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AN INFLUENCE OF SOLAR AND GEOMAGNETIC ACTIVITY ON HONEY BEES AND WORLD HONEY PRODUCTION

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Some major results of studies on the possible influence of space weather (periodical and aperiodical changes of solar and geomagnetic activities) on honey bees and honey yield are described in this paper. Investigations revealed that there is well pronounced quasi-12-year periodicity in the world honey yield changes as well as in the number of honey bee colonies. It is supposed that nano-scale sized magnetite found in the bee's abdomen make them very sensitive and vulnerable to geomagnetic disturbances.

INTRODUCTION

An influence of space weather, which is determined [1] by the most varied interactions between the Sun and interplanetary space, and the Earth, ranges from technical problems on satellites arising from charged particles, through the effects of radiation on humans both in space and in high altitude aircraft, to problems experienced by power transmission grid operators on the ground during severe geomagnetic storms. Solar activity, as a main driver of "space weather" phenomenon, can negatively affect not only technological [2, 3], but also ecological and biological systems, including human life/health and all-kind of human activities [3-5].

Biosphere, particularly, human beings and animals are very sensitive to solar and geomagnetic activity and to changes in these activities and their manifestations in the Earth [6]. According the US NOAA "Space Weather Scale for Geomagnetic Storms" animal effects start at a G1 level (with maximum of G5) and these effects are more pronounced as the geomagnetic field is more disturbed.

Since all living organisms are probably affected by magnetic fields, anything that influences those fields (solar activity changes, solar flares, solar wind variations, coronal mass ejections, geomagnetic field disturbances and/or storms, etc.) will indirectly or even directly perturb living organisms. It is well accepted [7] that homing pigeons and honey bees, and probably sharks, rays and various bacteria, react to the Earth's magnetic field and its variations. Experiments suggest that pigeons use the magnetic field to find their way home; during disturbed conditions of geomagnetic field, they fail to navigate home.

Honey bee, *Apis Mellifera*, is known [8] to be sensitive to magnetic fields and its famous "waggle dance" is modified when the Earth's magnetic field is cancelled, which is a strong indication of a highly sensitive magnetic detection system. Studies of honey bees in terms of their "dances" have revealed that the orientation of the dance (indicating direction of good forage) can be in error up to 20% in disturbed geomagnetic conditions. These errors are not "system noises", but are constant with all bees that are dancing at any particular time.

Bees returning to the hive will go to where the opening had been, if the hive has been moved vertically, horizontally or rotated, even when the opening is still in view to them. Bee swarms also show an inherited magnetic field effect; they invariably construct new comb oriented in the same direction as their parent colony. Bees have been seen evacuating their hive in a panic, minutes before an earthquake, and then not returning until fifteen minutes after the quake ended.

Honey bees, their biology, life and working style are so interesting that they are always under investigations, carried out by scientists from different disciplines. In this interdisciplinary paper we have studied [9-12] the possible influence of changes of heliogeophysical conditions on the beekeeping, particularly, on the honey yield level and changes of number of honey bee colonies.

MATERIALS AND METHODS

For the purposes of studies of possible space weather influence (periodical changes in solar and geomagnetic activities, as well as solar energetic events and caused by these events geomagnetic storms) on honey bees and honey production, we have collected honey yield data from different regions of Azerbaijan with traditions of beekeeping; these regions (spread on longitude and latitude) were grouped taking into account local peculiarities and climatic conditions [9]. After the relevant testing among number of digital databases we have chosen only reliable ones. Three of them were very interesting from the point of view of conducting continuous experiments (with detailed notes) during long period of time (covering almost two 11-years solar cycle). They were carried out by two professional beekeeper-astronomers and professional beekeeper-school teacher in different sites of Azerbaijan. In each case (site), the average number of hives in bee colonies (mainly, *Apis Mellifera Caucasica*) and number of used frames were approximately constant; average honey yield was used in our studies.

In order to carry out comparison, we have collected relevant data from other countries – close and far regions. We could handle data on total honey yield from Russia, Europe, Canada, and whole world.

