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COMPUTER MODELING OF FLOWER PISTIL THERMOREGULATION

A bionic model of thermoregulation of a flower pistil of fruit plants is presented, on the basis of which a computer program "BioNA-2" for conducting a numerical experiment was created. The central concept of this model is the author's abstract 5-petal flower of a parabolic shape. The geometry of this flower is well described mathematically. The main dimensions of the flower and the flower pistil are very realistic. The given model has the series of simplifications and limitations, namely: "no wind" weather, direct sunrays only that fall upon the flower petal surface; 6 degrees of transparency of the Earth's atmosphere; the model flower corolla is vertical directed to the Sun (or its zenithal orientation); the wavelength of the Sun's radiation falling on the flower is limited to values from 300 to 700 nm, which was dictated by the instrumental data on the spectrum of reflection of the petals that were available. Within the framework of presented computer model, calculations of the solar radiation power (the direct rays only) reflected from the floral petals of different basic colors were made. The calculations take into account the standard characteristics of the solar spectrum on the Earth's surface and the spectrum of reflection of the petals of certain colors – white, yellow, red, blue and purple ones – as the basic flower petal colors. As a result of the calculations performed, taking into account the adopted model assumptions, the following outcomes were obtained for various atmospheric transparencies: 1) it was found out that under all equal conditions the least effective reflector turned out to be the purple petals; 2) the temperature difference between the outside air and the flower pistil was calculated after a 2-minute exposure in the sun under different insolation conditions: the obtained results are in good agreement with experimental data; 3) as a result of the numerical experiment accordingly to the assumed model it was also found that the flower of the parabolic form developed in the course of its evolution the ability for effective thermoregulation of the pistil, despite a significant change in the ambient air temperature.

***Keywords**: bionic model, physics-based simulations, numerical experiment, flower pistil thermoregulation.*

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КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ ТЕРМОРЕГУЛЯЦИИ ЦВЕТКОВОГО ПЕСТИКА

Представлена бионическая модель терморегуляции пестика цветка плодового растения. На основе этой модели создана компьютерная программа «BioNA-2». Центральной фигурой этой модели есть авторский «абстрактный» 5-лепестковый цветок параболической формы. Геометрия этого «цветка» хорошо описывается математически. Основные параметры модельного цветка и цветкового пестика очень реалистичны. Данная модель имеет ряд ограничений и упрощений: предполагается безветренная погода; учитывается воздействие только прямых солнечных лучей; 6 степеней прозрачности земной атмосферы; зенитная ориентация цветкового венчика; расчеты производятся в ограниченном диапазоне длин волн (300–700 нм). В рамках принятой модели произведены расчеты температуры пестика при различных внешних условиях. При расчетах учитывались особенности спектра солнечного излучения на уровне моря и спектров отражения лепестков 5 базовых пигментов – белого, желтого, красного, синего и лилового. В результате выполненного численного эксперимента выяснилось, что наименее эффективными с точки зрения терморегуляции при прочих равных условиях являются лепестки лилового цвета. Расчеты убедительно показали, что данная форма цветка, а также параметры цветкового венчика и пестика хорошо «приспособлены» для успешной терморегуляции пестика при разных погодных условиях и разного вида инсоляции, что есть результатом эволюции цветковых растений. Расчеты, проведенные на основе предложенной модели, хорошо согласуются с независимыми экспериментальными данными.

***Ключевые слова**: бионическая модель, компьютерное моделирование, биофизика, терморегуляция цветкового пестика.*

Introduction

The floral diversity of the Earth impresses our imagination. And from our school years we know that plants are been developing at least 475 million years, and flowering plants appeared about 130 million years ago, and flowers play an important physiological function: due to them plants are able to be reproduced over and over. Thus the presence of flowers is a herald of the harvest, and this fact is no longer only beauty in its pure form.

Any plant itself is able to generate energy for its own existence – due to cellular respiration, but sometimes only this amount of energy is not enough, for example, during the flowering period [1, 2]. For guaranteed reproduction, a plant flower "learned" how to effectively use an external source of energy – the sunlight stream falling on the Earth. This energy it consumes for its living and partially accumulates to ensure the development of the seed (fetus).

Most of the fruit tree flowers have the form of a paraboloid of rotation, in the focus of which is a flower pistil. Due to this form, the radiant solar energy, which is captured and reflected by the blossom petals, is transferred to the flower pistil when blooming.

But there is, it would seem, a simple question: why exactly the paraboloid form? Why do plants need this form of a flower? What preferences can give their own parabolic form for fruit plant flowers? Usually such questions are answered well by physics and mathematics.

Despite the significant growth of the number of publications on biological topics in which "serious" mathematics is applied, the author has not found any studies on the thermodynamic balance of the internal cavity of fruit plant flowers.

