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Cell response to quasi-monochromatic light with different coherence

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Abstract. **The problem of the light coherence effect on the magnitude of the photoinduced cell response is discussed. The origins of ambiguous interpretation of the known experimental results are considered. Using the biological models, essentially differing in anatomy, morphology and biological functions (acrospires of radish, blackberry microsprouts cultivated *in vitro*, plum pollen), the effect of statistical properties of quasi-monochromatic light (λ_{max} = 633 nm) on the magnitude of the photoinduced cell response is shown. It is found that for relatively low spatial coherence, the cell functional activity changes insignificantly. The maximal enhancement of growing processes (stimulating effect) is observed when the coherence length L_{coh} and the correlation radius r_{cor} are greater than the cell size, i.e., the entire cell fits into the field coherence volume. In this case, the representative indicators (germination of seeds and pollen, the spears length) exceeds those of non-irradiated objects by 1.7–3.9 times. For more correct assessment of the effect of light statistical properties on photocontrol processes, it is proposed to replace the qualitative description (coherent–incoherent) with the quantitative one, using the determination of spatial and temporal correlation functions and comparing them with the characteristic dimensions of the biological structures, e.g., the cell size.**

Keywords: *coherence, laser ligth, quasi-monochromatic light, plants, photocontrol processes, coherence volume, cell size.*

1. Introduction

As a rule, in photobiology only the energy parameters of irradiation, i.e., intensity, duration, dose and wavelength of incident light, are considered. However, the process of generating photons is not deterministic and requires statistical methods for its analysis. Random wave fields can be described using the correlation functions of spatial and temporal coherence [1]. For quantitative comparison of the statistical parameters of laser and thermal radiation sources it is convenient to use the characteristic parameters of these functions, namely, the coherence length L_{coh} and correlation radius r_{cor} that determine the coherence volume as a space domain in which the phase correlation in the photon ensemble is observed.

The role of light coherence in photocontrol processes has been discussed for 30 years. The most popular point of view is that the response of living organisms does not depend on the statistical ordering of the incident light. It is based on the experimental results obtained using the standard technique, in which the biological effect was compared for laser and non-laser (thermal, gas-discharge, light-emitting-diode) sources of light. In the latter case, in order to provide comparable exposure parameters (power density and mean wavelength) the light flux was formed using spectral and spatial filters. Such light was referred to as "quasi-monochromatic incoherent" [2], "monochromatic incoherent" [3], "narrow-band light" [4], whereas the laser light was referred to as "coherent".

Quantitatively comparable results were obtained in animals, plant and bacterial cells, which proves the generality of photoinduced response formation mechanisms. With respect to antioxidant activity in rat wound tissue, "… coherent laser radiation and incoherent light-emitting diode radiation had nearly the same effect" ([5], page 339). Similar conclusion is drawn in Refs [6–9], where the same irradiation sources were used to consider other types of response in animal cells.

It was shown that in leaves of plants the electric response to the radiation of a helium–neon laser (λ = 632.8 nm) and the light beam obtained from a halogen lamp using a narrow-band filter (λ_{max} = 632 nm, $\Delta\lambda$ = 8.5 nm) "… did not differ from each other within the error" [10].

In *Escherichia coli* bacteria the response to stimulation by the so called incoherent ($\Delta\lambda$ = 14 nm) and coherent (laser) light was practically similar [11]. Based on the likeness of the stimulating effect of laser and non-laser light sources, the following conclusion was drawn: "The results of experimental studies, in which correct comparison of the effect of coherent and incoherent light on biological objects was carried out, demonstrate that the light coherence is really not essential" ([11], page 370).

The opposite point of view also exists, which is also based on the results of experiments with different light sources. In Refs [12–15] the data are presented that evidence in favour of greater biological efficiency of laser light as compared to the non-laser one. Under the action of high-coherence laser radiation and low-coherence quasi-monochromatic light with the same intensity and mean wavelength, the essential difference was reported for the mobility of water-soluble plant proteins [16], the activity of metabolic processes in human survival tissues [17], the absorption coefficient of hemolysate, oxygenated haemoglobin, and catalase [18], the energy indicators

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and the level of free-radical oxidative reactions in rat liver [19].