As the considered task was bearing multifactor influence nature and had interdisciplinary character, after detailed consultations and discussions with scientists-biologists and experienced beekeepers, we have introduced a special scale of better evaluating of honey production for each case in Azerbaijan. In fact, in general, it is difficult to separate effects of, for example, climate, *melliferous resources* (honey yielding vegetation), specific bee illnesses, artificial feeding of bees in case of necessity, self-regulation of honey bee family, other many external factors. Beekeeper knew the situation better and, taking into account, by natural and gained reflex or "automatically", all of mentioned factors, could determine average honey yield on the base of introduced evaluation scale. In parallel, digital honey yield data was created and was subjected to processing and analysis using relevant mathematical statistical methods, such as correlation analysis, Fourier analysis, etc.

Each data from different sites was studied separately and results were used in interpretation. In this paper, a special attention was paid to the analysis of world honey yield data (time span: 1975-2001), which, has reliable statistics and, in our opinion, reflects the possible global space weather impact better than in the case of regions having their own peculiarities making the task more complicated. As Canada is thought to be one of the worst places because of direct and potential influence of space weather conditions (high geographical latitudes, closeness to the magnetic pole where energetic particles can spiral down easily along almost perpendicular geomagnetic force lines, so on) on technological and biological systems, we carefully investigated world honey production and change of number of bee colonies in the case of Canada.

Such space weather parameters as sunspot numbers, solar radio flux at the wavelength of 10.7 cm, sunspot areas, solar flares, solar wind, interplanetary magnetic field, geomagnetic activity indexes, cosmic rays, etc. were involved in our studies. Results of correlation analysis show quite high values, but they are not provided in this paper as in the case of biological systems these kinds of analyses not always give unambiguous picture and require careful approach [6].

RESULTS AND DISCUSSIONS

Conducted Fourier analysis has revealed a steady quasi-12-year periodicity in the world data on honey production (Fig.1.) within the considered time interval (about 27 years which covers almost 2.5 solar activity cycles). This period is very close to the well-known quasi-11-year periodicity (this an average value, in fact, a length of solar cycle varies between 9 and 12.75 years) in solar activity changes and to the 12.5-year changes found in the geomagnetic disturbance indexes [4]. It should be noted that an observed divergence on the edges of honey production curve in the considered time interval also shows the quasi-periodic nature of curve. Another well pronounced rhythmic changes have periods of quasi-6- and quasi-4-years which are displayed in geomagnetic activity and solar wind changes [4].

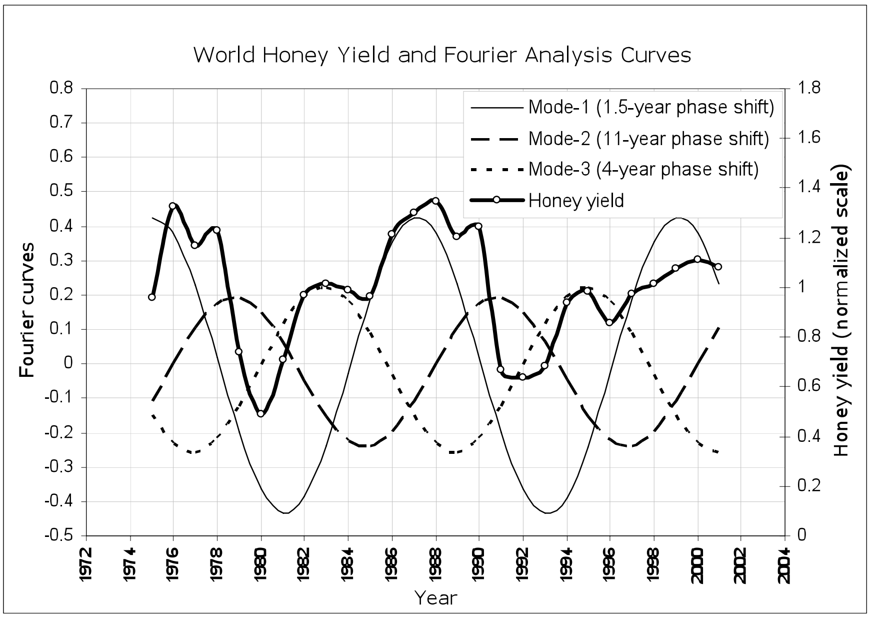

Figure 1. World honey production and results of relevant Fourier analysis.

