there were two terrible droughts in this area: one in 2011-2012 and another in 2015. High air temperatures and terrible droughts have had a negative impact on the flora and fauna of the given ecosystem, especially on agriculture in this area. We can suppose that if the warming of the air will continue at this rate, over several decades we will be witness of transformation of this area into an arid and deserted one.

Researches have shown that air temperature is one of the most important climatic factor that influences the vital activity of Apis mellifera bee families. Between this climatic factor and the evolution of the morpho-productive characters of the bee families there are correlative links of different size. The impact on bee families of the climate change in air temperature depends of the year period. It was found that the impact of air temperature on the vital activity of bee families is caused both by monthly average temperatures, in some concrete times of the year, and the annual average of air temperature. Climate change in air temperature in the first half of the year, especially in January, February, April and June, had the greatest impact on the vital activity of bee families (Table 1).

Thus, between the average air temperature in January and the queens prolificity, determined at the end of June, a significant positive correlation was found ($\mathbf{r_{xy}}$=0.464±0.076; $\mathbf{t_r}$=6.11; P<0.001).

This means that with the increase of air temperature in January, there is an increase in the prolificity of queens at the end of spring - early summer. Also, the January air temperature positively influences the wintering resistance of bee families (evaluated at the end of March), brood viability and honey production, appreciated at the end of summer. The correlation coefficients between these characters are of average size and are comprised among 0.469 - 0.495 (t_r=1.74 – 1.85; P <0.1).

At the same time, researches have shown that February's air temperature variability has a significant negative correlation on with queens prolificity and positive with brood viability, assessed at the beginning of the summer (June). The correlation coefficient between these variables is of medium size, but quite significant ($\mathbf{r_{xy}}$= -0.594±0.129; $\mathbf{t_r}$=2.59; P<0.05 and $\mathbf{r_{xy}}$=0.511±0.262; $\mathbf{t_r}$=1.96; P<0.05).

This means that the higher is air temperature in February, the lower the queen prolificity in the early summer, and the higher brood viability will be.

About the March air temperature we can not say if it influences in some way the vital activity of the bee families, since the correlation coefficients of this variable with the main morpho-productive characters are not significant, which does not allow us to make any definite conclusions.

Table 1. The correlation coefficient between the average monthly air temperature in the apiary area during the first half of the year and the medium value of the morpho-productive characters of bee families

Morpho-productive characters	$r_{xy} \pm m_r$	t_r	P	Morpho-productive characters	$r_{xy} \pm m_r$	t_r	P
Air temperature in January, t^0C				**Air temperature in February, t^0C**			
Wintering resistance	0.469±0.275	1.74	<0.1	Wintering resistance	0.015±0.353	0.04	>0.1
Queen prolificity	0.464±0.076	6.11	<0.001	Queen prolificity	-0.594±0.129	2.59	<0.05
Colony strength	0.439±0.285	1.54	>0.1	Colony strength	-0.006±0.353	0.01	>0.1
Disease resistance	0.269±0.328	0.82	>0.1	Disease resistance	0.009±0.353	0.03	>0.1
Brood viability	0.495±0.267	1.85	<0.1	Brood viability	0.511±0.262	1.96	<0.05
Honey production	0.488±0.269	1.81	<0.1	Honey production	0.370±0.303	1.21	>0.1
Air temperature in March, t^0C				**Air temperature in April, t^0C**			
Wintering resistance	0.107±0.349	0.31	>0.1	-	-	-	-
Queen prolificity	-0.129±0.347	0.37	>0.1	Queen prolificity	-0.795±0,130	6.12	<0.001
Colony strength	-0.331±0.314	1.05	>0.1	Colony strength	-0.603±0,225	2.68	<0.05
Disease resistance	0.161±0.344	0.47	>0.1	Disease resistance	0.070±0,352	0.20	>0.1
Brood viability	0.449±0.282	1.59	>0.1	Brood viability	0.182±0,342	0.53	>0.1
Honey production	0.401±0.296	1.35	>0.1	Honey production	-0.222±0,336	0.66	>0.1
Air temperature in May, t^0C				**Air temperature in June, t^0C**			
Queen prolificity	0.332±0.314	1.06	>0.1	Queen prolificity	-0.461±0,278	1.66	<0.1
Colony strength	0.421±0.291	1.45	>0.1	Colony strength	-0.691±0,184	3.76	<0.001
Disease resistance	-0.451±0.282	1.60	>0.1	Disease resistance	-0.350±0,310	1.13	>0.1
Brood viability	-0.548±0.247	2.22	<0.05	Brood viability	0.192±0,341	0.56	>0.1
Honey production	0.038±0.353	0.10	>0.1	Honey production	-0.497±0,266	1.87	<0.1