Independent of the used light sources, the biological effect increased with the statistical ordering of the acting field. Thus, e.g., for the plant tissues "... with respect to the amplitude of electrophysiological reaction the polarised coherent light appeared to be by 1.5 times more efficient than the polarised incoherent one and by 1.7 times more efficient than the unpolarised incoherent one" ([20], page 146). In the analysis of the lymphocyte functional activity it was noted that "...the effect of incoherent radiation of both IR and red spectral range is of similar character as that of the laser radiation of the same spectral ranges, but less efficient" ([21], page 9). In Ref. [22] a review of foreign publications is presented, in which the therapeutic effect is compared for different lasers and light-emitting diodes having the same power and wavelength. In all cases the laser radiation gave better results. They relate it to deeper penetration into the tissues for the high-coherence (laser) light, the scattering of which gives rise to the formation of speckles (spatial intensity redistribution in the form of a spotted pattern) [23, 24]. In plant tissues the stimulating effect of a helium–neon laser, i.e., the source having higher radiation coherence [25], was greater than that of a semiconductor laser.

The experiments, carried out using analogous techniques, led to antipodal conclusions even in the same or alike biological models. (In more detail this discussion is considered in Refs [7, 26, 27].) In our opinion, the cause of this contradiction is the use of qualitative description of the statistical properties of the acting radiation in terms of 'coherent–incoherent' contraposition, which is physically incorrect.

First, there are no completely coherent or completely incoherent fields in the nature [28]. Any real radiation possesses a definite statistical ordering, which has its qualitative estimate. As mentioned above, the statistical ordering can be characterised by the values of L_{coh} and r_{cor} for the correlation functions of the random processes. The lowest coherence is that of the scattered radiation from extended thermal sources, e.g., the Sun [1], and the highest one is that of lasers, particularly, the single-frequency and single-mode gas lasers. The difference in the coherence degree can achieve ten orders of magnitude. However, the use of spectral (monochromators) and spatial (aperture diaphragms) filters produces light beams with a significant coherence volume even from thermal sources. At the same time, the statistical ordering of radiation generated by multimode lasers, particularly, semiconductor ones, appears to be not so high. Therefore, laser radiation cannot be unconditionally considered as highly coherent and the non-laser one as incoherent.

Second, a criterion is necessary for assessing the obtained numerical results from the position of how the living organism 'perceives' the coherence, i.e., a certain 'biological measure' should be introduced to judge whether the statistical ordering of the acting radiation is sufficient or not.

As such a criterion the cell size has been proposed [26, 27]. The choice was based on the results of experiments, in which the cells of different size were irradiated by quasi-monochromatic light with high or low statistical ordering. The photoinduced response was most expressed in those that completely fitted into the field coherence volume.

This series of experiments [27] left a number of unsolved problems, significant for understanding the mechanisms of photocontrol processes. In particular, in the process of forming the light flux with given properties, the spatiotemporal coherence and, therefore, the spectral linewidth was changed. It remains unclear whether the spectral or the coherence properties of light affect the magnitude of the photoinduced response. It is worth noting that these properties of light are mutually related, but the corresponding biological mechanisms can differ. For example, the authors of Refs [4, 29] suppose that the cell response is determined by the light spectral bandwidth and does not depend on its coherence. However, this opinion has no sufficient substantiation, and the problem remains discussible. The second question is related to the choice of a biological model. In earlier experiments [27] this role was played by the cells of plants and fungi, interacting via the mechanism of induced immunity. The results of irradiation were assessed by the change of equilibrium in such a two-component system. It is important to find whether the response magnitude in the same organisms to the light having different coherence will be different. The third question follows from the biological specificity of tissues. It remains unclear, whether the ability to react to the light coherence is inherent in different cells, in particular, vegetative and regenerative ones. To answer these questions, it is necessary to irradiate a few biological models, having the cells of definite size, with quasi-monochromatic light having the fixed coherence length and different coherence radius of the field correlation. The present paper is devoted to studying these problems.

2. Materials and methods

We chose the biological models to be irradiated that essentially differ in anatomic-morphological constitution, biological function and cell size, namely, the acrospires of radish (breed Ledyanaya Sosul'ka), the microsprouts of blackberry (breed Black Satin) cultivated *in vitro* and the plum pollen (breed Etude).