It is well-known fact [3-6] that the *basic flower petal colors* are: white, yellow, red, blue and purple. The search for information in scientific sources about the influence of the color of the petals on the flower pistil thermoregulation did not give any answers to questions connected with the dependence of certain parameters of the thermodynamics of the internal cavity of the flower on the reflection spectrum of the petals.

In this paper the author is interested in the answer to the following question: which of the basic petal pigments are the most effective reflectors of the light incident on them? Therefore, the main direction of the research is the study of the spectral factor on thermodynamic processes in the flowers of fruit trees.

The current work is the evolution of the last year's research (it was the "BioNA-1" program as the result of [7]). The previous model operated with an averaged *albedo* of flower petals. In its present form, the work results one can present as the computer program "BioNA-2", designed to perform a numerical experiment and visualize the results obtained, according to the basic equation of the thermodynamic balance of the flower pistil, taking into account a number of external and internal factors that affect the fertility of fruit plants to varying degrees. In this work the main attention is paid to the search for the influence of the color of petals of the flower corolla on the flower pistil thermoregulation.

Wishing to continue the work begun last year on modeling the thermodynamic balance of a flower pistil that is exposed to solar radiation, the author used data of spectrometric measurements published by other researchers (see the list below).

The **objective of the work** was to create a computer model capable to reflect adequately the process of additional heating of the flower pistil by focusing the direct sunlight using its corolla petals. This model is based on a number of simplifications and operates with the specially created "*abstract flower*" and at the same time takes into account some external and internal (relative to the flower) factors.

The **research tasks** were: 1) researching and finding of the temperature dependence of the flower pistil from the geometric and optical properties of the flower, as well from some external factors, and 2) on the basis of the found relationships one has to create a computer program capable to make the appropriate calculations, as well as to provide 2D-3D visualization of simulation results.

The **object of study of the work** were the processes of thermoregulation of the fruit flower pistil (the flower has the form of a paraboloid of rotation), and the determination of the dependence of these processes on the transparency of the atmosphere, the ambient temperature and the optical properties of the petals of the flower.

The **subject of the study of the work** is temperature dependence of the pistil of the mentioned "abstract" flower on time and other specified factors, provided only direct sunlight falls upon the 5-petal flower [8], which is oriented zenithal to the Sun. Why exactly 5 pieces of petals? Because the 5-petal flower is the most common structure of flowers in Nature – 52.8% of all modern flower forms [8].

The input data for the current computer model are: tabular physical quantities; spectral and energy characteristics of solar radiation; mathematically processed spectrometric data from different researchers (instrumental measurements taken from nature experiments [3, 4, 6, 9–13]); ambient air temperature; some parameters of the flower corolla and others.

The output data for the computer model are: calculated values of the temperature of the flower pistil over time under various conditions of its insolation and ambient temperature; the effectiveness degree of the thermal stabilization of the flower pistil for the mentioned five basic colors of the flower petals; visualization of the solution of the energy balance equation in the form of the corresponding plot.

The presented mathematical model in general

The flower as an organ of a plant, after millions of years of its evolution, has developed in itself abilities at a certain time of vegetation (when there is a need for an additional source of energy) to get such "useful adaptation" as petals that not only attract pollinator insects, but also able to accumulate the radiant energy of the Sun. This "adaptation" should help to warm their "future descendants", and do it in time, i.e. in the period of relatively cool days (within our latitudes this is April-May). But the same petals must leave the flower in time too, if the plant no longer needs insect help and the air will be warmer (usually it happens in the summer).

It is no coincidence that the floral corolla, or its crown, has the form of a paraboloid of revolution: evolution of plants has "considered" exactly this form of flowers as the optimal one. The reason for this is the optical properties of the paraboloid: it focuses all the rays that it – a paraboliod – was "able to catch" by its own cross section [14].

Flower under the Sun: what are we going to take into account?

Let's look at the Sun as a giant radiation generator. When an imaginary flower is under the Sun, it does absorb radiant energy and will be heated at the same time. In Nature, for the stable existence of something, there must be an energy balance.

Consider the thermodynamic balance of a small biological object – the flower pistil. In reality, the pistil can be heated by absorbing sunlight – both direct and scattered ones, and it can cool down due to both convection types – natural and forced ones, and also due to its own radiation as an already heated body (see Fig. 1).

The proposed author's model of thermoregulation of a flower pistil has several simplifications: neither forced convection ("***no wind***") nor absorption of scattered sun rays is taken into account. In addition, the flower itself is not the same, natural, but "mathematical". A natural flower has many parameters. But, in order not to "get lost in unnecessary details" of a real flower, an "artificial" or "abstract" Flower was chosen to build a computer model of the process.