For increasing of reliability in the revealing of solar and geomagnetic activity effects on the considered system, the main (with biggest amplitudes) periodical changes were excluded from analysis; major periodical components were first determined, and then, with purposes of decreasing of the above-mentioned multi-factor influence nature of task as much as possible, the obtained dominating quasi-12-year rhythm (hereinafter we will call them as a mode-1 with phase shift of 1.5 year, so on) was excluded from the initial data series. Next step was an excluding of next established quasi-12-year periodicity with 11-year phase shift from the last obtained "clean" data series (mode-2), and so on. The difference between 11-year (mode-1) and 1.5 year (mode-2) shifts is equal to 9.5-year. This value is known to be one of existing periods in solar activity alongside with other well-known values ([4], p.61).

Because of the solar wind originating from the Sun, the Earth is hit by hot, magnetized, supersonic collisionless plasma (mainly protons) carrying a large amount of kinetic and electrical energy. Some of this energy finds its way into terrestrial magnetosphere creating, e.g., geomagnetic activity. The 11-year variability of the geomagnetic activity can be divided into three peaks [13]: a) shortly before sunspot maximum; this activity is linked with transient solar activity; b) about 2 years after sunspot maximum; largest peak compound of transient and recurrent magnetic activity; c) descending phase of the solar cycle, largely recurrent.

In the years of maximum of 11-year solar sunspot cycle number of geo-magnetic storms are less intense but they are very powerful. There are typically two peaks in the frequency of storms, one somewhat ahead or at solar maximum and the other 2 or 3 years after it. This double peak is the result of weak and mild geomagnetic storms which play a role of background. The above mentioned rare but severe geomagnetic storms at solar maximum years are the causes, in our opinion, of negative influence on biological organisms, including honey bees, resulting in the comparatively minimum honey yield. Besides, there are signs that two peaks in the geomagnetic activity behavior have different impacts: second peak at the descending phase of solar activity cycle is more pronounced and has comparatively bigger amplitude than the first one. It seems that this first peak of geomagnetic activity (2-3 years before solar maximum) causes stimulating effects to honey bees, making them an agile while the second peak impacts negatively honey bees resulting in the honey production level decrease. As a result, ascending and descending phases of solar 11-year activity exert different influence upon the honey yield and bees, which is connected to the physical nature of these phases.

There are clearly observed so called secondary peaks (after the "main" maximums) which appear after shallow and short-lasting minimums on the honey production curve (Fig.2.). Similar behavior is traced in the solar activity changes when 11-year solar cycle maximum usually displays two outlined peaks with different amplitudes, though in our case pictures of honey production and solar activity changes do not always coincide precisely within considered time span because of different lengths of solar cycles.

The remarkable established fact is that all of obtained by this way data series show quasi-12-year rhythm which is indicative of a statistical signify-cance. As it was mentioned above, even after "cleaning" of the data from significant periodical components (modes 1 and 2), bearing (or "hiding"), in our opinion, probable subjective influence factors, it was possible to find once again the same quasi-12-year rhythm (mode-3) with 4-years phase shift, but a statistical significance in this case was less than in the previous cases.

Honey production shows a remarkable rise in the years when minimums of solar and geomagnetic activity approximately coincide (1975-1978, 1986-1989, 1995-1998) (Fig. 2.). As a rule, years of maximum honey production are located between maximums of the geomagnetic activity at descending and ascending phases (belonging to different neighbor solar cycles) of sunspot maximum cycle. Relatively deep minimum in honey production usually takes place in years of anti-coinciding of solar and geomagnetic activities, for example, in 1980, and then there starts a long, about ten-eleven years rise (showing secondary but shallow minimum) until next anti-coinciding in 1992, so on. As solar cycle is a quasi-periodical process (for example, solar cycles 20, 21 and 22 had the following lengths: 11.67, 10.25 and 9.75 year) with different lengths of ascending and descending branches, it is not so reasonable to expect precise coinciding of obtained pictures describing honey production and heliogeophysical situation within a long time of period.