The radish seeds were placed in Petri dishes on wet filter paper, 100 pieces in each dish, and cultivated in darkness in closed dishes at room temperature. A day later the irradiation was carried out. Two and three day later the number of germinated seeds was counted. In some cases on the fourth day the length of the first-order roots was measured. In each version of the experiment no less than five dishes were used. In each dish the percentage of germinating seeds was determined, and using these data the mean value and the standard error of the representative indicator were calculated using the Excel data analysis package, as well as the statistical confidence P of the difference between the particular experiment versions. Alongside with these measurements, the size of 300 cells was determined using the temporary cytological preparations, and the size distribution was found. Most of the cells had the size $D = 15–25$ μm.

In the experiments with the plum pollen the special cytological preparations were used. The surface of microscope slides was coated with a thin layer of nutritive medium, containing 0.8% of agar, 15% of sacharose and 0.001% of boric acid. On the stiff medium the pollen was seeded with the mead density of 20 seeds per 1 mm^2. After irradiation the preparations were placed in Petri dishes with wet filter paper, where they were kept at the temperature 28 °C during 24 hours. Then the pollen was inactivated with chloroform, and using the standard technique [30] (microscope) we determined the fraction of the germinating pollen seeds. Each version of the experiment involved six preparations with 10 fields of view browsed in each of them. The size of most pollen particles lied

in the interval 40–60 μm. The statistical processing was carried out similarly to the radish seeds case.

The blackberry microsprouts were cultivated on agar-based nutritive media, prepared according to the prescription MS [31] in the modification for acceleration, i.e., 1/2 macro salts by MS, micro salts and vitamins completely by MS, sacharose (15 g L^{-1}), and β-indolyl-3-butyric acid (1.0 mg L^{-1}). The cultivation was carried out at the temperature 25 °C, illuminance 2500–3000 lx and 16 daylight hours. The number and the mean length of roots per plant were taken into account. The experiment was repeated ten times. The revisions were carried out after two months of cultivating *in vitro*. The mean cell size was D = 10–20 μm.

The control samples were subjected to the same procedures as the experimental ones under the same conditions, except the irradiation with quasi-monochromatic light. They were also protected from scattered coherent light. In the process of cultivation each experimental version was isolated using non-transparent shields to avoid mutual influence via biochemiluminescence [32, 33].

For irradiation use was made of a thermal light source, namely, a high-temperature incandescent lamp with silica bulb. Using a spherical reflecting mirror and a collimator objective, the light flux was passed to the filter with the transmission half-width 12–13 nm and $\lambda_{max} = 633 \pm 2$ nm. After the filter the apertures with the diameter 8 ± 0.1 or 32 ± 0.1 mm were installed at the beam centre. This optical scheme produced a quasi-monochromatic, transform-limited wave with a relatively uniform intensity distribution over the wave front. In this case, the absolute value of the normalised transverse correlation function can be presented as [34] $\gamma(s) = 2|J_1(kas/z)/(kas/z)|$, where $J_1(kas/z)$ is the Bessel function; $k = 2\pi/\lambda$ is the wave number; $2a$ is the linear dimension of the source aperture; $s = |\boldsymbol{r}_1 - \boldsymbol{r}_2|$; and z is the distance from the radiation source to the object. The function $\gamma(s)$ takes the first zero value at $kas/z = 3.83$ and, therefore, in this case $r_{cor} = 0.61\lambda z/a$. The coherence length of the formed light flux was equal to 32 ± 1 μm, and the correlation radius 5 ± 0.2 or 40 ± 0.2 μm, depending on the specified angular size of the radiation source.

To clarify the potential ability of the cells to demonstrate photoinduced response, in independent experiments all biological models were exposed to laser light (L_{coh}, r_{cor} > 100 μm), providing a high stimulation effect. LG-113 and LGN-222 helium–neon lasers (Russia) tuned to the oscillation with a single TE_{00} mode with the wavelength 632.8 nm were used. The light flux of given intensity was shaped using the objective with a Fourier filter having the diameter 35–40 μm. The latter was necessary to remove the higher spatial frequencies, arising in the optical path due to the diffraction effects.