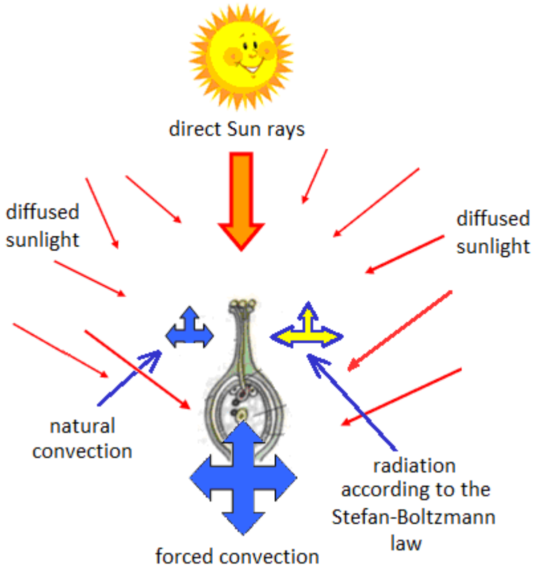

Fig. 1. The scheme of the main energy flows to and from a flower pistil (as a flower is under the Sun)

About the “abstract” flower and general requirements for the mathematical model which used

The author's concept of an “abstract” flower is very similar to a natural flower of the same structure, while the “abstract” flower is easy to describe mathematically. The main parameters of the “abstract” flower are similar for many flowers of ordinary fruit plants. This model “flower” itself fits into a paraboloid of rotation. The description of the flat projection of its petals was based on the well-known equation called the 5-*petal polar rose*: $\rho = A \cdot \sin(5\varphi/3)$, where A is the largest parameter of the petals (Fig. 2a).

Fig. 2b shows the visualization of the results of calculations of the path of vertically incident sun rays upon the corolla, followed by their reflection from the flower petals.

In the Table 1 it is presented some parameters of the “abstract” flower used for modeling. Some physical characteristics of the plant tissue used in the author's model are identical to natural ones, namely the density of the biological tissue, the specific heat capacity, petal colors and so on [15, 16]. Such an abstraction allows us to concentrate on the main task of this study – the search for the dependence of the thermoregulation of a flower pistil on the color of the flower petals as well the atmospheric transparency.

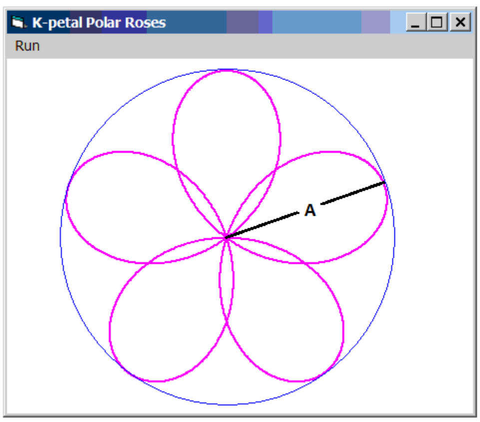

Fig. 2a. The general view of the 2D projection of the “abstract” flower, which is the basic element for the author's computer model

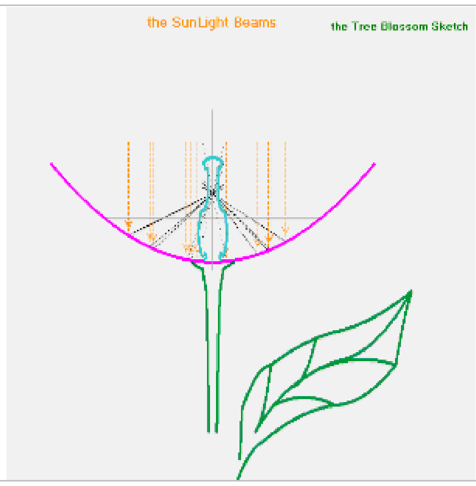

Fig. 2b. the scheme that is adopted in the author's model: the illustration of the zenithal arrangement of the flower corolla as well Sun rays that fall vertically

Table 1

Some parameters of the "abstract" flower which is used in the model:

The external diameter of the Flower =	2.83 cm
The total height of the Flower pistil =	15 mm
The maximum diameter of the Flower pistil =	2.3 mm
The mass of the pistil =	47 mg

When making the current computer model, the author took into account such assumptions and limitations:

- in order to imitate the real flowers and their basic properties the concept of an "abstract" flower (hereinafter referred to the ***Flower***) was introduced, which concentrated several real features and parameters of natural flowers of fruit plants, for example, 1) the general structure of the Flower (this is a 5-petal flower, the corolla of a such flower is a paraboloid of rotation); 2) the geometric dimensions of the biological object (see Table 1); 3) the five basic colors of the Flower petals – white, red, yellow, blue and purple [4, 5, 10, 11];
- only one orientation of the Flower with respect to the Sun was considered – the *zenithal position of the Flower corolla*, that is, the axis of symmetry of the paraboloid is directed vertically, and the Sun rays fall on the floral corolla also vertically (Fig. 2b);
- it is assumed that *there is no wind*, that is, in the final equation of the model, one did not take into account the forced convection;
- in the final equation of the model *only direct solar radiation* is taken into account – and that radiant energy that falls directly on the pistil, as well as energy that is absorbed by the pistil after reflection from the Flower petals;
- the model takes into account the "fine structure" of the following spectra: 1) the solar spectrum as the generator of radiant energy, 2) the reflection spectrum of the five floral petal pigments. These spectral factors are very important for constructing an adequate model for the thermoregulation of the Flower pistil;
- in the presented model the spectrum of solar radiation with a wavelength from the range of 300 nm to 700 nm ($\lambda \in [300...700]$ nm), or from ultraviolet up to red rays) is taken into account.