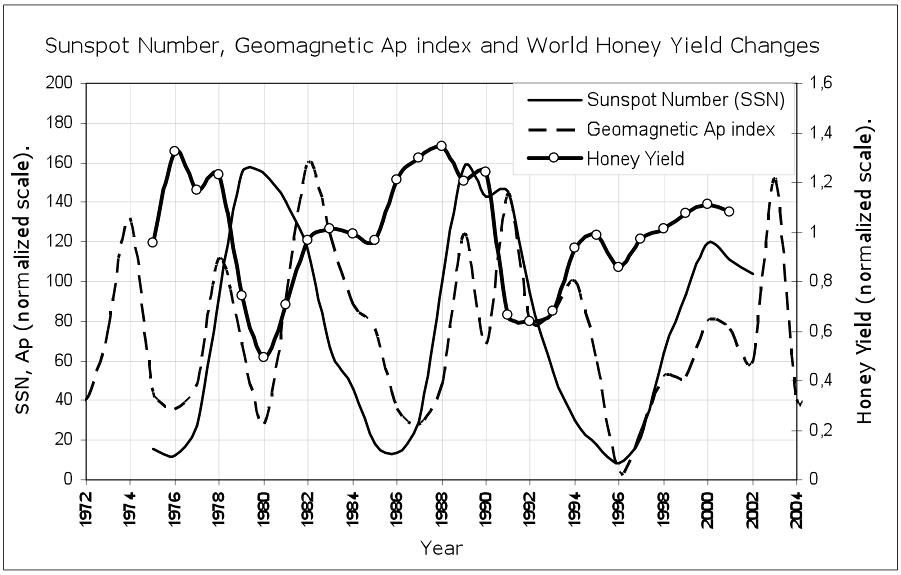

Figure 2. World honey production changes and variations of heliogeophysical parameters

An analysis showed that the mode-2 describes well minimums (in 1985 and 1996) followed after secondary small amplitude maximums (in 1983 and 1995) and so called secondary maximums in 1978 and 1990 displayed after main maximums in 1976 and 1998, while mode-3 well suits comparatively small amplitude maximums appearing in 1983 and 1995 after deep minimums in 1980 and 1992 in the honey yield curve and shallow minimums in 1977, 1989 and 2001 located between main maximums (in 1976, 1988 and 2000) and next secondary maximums (in 1978 and 1990).

There is some kind of impression that each impulse (rise) of geomagnetic activity gives a jerk leading to the increase of honey production with inertia of 1-2 years. Relatively small amplitude geomagnetic activity gives more significant rise in honey production curve (more probably, because of stimulating effect of geomagnetic disturbances to honey bees) while stronger disturbances lead to smaller increase in yield (negative impact of severe geomagnetic conditions to biological systems).

We suppose that geomagnetic disturbances influence bees through magneto-reception mechanism. Some animals possess a specialized set of neurological receptors containing tiny crystals of magnetite, which allow them to "sense" and navigate by the geomagnetic field [14, 15]. Crystals of magnetite have been found in some bacteria (e.g., *Aquaspirillum magnetotacticum*) and in the brains of termites, of some birds, and of humans. These iron oxide crystals are thought to be involved in magneto-reception, the ability to sense the polarity or the inclination of the Earth's magnetic field. Possibly the most closely studied of the variable Sun's biological effects has been the degradation of homing pigeons' navigational abilities during geomagnetic storms. Pigeons and other migratory animals, such as dolphins and whales, have internal biological compasses composed of the mineral magnetite wrapped in bundles of nerve cells. Magnetic properties of magnetite particles change with their size and shape. Certain small particles (supermagnetics) below a certain critical size can modify their direction (magnetized vector) based on temperature changes without losing their magnetic properties or physically moving.

It has been found [16] that bees also have magnetite – nano-scale-sized transversely oriented ferrimagnetic material (mineral) with chemical formula Fe_3O_4 (magnetic receptors linked in with their nervous systems) in front of their abdomens (relatively "large" magnetite particles with a size larger than 30 nm) - in trophocyte cells, a specific cell type of the fat body of insects - on one hand, and probably, smaller ones (with a size comparable with ferritin cores) on heads and thoraxes of bees on the other hand, which can be affected even by weak geomagnetic field fluctuations, considered as "noise".

Small magnetite particles are superparamagnetic (SPM), larger ones are single domain, magnetically blocked at room temperature [16]. Some researchers consider sensors using the properties of SPM particles, mainly mutual anisotropy induced by the dipolar coupling between nearby crystals. Building sensors with single domain particles seems more natural, simply because angular information is easier to get if the sensor has its own magnetization direction, fixed with respect to the animal body, rather than a magnetization aligned onto the external field.