The laser power and power density were measured using a VEGA Ophir laser radiation meter (Israel) and an IMO-2N calorimetric meter ('Etalon', Russia) with the error not exceeding 5%. The particular parameters of exposure are indicated below in the description of each experiment. The viewing of cytological preparation and estimation of cell size was carried out using an Opton Axiophot-2 microscope (Germany) in accordance with the standard technique [30]. For convenience of comparing the photoinduced effects in different experiments, the coefficient of stimulation K_{st} was used, calculated as the ratio of the mean value of the representative indicator in the experiment and in the control measurement; the confidence of the difference between them was also calculated.

3. Experimental results

In all types of biological models the same regularity was observed. The value of photoinduced response increased with increasing statistical ordering in the incident light. As expected, the maximal stimulating effect was obtained using the laser radiation, possessing high spatiotemporal coherence (L_{coh}, r_{cor} > 100 μm). In radish seeds the less coherent light from a thermal source (L_{coh} = 32 μm, r_{cor} = 40 μm) induced also a statistically significant (P > 0.98) but not very large increase in the functional activity, K_{st} = 1.7 (Fig. 1, Table 1). This can be due to the fact that the size of the largest cells exceeded the parameter L_{coh} (Fig. 2) and, therefore, these cells did not fit into the field coherence volume completely.

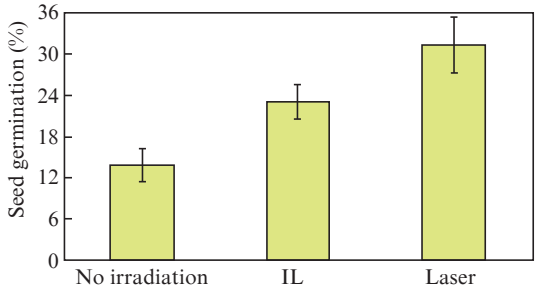

Figure 1. Influence of red quasi-monochromatic light of an incandescent lamp (IL) and helium–neon laser on the germination of radish seeds. The irradiation time is 128 s, the power density is 2.5 W m^{-2}, and the wavelength is 633 nm.

Table 1. Dependence of the photoinduced effect on the statistical parameters L_{coh} and r_{coh} of the incident light.

Biological model	D/μm	L_{coh}/μm	r_{cor}/μm	K_{st}	P
Radish seeds	15–25	>1000	>1000	2.2	> 0.98
		32	40	1.7	>0.98
Blackberry microsprouts	10–20	>1000	>1000	3.9	>0.99
		32	5	2.1	0.85
Plum pollen	40–60	>1000	>1000	2.9	>0.99
		32	40	1.4	>0.99
		32	5	1.1	<0.93

For blackberry the stimulation effect took place even at relatively low statistical ordering of the quasi-monochromatic light (L_{coh} = 32 μm, r_{cor} = 5 μm). The cells of microsprouts cultivated *in vitro*, particularly, the meristematic ones, have small size. They often fit into the field coherence volume, which provided the stimulation effect K_{st} = 2.1, but its statistical significance is not high (P = 0.85).

The role of light statistical ordering is particularly noticeable in the irradiation of large cells. The short-term action of low-coherence radiation from a thermal source (L_{coh} = 32 μm, r_{cor} = 5 μm) practically did not affect (K_{st} = 1.1) the functional activity of the plum pollen (Fig. 3), the size of which was by 3–4 times larger than the blackberry cell size. The increase in the correlation radius to 40 μm for the same radiation spectral linewidth increased the pollen germination (K_{st} = 1.4) with high confidence ($P \gg 0.99$). In the latter case a certain part of the cells having smaller dimensions could already fit into the field coherence volume. Even a greater stimulation effect took

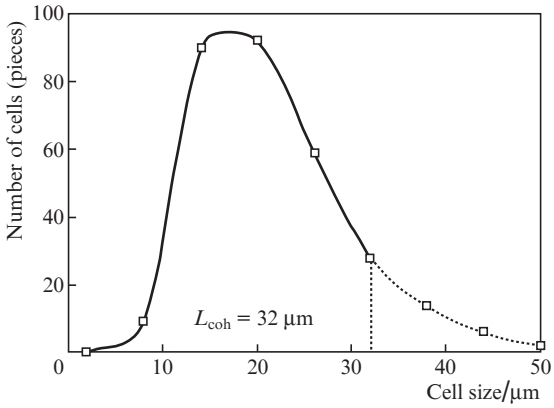

Figure 2. Size distribution of cells in radish acrospires. The dotted line shows the fraction of larger cells that do not completely fit in the coherence volume of the field from the thermal quasi-monochromatic source with L_{coh} = 32 μm, r_{cor} = 40 μm.