Research data demonstrates that April air temperature has an obvious impact on vital queen reproduction functions and bee family development. Thus, the air temperature in April is significantly negative correlated with the prolificity of the queen (**r_{xy}**= -0.795±0.130; **t_r**=6.12; P<0.001), and the colony strength (**r_{xy}**= -0.603±0.225; **t_r**=2.68; P<0.05). That is, with increasing of air temperature in April, queens prolificity decreasing will occur in early summer, which will diminish the strength of bee families.

We can say that the air temperature in May influences negatively the viability of the brood. Also, we observed that increased air temperature in May, led to decrease of the viability of brood. The correlation coefficient between these two variables is significant, of medium size and constitutes **r_{xy}**=-0.548±0.247; **t_r**=2.22; P<0.05. As for the impact of air temperature in May on other morpho-productive characters, we can not deduce certain conclusions, as the correlation coefficients between this variable and the main morpho-productive characters are not significant.

It was found that the air temperature in June has a greater impact on vital activity of bee families. Namely, the air temperature in this summer month has an obvious negative impact both on the reproduction and development functions and on the honey production capacity of the bee families. Thus, research data demonstrates that there is a significant negative high-level correlation between the air temperature in June and the colony strength. (**r_{xy}**=-0.691±0.184; **t_r**=3.76; P<0.001). The climatic variability of the air temperature in June has a negative correlation tendency with both the queen prolificity (**r_{xy}** = -0.461 ± 0.278, **t_r** = 1.66, P <0.1), as well as honey production (**r_{xy}**= -0.497±0.266; **t_r**=1.87; P<0.1). This means that as the June air temperature increases, there will be a fall in the strength of bee families and the production of honey, accumulated in the nest.

Generalizing the impact of climate changes in air temperature in the first half of the year, we can conclude that the raised temperatures during this period, especially in April-June, negatively influence the vital activity of bee families. First of all, the negative impact is directly manifested on honey flowers.

Under the action of high temperatures, they bloom suddenly and for a short time, and the removed nectar evaporates rapidly, becoming too consistent and inaccessible to bees. Secondly, excessively high temperatures inhibit the vital activity of nurses and worker bees, which leads to diminishing of the reproduction functions of queens and harvesting functions of worker bees.

This conclusion is in line with some of our previous researches (Cebotari et al., 2013) in which it was demonstrated that the excessively high spring-summer temperatures of a dry year, caused a drastic decrease in morpho-productive indices of bee families.

Starting in the second half of the year (Table 2), the air temperature in July-December has no impact on previously evaluated morpho-productive characters (by the end of June), but can have a direct impact on the vital activity of bees families, which is related to the consolidation of the colonies' strength and their preparation for wintering, as well as, indirectly, to the evolution of morpho-productive characters in the next year.

Table 2. Coefficient of correlation between the average monthly air temperature during the second half of the current year and the value of morpho-productive characters of bee families in the next year