Presence of supermagnetic particles isolated from magnetite such as that found in honey bee abdomens allows responding rapidly to magnetic field variations during a honey bee's flight. The magnetic moment apparently develops in the pupal state and persists in the adult bees [8]. In the absence of all other cues, bees seem to set their circadian rhythms by regular daily variations in the geomagnetic field; an abnormally strong field disrupts the rhythm.

Based on the theory of phase transition induced by the noise and applied in biology, in our researches we consider the honey bees as a biological object acting as an open non-linear system being in the state of non-stable dynamic balance. Transition of this system into another state ("critical" or "disrupted rhythmical") can happen even in the case of very weak external influence having a level of noise and acting as failure of rhythm. Any changes of natural electromagnetic field (geomagnetic field) caused by solar sources can play a role of one of these external factors. Depending on the strength or level of external influence factor, bees react differently which is, in turn, reflected in honey production. As honey bee colonies as a rule are located in the country areas, far from urban area and sources of technological "noise", their effects are less than space weather effects.

Honeybees are social insects that live in a colony, in large hives, each of which has a single queen, together with workers and drones. Changes of average number of honey bee colonies per apiary per year were also investigated in the base of Canadian database. Results of Fourier analysis show (Fig.3.) that changes in this number have a periodicity of quasi-12-year. Number of honey bee colonies per apiary follows well the solar cycle variations; this number increases in the years of solar maximum which is probably related to the honey bee's physiology. An increase in solar activity and possible changes in the bee's immune system, less intense cosmic rays and electron flux during solar maximum activity years and established a good correlation between galactic cosmic rays and low cloud formation, etc. could be additional mechanisms in explaining of this picture.

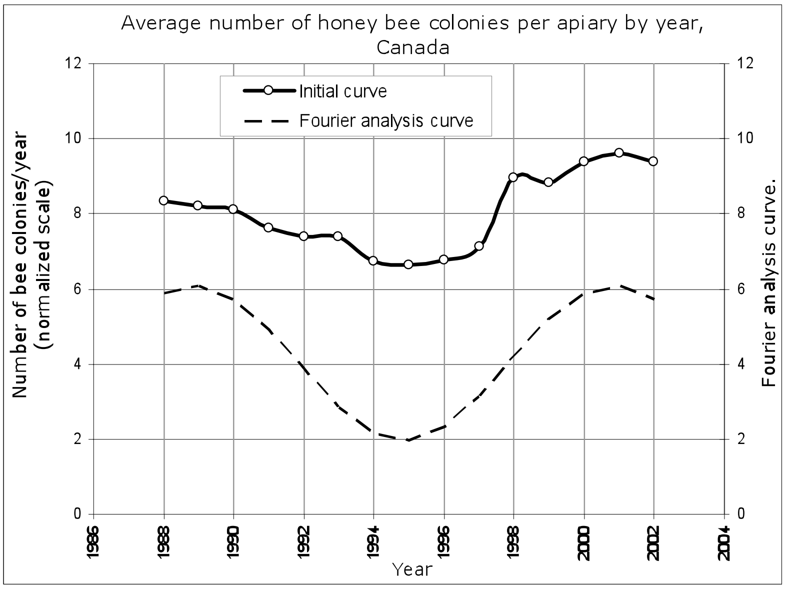

Figure 3. Changes of average number of honey bee colonies per apiary and results of Fourier analysis.

Climatic conditions, gradual and/or extreme climatic changes and their effects on bees and honey yielding vegetation in the areas under investigation should be taken into account in this quite complicated research work in consideration of problem for separate regions and in some cases, for whole world. Variations in solar constant are significant and it can modify climate over time. Scientific database and notes made by individual beekeepers, as well as data on precipitation and drought periods that influence directly beekeeping must be involved in these studies. For example, in the case of Azerbaijan, it must be taken into account that the *Grey Caucasian Bee* has the longest tongue of any economically important race. In fact the Caucasian bees forage at lower temperatures and in less favourable climatic conditions than hybrid- and three-banded Italian bees. Caucasian bees are not inclined to excessive swarming and develop into strong colonies.