On the characteristics of the chosen mathematical model. The Solar spectrum and the Spectrum of reflection of basic petal colorants

The computer model created for more accurate calculations of the temperature balance of the flower pistil should reflect the interaction of the "fine structures" of both spectra – the spectrum of the EM-radiation generator (it is the Sun), and the spectrum of the reflector of this radiation. Such information can be gathered from scientific sources, where the results of instrumental measurements of the solar spectrum as a generator of radiant energy are collected [17, 18], as well as the results of measurements of the absorption or reflection spectra of petals of various colors.

For this, a number of relevant scientific papers on the spectra of the reflection of multicolor flower petals were found and studied [3–6, 9–13]. The purpose of such a search work is to obtain unified experimental data suitable for application in the current mathematical model. The experimental data found in the scientific literature were obtained by various researchers, and moreover with the help of various measuring devices. Another complication in this matter was the diversity of the examined plants and the absence of any standards for determining the "purity" of the color of the floral petals. So, this is an ordinary spectroscopic question: in the absence of criteria for "unifying" the base colors, it was not entirely clear how much "such a white" color was really white, or how much "this blue" color was the blue one, and so on.

It is well known that shades of colors indicate the variability of the certain pigment concentration (in this case – *anthocyanins*). Therefore, the spectrometric data found in the scientific literature were properly "filtered" and averaged (piecewise linear spline approximation of averaged spectral data), after which they were used as a set of linear functions of $R_{petal\#Color}(\lambda)$, where $Petal\#Color$ is the certain color of the floral petals from the mentioned series of basic pigments under investigation (i.e. colors: white, yellow, red, blue and purple). In fact, these functions $R_{petal\#Color}(\lambda)$ are spectral reflection functions for certain petal pigments.

These reflection spectra $R_{petal\#Color}(\lambda)$ for the five basic petal pigments are shown in Fig. 3a: each curve in this figure is the average reflection spectrum for each of the selected petal dye.

In Fig. 3b it is shown the emission spectra of the Sun – the author was used the one of the given spectrum which described the solar radiation at sea level, that is after the passage of sunrays through the Earth's atmosphere [18]. Note: at his disposal the author had only graphic data on the corresponding spectrum. So, these data were also digitized and as a result they acquired the form of a piecewise linear function of $S_{RadSeaLevel}(\lambda)$.

The final equation for the given model of a Flower pistil thermoregulation

The actual model takes into account the fact that the floral corolla is frequently not continuous: the flower petals are rather not connected one to another, which is natural for the overwhelming number of flowers (*see* Fig. 4a). Such a combination of floral petals should be evaluated by a special coefficient of aperture $F_{aperture}$, the value of which was found through the integration of natural "openings": $F_{aperture} \approx 0.3$. This value means that the effective total area of the flower petals within the model is approximately 70% of the circumference by the radius A (this circle is the section of the corresponding paraboloid of revolution!).

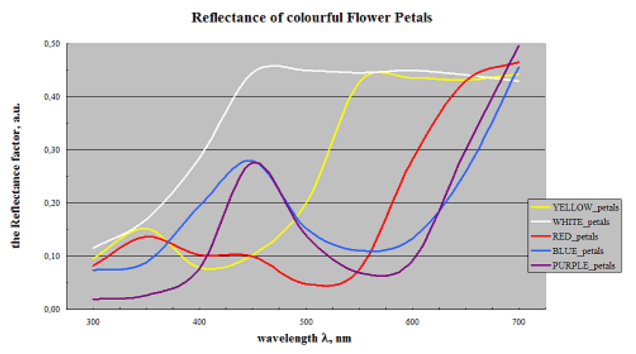	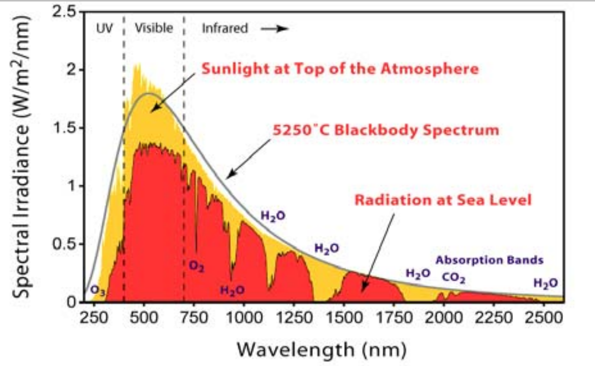
Fig. 3a. Spectra of reflection $R_{petal\#Color}(\lambda)$ of petals of different colors (see the inset). The provided spectra were obtained by the author: the initial data for this were taken from the experimental data [3-6, 9-13], and then averaged and analytically "smoothed"	**Fig. 3b. The Spectra of Solar radiation [18]: the spectrum of radiation at sea level (the red one at the picture) was used by author for the modelling**

The pistil of the "abstract" flower was represented as a combination of two cylinders with the corresponding parameters (Fig. 4b).