Morpho-productive characters	**$r_{xy} \pm m_r$**	**t_r**	**P**	**Morpho-productive characters**	**$r_{xy} \pm m_r$**	**t_r**	**P**
Air temperature in July, t^0C				**Air temperature in August, t^0C**			
Wintering resistance	-0.479±0,272	1.76	P<0.1	Wintering resistance	-0.699±0,181	3.86	P<0.001
Queen prolificity	-0.531±0,254	2.09	P<0.05	Queen prolificity	-0.146±0,346	0.42	P>0.1
Colony strength	-0.233±0,334	0.70	P>0.1	Colony strength	0.040±0,353	0.11	P>0.1
Disease resistance	-0.045±0,353	0.13	P>0.1	Disease resistance	-0.067±0,352	0.19	P>0.1
Brood viability	0.157±0,345	0.46	P>0.1	Brood viability	0.388±0,300	1.29	P>0.1
Honey production	-0.548±0,247	2.22	P<0.05	Honey production	-0.206±0,339	0.61	P>0.1
Air temperature in September, t^0C				**Air temperature in Octomber, t^0C**			
Wintering resistance	-0.494±0,267	1.85	P<0.1	Wintering resistance	0.768±0,145	5.30	P<0.001
Queen prolificity	-0.711±0,175	4.06	P<0.001	Queen prolificity	-0.063±0,352	0.18	P>0.1
Colony strength	-0.606±0,224	2.71	P<0.01	Colony strength	0.517±0,259	2.00	P<0.05
Disease resistance	-0.139±0,347	0.40	P>0.1	Disease resistance	0.404±0,296	1.36	P>0.1
Brood viability	0.384±0,301	1.27	P>0.1	Brood viability	0.186±0,341	0.54	P>0.1
Honey production	-0.684±0,188	3.64	P<0.001	Honey production	0.513±0,261	1.97	P<0.05
Air temperature in November, t^0C				**Air temperature in December, t^0C**			
Wintering resistance	-0.264±0,329	0.80	P>0.1	Wintering resistance	-0.223±0,337	0.66	P>0.1
Queen prolificity	0.108±0,349	0.31	P>0.1	Queen prolificity	-0.100±0,350	0.28	P>0.1
Colony strength	0.394±0,299	1.32	P>0.1	Colony strength	-0.289±0,324	0.89	P>0.1
Disease resistance	0.222±0,336	0.66	P>0.1	Disease resistance	-0.061±0,352	0.17	P>0.1
Brood viability	-0.040±0,353	0.11	P>0.1	Brood viability	0.402±0,296	1.36	P>0.1
Honey production	0.260±0,330	0.79	P>0.1	Honey production	-0.055±0,353	0.16	P>0.1
Annual average, t^0C							
Wintering resistance	-0.528±0.255	2.07	P<0.05				
Queen prolificity	-0.440±0.285	1.54	P>0.1				
Colony strength	-0.295±0.323	0.91	P>0.1				
Disease resistance	0.178±0.342	0.52	P>0.1				
Brood viability	0.833±0.108	7.71	P<0.001				
Honey production	-0.121±0.348	0.35	P>0.1				

After analyzis of the atmospheric air temperature variability in the second half of the current year, correlated with the evolution of morpho-productive characters of bee families, evaluated in the first half of the next year, we found that this (air temperature) also had an impact quite obviously on the vital activity of bee families.

Thus, the atmospheric air temperature in July has a tendency negative impact on wintering resistance (**r_{xy}** = -0.479 ± 0.272; **t_r** = 1.76; P <0,1) and a significant negative impact on queens prolificity (**r_{xy}** = 0.531 ± 0.254, **t_r** = 2.09, P <0.05), as well as on honey production in the following year (**r_{xy}**= -0.548±0.247; **t_r**=2.22; P<0.05). This means that with the increase of atmospheric air temperature in July, a downward trend in wintering resistance of bee colonies, as well as, a significant decrease in the prolificity of queens and honey production, accumulated in the nest, in the next year will occur.

In August, climate change, by increasing atmospheric air temperature, has a significant negative impact on the wintering resistance of bee families the following year. The correlation coefficient between these two variables is high and quite significant, and according to the probability prognosis theory without error by Student, it has the highest threshold of certainty ($\mathbf{r_{xy}}$=-0.699 ±0.181; $\mathbf{t_r}$=3.86; P<0.001). This means that the higher is the atmospheric air temperature in August, the lower will be bee's wintering resistance. About variability of the values of other morpho-productive characters of the bee families, we can not say if they were or not influenced by the atmospheric air temperature in August, because the values of the correlation coefficients between these variables were not significant.