CONCLUSIONS

There is a growing body of evidence that changes in the geomagnetic field and in the solar activity affect biological systems. Studies indicate that biological systems, depending on their physiological state, may respond to fluctuations in the geomagnetic field. Interest and concern in this subject have led to intensive investigations on space weather influence on biological systems, particularly, on honey bees.

Conducted in this paper study on possible influence of changes of heliogeophysical conditions on beekeeping shows an evident influence of solar and geomagnetic activities on honey bees and honey yield. Considered problem is very complicated because of influence of many factors on beekeeping which are, in turn, interconnected and are clearly reflected, at first, in honey production.

Investigations have revealed that honeybees' working ability and as a result, honey yield, are more subjected to influence geomagnetic disturbance, than to the influence of solar activity while number of bee colonies is significantly affected by solar activity changes. There is an evidence that gradual changes in geomagnetic activity (weak and moderate geomagnetic storms during ascending and descending phases of 11-year solar maximum activity) exert stimulating influence for healthy bee colonies while the strong disturbances of the geomagnetic conditions, which are common during solar maximum years, affect honey bees negatively (ill bees are affected more significantly). Most likely, stimulation occurs through the mechanism of bee's physiological response to magnetic fields (fluctuations of geomagnetic field) by means of magnetic receptors making them agile. We conclude that honey bees are sensitive to the geomagnetic field and its variations and they are "governed" by this field through magnetite in their abdomen. The following mechanisms could be considered as a basis for bee's magnetoreception: a) ferromagnetic, magnetite particles that act in conjunction with geomagnetic field fluctuations; b) modification of bee vision through chemical radicals, which depend on the presence of magnetic fields; c) electromagnetic induction, where magnetic flux produces electric fields and currents.

There appear well pronounced quasi-12-year and quasi-6-year periodicities in honey production which are probably related to relevant well-known changes in solar and geomagnetic activities.

The technique of forecasting of honey productivity in Azerbaijan taking into account the space weather effects is developed. Prognosis given in advance by authors on expected low level of honey production for 2004 and, particularly, for 2005 was justified. Our results allow predicting the gradual rise of honey production starting in 2006 which will be a year of solar activity minimum of solar cycle 23 and minimum of geomagnetic activity.

Results of these researches could be used at planning of beekeeping.

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GÜNƏŞ VƏ GEOMAQNİT FƏALLIĞININ BAL ARILARINA VƏ ÜMÜMDÜNYA BAL MƏHSULDARLIĞINA TƏSİRİ

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XÜLASƏ

Kosmik havanın (Günəş və geomaqnit fəallığının periodik və apreiodik dəyişmələrinin) bal arılarına və arı məhsuldarlığına mümkün təsirinin öyrənilməsi üzrə aparılmış tədqiqatların bəzi əsas nəticələri bu məqalədə əks olunmuşdur. Tədqiqatların nəticələri göstərir ki, ümümdünya bal məhsuldarlığı dəyişmələrində və bal arıları ailələrinin sayında qabarıq şəkildə kvazi-12-illik periodiklik mövcuddur. Hesab olunur ki, arıların qarın boşluğunda tapılmış nano-ölçülü maqnetitlər onları geomaqnit həyəcanlaşmalarına qarşı həssas və tez təsirə məruz qalan edir.

ВЛИЯНИЕ СОЛНЕЧНОЙ И ГЕОМАГНИТНОЙ АКТИВНОСТИ НА МЕДОНОСНЫХ ПЧЕЛ И ВСЕМИРНУЮ ПРОДУКТИВНОСТЬ МЕДА

Э.С.БАБАЕВ, Ф.Р.МУСТАФА, П.Н.ШУСТАРЕВ, А.Б.АСКЕРОВ

РЕЗЮМЕ

В данной работе приведены некоторые основные результаты по исследованию возможного влияния космической погоды (периодических и апериодических изменений солнечной и геомагнитной активности) на медоносных пчел и на продуктивность меда. Результаты исследований показывают, что в изменениях продуктивности меда в мировом масштабе и в числе медоносных пчелиных семей присутствует ярко-выраженная квази-12-летняя периодичность. Предполагается, что магнетиты нано-размера, найденные в брюшной полости пчел, делают их очень чувствительными и уязвимыми к геомагнитным возмущениям.