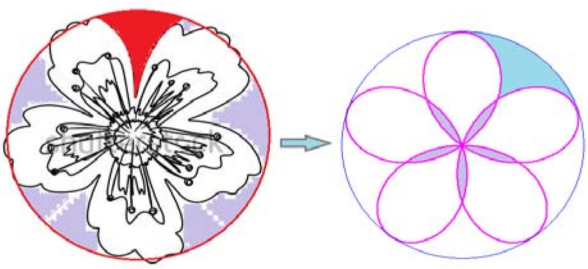	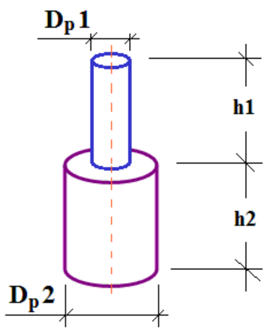
Fig. 4a. To illustration for the mathematical modelling of the 5-petalled "abstract" Flower with certain areas of apertures between its petals (like natural openings): the sketch of a natural flower (*on the left*) and the taken form of an "abstract" Flower according to the considered model (*right*)	**Fig. 4b. Representation of the pistil for the taken into consideration "abstract" Flower**

Taking into account the parameters of the considered flower, the author believes it is suitable to find the ratio of characteristic sizes of important parts of this flower, namely the largest diameter of the flower pistil *vs*. the diameter of the floral corolla. The ratio of these values is about 8%, that is, a typical floral pistil one can consider as a fairly small object, but the found ratio of the parameters of the flower does not allow to perceive the pistil as a point object. And despite this, the current model does not take into account the thermal conductivity of the biological tissue for the reason of simplifying the final equation of the model.

Based on the considered "structure" of the Flower pistil one can easily get the following formulae in order to obtain corresponding values for the pistil:

The effective pistil area:	The effective volume of the pistil:
$S_{sum(1+2)} = \pi \cdot \left(D_{p1} \cdot h_1 + D_{p2} \cdot h_2 + D_{p2}^2 / 4\right)$	$V_{pistil} = \left(D_{p1}^2 \cdot h_1 + D_{p2}^2 \cdot h_2\right) \cdot \pi / 4$

Get going from the above assumptions and limitations, the equation of thermodynamic balance for the process of additional heating of the pistil when it is insolated by direct sunrays can be represented in this form:

$$P_+ \cdot \Delta t = \left(P_{conv} + P_{S-B}\right) \cdot \Delta t + \Delta T^\circ \cdot c_{plant} \cdot m_{plant} \ ,$$

where ΔT° is the difference between the flower pistil temperature and the ambient air temperature;

Δt is time of insolation of the floral pistil;

P_{conv} is power of natural convection of the pistil;

P_{S-B} is the heat radiation power of a heated pestle according to the Stefan-Boltzmann law; here:

$$P_+ = \left(P_{+Solar} + P_{Solar\#Color}\right)$$

is the total power of direct sunlight absorbed by a flower pistil, namely:

the power P_{+Solar} of direct sunlight, which is straight absorbed by the flower pistil;

the power $P_{Solar\#Color}$ of direct sunlight reflected from the petals of a certain color:

$$P_{Solar\#Color} = Tr_{atm} \cdot \sum_{\lambda} S_{RadSeaLevel}(\lambda) \cdot R_{petal\#Color}(\lambda) \cdot S_{eff\_Petals} ,$$

here: Tr_{atm} is the degree of transparency of the Earth atmosphere; $S_{RadSeaLevel}(\lambda)$ is the specific solar power at sea level (W/m^2, *see* Fig. 3b); S_{eff_Petals} is the total area of petals of the flower corolla as a paraboloid of rotation (the mentioned apertures are taken into accounts, *see* Fig. 5). One can calculate the value of S_{eff_Petals} for the given Flower data (*see* Table 1): $S_{eff\_Petals} = (1.904 \pm 0.004) \times 10^{-3}$ m^2.

Table 2 presents the degrees of transparency Tr_{atm} of the Earth's atmosphere that used in the given computer model.