At the same time, the climatic change of atmospheric air temperature in September has an obvious impact on several morpho-productive characters of the vital activity of bee families in the coming year. Thus, the atmospheric air temperature in this autumn month has a negative impact on the wintering resistance of bee colonies ($\mathbf{r_{xy}}$=-0.494±0.267; $\mathbf{t_r}$=1.85; P<0.1) and a significant negative impact on queens prolificity ($\mathbf{r_{xy}}$=-0.711±0.175; $\mathbf{t_r}$=4.06; P<0.001), on the strength of bee families ($\mathbf{r_{xy}}$=-0.606±0.224; $\mathbf{t_r}$=2.71; P<0.01) and amount of honey accumulated in the nest ($\mathbf{r_{xy}}$=-0.684±0.188; $\mathbf{t_r}$=3.64; P<0,001). That is, with the rise of atmospheric air temperature in September, the next year there will be a decrease of wintering resistance, of queens prolificity, of colonies strength and their honey production.

Climate changes in atmospheric air temperature in October havean entirely different (contrariwise) influence on the vital activity of bee families. It has been found that the rise in atmospheric air temperature during this autumn month has a beneficial impact on the main morpho-productive characters of bee families. The high temperatures of this month correlate positively with the wintering resistance of bee colonies ($\mathbf{r_{xy}}$=0.768±0.145, $\mathbf{t_r}$=5.30, P<0.001), their strength ($\mathbf{r_{xy}}$=0.517±0.259; $\mathbf{t_r}$=2.00; <0.05) and honey production in the next year ($\mathbf{r_{xy}}$=0,513±0,261; $\mathbf{t_r}$=1,97; P<0,05). This means that with the rise in atmospheric air temperature in October this year, we will have an amelioration of the values of the main morpho-productive characters of bee families in the next year.

We can not pronounce somehow about the influence of climatic changes of atmospheric air temperature in November and December on the variability of the morpho-productive characteristics of bee families, because the correlation coefficients between these variables are insignificant, which does not allow us to make any clear conclusions.

Regarding the climatic change of the annual average temperature, we found that it has a significant impact on the variability of the values of some morpho-productive characters of bee families in the following year. Thus, the annual average temperature has a significantly negative correlation with the wintering resistance of colony ($\mathbf{r_{xy}}$=-0.528±0.255; $\mathbf{t_r}$=2.07; P<0.05) and significantly positive, very high correlation, with brood viability in the next year ($\mathbf{r_{xy}}$=0.833±0.108; $\mathbf{t_r}$=7.71; P<0.001). That is, once the average annual air temperature is raised, we will see a reduction of wintering resistance of bees (evaluated in March) and the increase of brood viability, assessed in June next year.

Therefore, generalizing the data on the correlation between climate changes of atmospheric air temperature and the values of the main morpho-productive characters of bee families, we can conclude that they (climate change) have a significant influence on the vital activity of bee colonies. The variability of atmospheric air temperature in different months of the year influences differently the development of morpho-productive characters of bee families. Moreover, climatic changes in air temperature in the first half of the year directly affect the variability of morpho-productive characters, evaluated by the end of June, and the air temperature in July-December indirectly influences the variability of their values in the next year. Knowledge of the particularities of impact of climate change of atmospheric air temperature on the variability of the morpho-productive characteristics of bee families, during concrete months of the year, will allow beekeepers to undertake certain mitigation measures, by applying special care proceedings and additional directed feeding of bee families, depending on the specific periods of the year.

CONCLUSIONS

The wintering resistance of *Apis mellifera* bees colonies is positively influenced by the atmospheric air temperature in October of last year and January of current year. At the same time, the high air temperatures in July, August and September have a negative influence on the wintering resistance of bee families.
The queens prolificity is positively influenced only by the January temperatures. The high atmospheric temperatures in February, April and June have a negative impact on the queens prolificity, assessed in June. High temperatures during the second half of the year, especially in July and September, have a negative impact on the prolificity of queens in the next year.
The strength of bee families, appreciated in June, is negatively influenced by atmospheric temperatures in April and June. High temperatures in September have a negative impact, and those in October have a positive impact on the colonies strength in the next year.
Atmospheric temperatures in January and February influence positively, and those in May have a negative impact on the viability of bee brood. Overall, the average annual air temperature have a positive impact on the viability of the brood.
Honey production, appreciated at the end of June, is positively influenced by the atmospheric temperature in January and negative - by the atmospheric temperature in June. At the same time, atmospheric temperatures in July and September have a negative impact, and those in October - a positive impact on honey production of bee families in the next year.

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