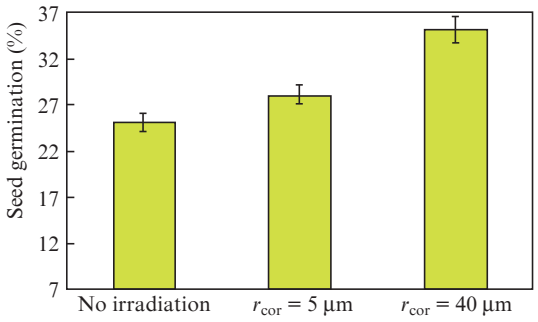

Figure 3. Influence of quasi-monochromatic light with the fixed coherence length L_{coh} = 32 μm and the correlation radii r_{cor} = 5 and 40 μm on the germination of plum pollen. The irradiation time is 128 s, the power density is 0.7 W m^{-2} and the wavelength is 633 nm.

place under the laser irradiation, providing the fulfilment of the condition $D \leqslant L_{coh}$, r_{cor} for all cells without exception (Table 1).

From this series of experiments it follows that living organisms are able to react to the spatial coherence of light. It is possible to present schematically the relation between the cell size and the coherence volume (Fig. 4). For the same value of the coherence length (L_{coh} = const) and, therefore, the fixed width of the radiation spectrum $\Delta\omega$, the increase in the field correlation radius confidently increased the functional cell activity. Thus, the hypothesis that only the spectral linewidth of the radiation determines the intensity of photoinduced response [4, 29] does not find its confirmation.

4. Discussion

The results of the study allow the conclusion that the magnitude of the photoinduced response of different biological organisms is related to the statistical ordering of the field. Not only the temporal, but also the spatial coherence is physiologically significant for them. Generally, the stimulation effect of the quasi-monochromatic light will be determined:

– for an individual cell – by its part that fits into the field coherence volume;

– for an ensemble of cells differing in size – by the number of those that satisfy the condition $D \leqslant L_{coh}$, r_{cor}.

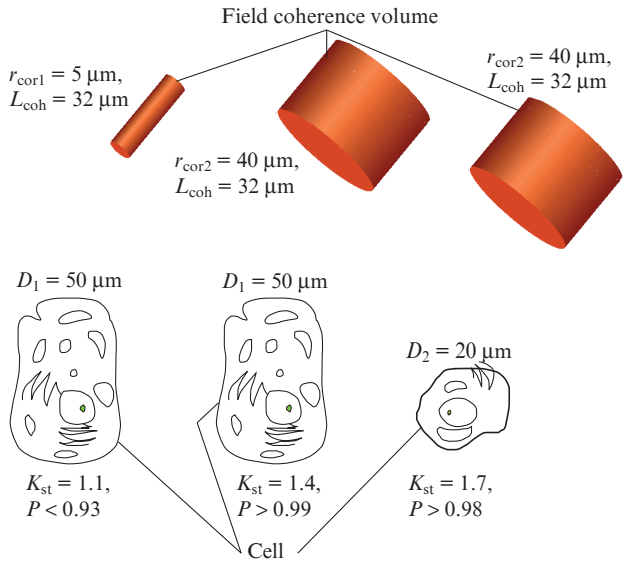

Figure 4. Schematic drawing of the relation between the cell size and the light source coherence volume.

There are definite reasons for choosing the cell size as a biologically significant criterion of the radiation statistical properties. The cell is a universal element of the living matter structural organisation. It is rather autonomous, particularly a prokaryotic one; it is capable of self-organisation and it is filled with biological membranes of different functional purpose. Photocontrol processes are implemented by specific chromoproteins (cryptochromes, phototropins, phytochromes, cytochromoxydase), which, as a rule, are associated with the lipid bilayer [35]. When a photon is absorbed, such protein molecule undergoes a conformation restructuring that leads to the change of physical and chemical properties of the adjacent areas of biological membranes [36]. This affects different vital functions of the cell up to the gene expression.