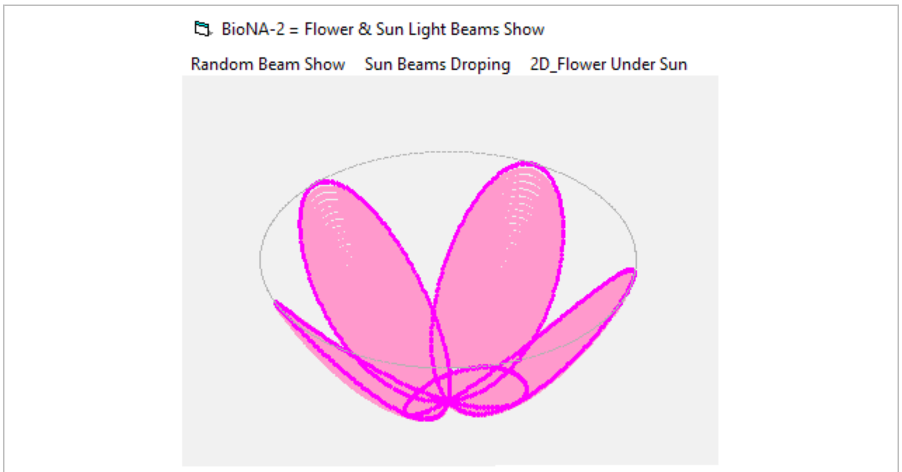

Fig. 5. The 5-petaled "abstract" Flower as the paraboloid of rotation (it is shown as 3D-image; the floral petals are painted, its pistil aren't shown)

Table 2

Degrees of transparency of the Earth's atmosphere [7]

the weather symbol	interpretation of the symbol	coefficient of transparency of atmosphere Tr_{atm}
	Clear	$Tr_{atm} = 0{,}8$
	Sunny intervals	$Tr_{atm} = 0{,}7$
	Light clouds	$Tr_{atm} = 0{,}6$
 MIST	Mist	$Tr_{atm} = 0{,}5$
	Thick clouds	$Tr_{atm} = 0{,}4$
	Drizzle	$Tr_{atm} = 0{,}3$

Thus, one can achieve the following equation of thermodynamic balance: $\Delta T^\circ \cdot c_{plant} \cdot m_{plant} = \left(P_{+Solar} - P_{conv} - P_{S-B}\right) \cdot \Delta t$, where $P_{conv} = h_{conv}(T - T_{air}) \cdot S_{pistil}$ and $P_{S-B} = \sigma \cdot \varepsilon \cdot S_{pistil}\left(T^4 - T_{air}^4\right)$.

The final equation of the computer model of thermoregulation of a flower pistil, obviously, has the following form (*see* [7]):

$$\Delta T^\circ = \frac{\left(P_{+Solar} - P_{conv} - P_{S-B}\right)}{c_{plant} \cdot m_{plant}} \Delta t .$$

And now comes the stage of computing based on the equations achieved for the given model and visualization of the results obtained.

Software implementation of thermoregulation process modelling and obtaining results of calculations (numerical experiment)

The author's program "BioNA-2" has a modular structure and a multi-window interface (MDI) (*see* Fig. 6). In order to provide the desired numerical experiment, this program uses input data of two types: 1) those that are entered by a researcher (user) from the keyboard; and 2) those that are internal constants of the program or are previously calculated by the program.

After downloading the "BioNA-2" program, a user can access the four menu items of "*Zenitar Flower View*" – a demonstration of the optical properties of a paraboloid-shaped Flower located zenithically towards the Sun. The corresponding submenu items can show:

- reflection of a lonely sunbeam falling on the surface of the Flower petals ("*Random Beam Show*");
- reflection of a series of incident sunlight beams ("*Sun Beams Dropping*") as an illustration of the continuous stream of sunlight falling into the cup of the floral corolla;
- 2D-projection of the Flower when insolating ("*2D_Flower Under Sun*") according to the given computer model;
- 3D-projection of the model's Flower when insolating ("*2D_Flower Insolation*").

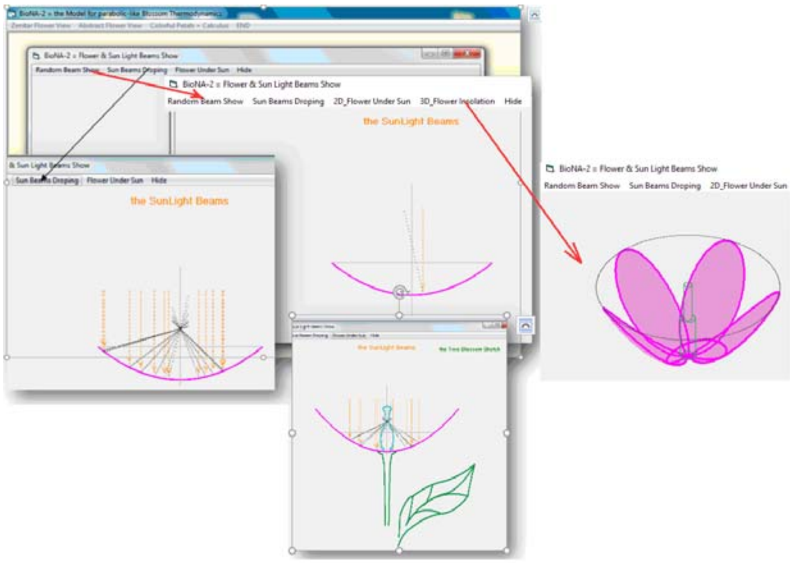

Fig. 6. The MDI-interface of the BioNA-2 program

Other forms of the program make it possible to work with the following modules:

- "*Abstract Flower View*" can build a flat projection of the 5-petal Flower according to the mentioned equation (*see* Fig. 7);
- "*Colorful Petals+Calculus*" opens the program module window for calculating the power of solar rays, which are reflected from the Flower petals taking into account the spectral characteristics of the light source as well the reflecting surface of the petals. The interface of this module assumes that the user chooses the degree of transparency of the Earth atmosphere (e.g. sunny, partly cloudy, light clouds, fog, cloudy), the ambient air temperature and the "right" color of the petals. The power of the radiation reflected from the Flower corolla is calculated by the program module in milliwatts (mW). Fig. 8 shows a part of the display with the results of calculations of the radiation power reflected from the colorful petals.

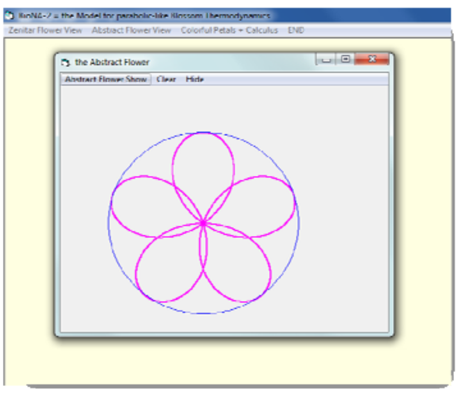

Fig. 7. View of 2D-projection of the 5-petal "abstract" Flower model

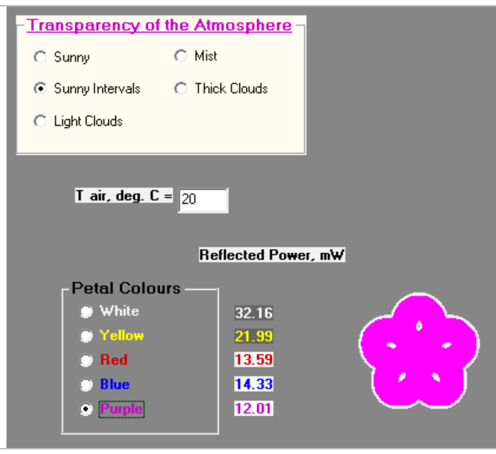

Fig. 8. Results of calculations of the irradiation power of the Flower pistil due to reflection from petals of direct sunlight (the results of calculations for all basic colors are indicated). Output values are given in mW

Results of calculations (numerical experiment)

Within the framework of given computer model, calculations of the power of solar radiation (direct rays only) reflected from the floral petals of different basic colors were made. The presented model of the flower pistil thermoregulation operates with spectrometric data of radiation and reflection within the range of (300…700) nm. The calculations take into account the standard characteristics of the solar spectrum on the Earth's surface and the spectrum of reflection of the petals of certain colors.

Obtaining of numerical values of the reflected (by means of the Flower corolla) solar radiation power and then drawing the plot of the corresponding function $T_{pistil} = f(t)$ is the result of a series of numerical experiments within the framework of the author's computer model (*see* Fig. 9). Here T_{pistil} is the temperature of the Flower pistil; t is duration of insolation under certain conditions of atmospheric transparency.

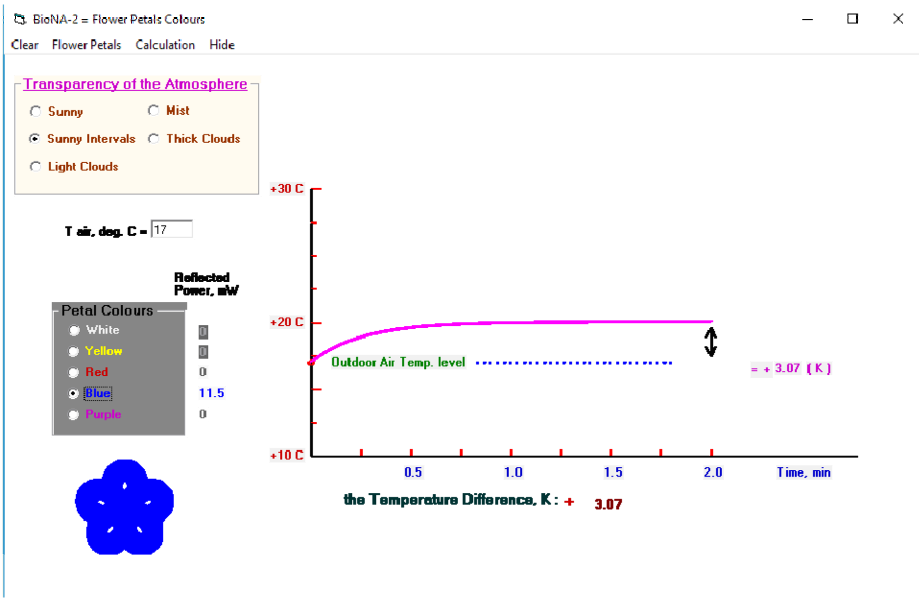

Fig. 9: General view of the display after the sequential working of the program modules "Calculation" and "Flower Petals"