There is a number of publications [37–40] pointing at the possibility of cooperative and coherent processes in biological systems, particularly, in biomembranes. Then the pool of cell membranes is most suitable to play the role of a phase detector, capable of responding to the statistical ordering of the acting radiation. It is localised in the entire cell volume and, besides the lipid bilayer, incorporates the chromoproteins that can absorb the light quanta. In this space the phase correlation should be high enough to provide the integral character of cooperative processes in biomembranes. The bounds of this space are given by the cell dimensions, and just these dimensions are proposed to be compared with the characteristic parameters of the field correlation functions as a biological scale (measure) of the coherence.

The absence of a biologically motivated criterion of field statistical ordering in the papers considered above makes the notions ‘coherent – incoherent’ or ‘low coherence – high coherence’ devoid of concrete sense and leads to contradictive conclusions. However, if we consider the arguments *pro et contra*, the influence of light coherence on the photocontrol process based on the quantitative estimations, the contradictions disappear. In all cases, when the optical radiation coherence volume exceeded the cell size, their functional activity became the highest. Similar results could be obtained using lasers (semiconductor and gas), light-emitting diodes, or thermal sources with appropriate filters and aperture diaphragms;

it is sufficient to fulfil the condition $D \leqslant L_{coh}, r_{cor}$. Naturally, the wavelength of the exciting light must correspond to the absorption spectrum of a certain photocontrol system, the intensity must meet the vital conditions, and the organism itself must be able to transit to a new stationary state with greater intensity of metabolic processes. It should be noted that the higher-order correlation functions are different in the mentioned sources, but, judging by the obtained data, it does not affect the character of the biological response.

When the cell only partially fitted into the field coherence volume, its photoinduced activity increased less significantly, or did not increase at all. Just by this reason it is possible to explain the difference in the biological effect of laser and low-coherence light sources, reported in a number of papers [4, 17, 27]. The results of Ref. [7] (Table 2) present a good confirmation of this statement. Since the size of fish embryonal cells amounts to 9–13 μm [41], a similar (within the error) stimulation effect of short-term laser radiation action and narrow-band light-emitting diode appeared to be rather expected. And the light of the broad-band diode, for which $L_{coh} < D$, affected the embryos essentially weaker.

Table 2. Increment of baby fish biomass in 50 days after the irradiation of embryos with quasi-monochromatic light with different coherence (from [7]).

Emitter type	L_{coh}/μm	Biomass increment with respect to the control object (%)	P
No irradiation	–	100.0 ± 1.8	–
Helium–neon laser	2000	120.4 ± 2.4	⩾0.999
Narrow-band light-emitting diode	26	118.6 ± 3.7	⩾0.999
Broad-band (luminescence) light-emitting diode	2.5	111.1 ± 1.8	⩾0.999

In recent years the papers began to appear in which a quantitative assessment of the coherence characteristic parameters was carried out [7, 42–45], but, unfortunately, their relation to the biological processes and structures is not analysed. Thus in the papers by Karu [44, 45] detailed data on the coherence length, correlation radius, and coherence volume of the field for lasers, light-emitting diodes, and 'spectrally filtered lamp light' are presented. Further this information is not compared to any experimental results, and it is only reported about the successful application of lasers and light-emitting diodes in clinical practice. The radiation of the latter with 50–100 μm and even larger correlation radius is referred to as incoherent. The cells having essentially smaller dimensions in the majority of cases can 'disagree' with this opinion and react in their own way.

The ability of cells to react differently to high and low coherence of the incident light manifests itself both in protozoa (bacteria) and in higher eukaryotes (plants and animals). This fact indicates the evolution stability of the property and, therefore, it should have a certain biological conditionality. The excitation of chromoproteins occurs independently of the light coherence degree; it is sufficient that its wavelength is coincident with an absorption band of some photocontrol system. For example, the red light (600–690 nm, λ_{max} = 660 nm) causes reversible changes of molecular conformation in phytochromes, accompanied with structural and functional reconstruction of adjacent local membrane areas [36, 46]. As a result the physiological activity of the cell is increased. The red light with a larger wavelength (λ_{max} = 730 nm) initiates the opposite photoconversion of phytochromes from the active form (P730) into the passive one (P660). As a result the intensity of metabolic processes decreases and returns to the initial state. Evolutionally this mechanism appeared due to the diurnal variation of the spectral composition of solar radiation at the surface of the Earth. The increase in the red light fraction in the morning hours shifts the equilibrium of phytochromes towards the P730 form, which allows the plants to prepare for the high illuminance and vital activity in the daytime.

As follows from the obtained data, the high-coherence (with respect to the criterion $L_{coh}, r_{cor} \geqslant D$) light exerts a stronger stimulating action than the low-coherence one (e.g., the scattered solar light). Probably, this is caused by the integral restructuring of the entire pool of membranes rather than by a local one. As a result of such triggering the concentration of the regulatory molecules (effectors, inductors, repressors, etc.) in the cytoplasm will be maximal even for an insignificant number of the absorbed photons.

It can be supposed that the protein–membrane complexes as radiation receptors have two operation regimes. One of them serves weak light signals and demonstrates the trigger (discrete) properties. In this case, the magnitude of the response weakly depends on the radiation intensity and will be greater affected by the phase correlation in the photon ensemble. Thus, under the action of laser radiation the change in intensity by 20 times had practically no effect on the magnitude of the stimulation effect [26]. Naturally, in this case there is no reason to speak about the validity of the Bunsen–Roscoe dose law.

The other (analogue) operation regime is used by the cell for reception of more intense light, e.g., the daylight. Its low coherence makes the cooperative process unlikely. Stochastic fields cause conformation rearrangements and, correspondingly, the change in the biomembranes physiological activity only within local zones in the vicinity of the excited chromoproteins [35]. The number of 'hot points', where the desorption of regulatory products occurs, will be proportional to the number of absorbed photons. Thus, in this regime the magnitude of the response is related to the intensity of the incident light. The described regularity is illustrated by the tropical reaction of cereals. The change in the light intensity by 1.5 times leads to almost the same decrease in the auxin concentration at the illuminated side of the plantlets [35]. Probably, the existence of two regimes of photoreception (analogue and trigger) allows the optical signals essentially differing in intensity and coherence to take part in controlling the cell vital activity.

The present statement is confirmed by the results of studying the photoinduced bioelectric activity of plants [10, 47]. It is shown that for providing the similar amplitude of the organism reaction the intensity of 'white' light from a thermal source ($L_{coh}, r_{cor} < D$) should be by nearly 40 times greater than the intensity of narrow-band (λ_{max} = 661 nm, $\Delta\lambda$ = 8.5 nm) light, extracted from the white light with an optical filter. Note, that the coherence length of the narrow-band radiation was 51 μm, which is approximately by 2–3 times greater than the irradiated cell size, and the spectral range corresponded to the region of photoconversion of phytochromes into the active form. Thus, the photocontrol systems get an ability to react both to relatively intense solar radiation

and to the ultra-weak radiation of cells (biochemiluminescence), participating in the intercellular communication [33].

5. Conclusions

The performed experiments have shown that the statistical ordering of radiation can affect the photoinduced response of different biological systems, executing both vegetative (germs, sprouts) and generative (pollen) functions. With other conditions being the same, the maximal stimulating effect can be obtained when the cell completely fits into the field coherence volume, i.e., the condition $D < L_{coh}$, r_{cor} is valid. It follows that both the temporal and the spatial coherence of the field, which determine the spatial region with strong phase correlation in the photon ensemble, are physiologically significant.

The analysis of literature data and the results of our own studies allows us to conclude that the ability to recognise the statistical ordering of light is inherent in any kind of cells: bacterial, fungal, vegetable and animal, i.e., from prokaryotes to higher eukaryotes. Hence, this property appeared at the early stage of the living matter formation and appeared to be evolutionally stable and, therefore, biologically necessary. This may be related to using the ultra-weak light fluxes of bioluminescence as regulatory signals.

If the magnitude of the cell photoinduced response is considered from the position of satisfying the condition $D < L_{coh}$, r_{cor}, then the contradictions in the assessment of physiological efficiency of quasi-monochromatic radiation from different light sources (laser and non-laser) become ruled out. The opposite viewpoints discussed above come to good agreement after replacing the qualitative (coherent–incoherent) criteria with quantitative (L_{coh}, r_{cor}) ones and introducing a certain biologically substantiated scale, corresponding to the cell size. From the established property of living organisms to respond to the light coherence it follows that the acceptor molecules (chromoproteins) of the photocontrol systems are rather integrated in a certain cooperative system able to execute the function of a phase detector, than act separately.

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