Table 3 displays the relative efficiency of the flower pistil thermoregulation for 5 basic petal pigments: the reflected power for white petals is assumed as 100%. For any weather conditions the following ratio of reflected energy efficiency is kept depending on the color of the flower petals.

Table 3

The relative efficiency of the flower pistil thermoregulation for 5 basic petal pigments:

Petal color	a.u.
White	100 %
Yellow	64.8 %
Blue	44.6 %
Red	42.3 %
Purple	37.3 %

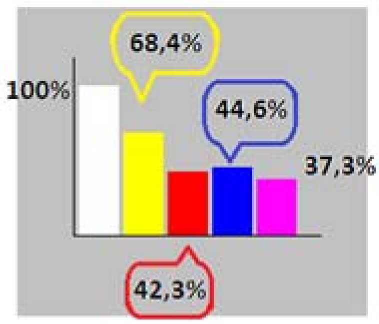

Table 4 shows the calculated data of the difference between the temperature T_{pistil} of the Flower pistil and the ambient air temperature T_{air} (according to the described mathematical model) under the most transparent atmosphere for the five basic colors of the petals: these calculations were made for each of the colors at temperatures $5°C \le T_{air} \le 25°C$. The results obtained make it possible to conclude that the Flower of a parabolic shape can effectively stabilize thermally its pistil, since the temperature of the pistil varies very little ($\Delta T_{pistil} \le 0.15$ K) at significant external temperature fluctuations ($\Delta T_{air} = 20$ K).

Table 4

The calculated values of the difference $(T_{pistil} - T_{air})$ between the temperatures of the Flower pistil and the

outside air at cloudless weather for the five basic petal colors:

T°_{air} →	5°C	10°C	15°C	20°C	25°C	ΔT_{pistil}
White	8,0	8,0	7,9	7,9	7,9	***0,14***
Yellow	5,5	5,4	5,4	5,4	5,4	***0,09***
Red	3,4	3,4	3,4	3,3	3,3	***0,06***
Blue	3,6	3,6	3,5	3,5	3,5	***0,06***
Purple	3,0	3,0	3,0	3,0	2,9	***0,05***

Summary

As a result of this work, a computer model for the thermoregulation of the pistil of the parabolic form Flower was created. This model is the basis for making appropriate calculations for the thermoregulation of the fruit flower pistil with five petals of various colors, depending on a number of different external and internal factors.

The presented model of a flower pistil thermoregulation "works" with the "abstract" 5-petalled Flower which has a number of quite realistic parameters, such as its shape, the size and the optical properties of the Flower petals, the presence of apertures in the Flower corolla, the size of the Flower pistil and its other physical parameters, and so on.

For this model some accepted simplifications and limitations are also important, for example, the zenithal orientation of the Flower corolla relative to the Sun, allowance for direct sunlight only, the absence of wind, limited spectrum of incident EM radiation ($\lambda \in$ [300-700] nm), 6 degrees of transparency of the Earth's atmosphere, etc.

One may consider the present work as a development for the previous simplified model of the thermodynamic balance of the pistil of a paraboloid-like flower. The work on improving the mathematical model of the described phenomena led to the following results:

- the given model was corrected for the reflection spectra of the selected five basic colors, and as result the final equation of the temperature balance of the flower pistil was improved [7];
- the differences between the temperature of the Flower pistil and the ambient air temperature were calculated for the five basic petal colors for the various atmospheric transparency states;
- it was found that the petal colors may be both the most and least effective reflectors of radiant energy. It has become apparent that the color of the floral petals is one of the important factors for the successful development and as well survival of plants;
- it was found that with a large change in the ambient temperature (ΔT_{air} =20°C), the temperature of the pistil varies insignificantly (ΔT_{pistil} ≈0,2°C), which indicates a high efficiency of thermal protection of the fruit germ is indisputable property of the flowering plant evolution.

The value of the current computer model lies in its applied nature:

1) the presented computer model will help to choose scientifically reasonable ways of increasing the fertility of fruit plants during the global climate changing (be it warming or cooling trends), as well as in selecting "new" climatic zones for the propagation of certain plant species;

2) information obtained as a result of this numerical experiment can be useful in the application of methods of biotechnology (possibly genetic engineering) to increase the fertility of fruit plants.

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