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PRODUCTION CHARACTERISTICS OF *PORPHYRIDIUM PURPUREUM* (BORY) DREW ET ROSS SEMI-CONTINUOUS CULTURE AT LOW IRRADIANCE

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The red microalga *Porphyridium purpureum* (Bory de Saint-Vincent, 1797) Drew et Ross, 1965 is of great interest to researchers as a source of various biologically valuable substances, with their content in cells being determined by cultivation conditions. Phycobiliproteins concentration in *P. purpureum* cells depends directly on nitrogen concentration in the culture medium and cell irradiance. Semi-continuous cultivation allows maintaining these parameters at a level given. The aim of the work was to study *P. purpureum* culture growth and B-phycoerythrin (B-PE) accumulation and production at low irradiance, with minimal rates of pigment photodestruction. *P. purpureum* semi-continuous (quasi-continuous) cultivation was carried out at a specific flow rate of 0.1 and 0.2 day^{-1} and mean surface irradiance of 5 and 25 $W \cdot m^{-2}$. *P. purpureum* culture productivity increased by 1.6–17 times both with a rise in surface irradiance 5 to 25 $W \cdot m^{-2}$ and an increase in the medium specific flow rate 0.1 to 0.2 day^{-1}. Maximum productivity values for the experimental conditions (0.21 $g \cdot L^{-1} \cdot day^{-1}$) were recorded at 25 $W \cdot m^{-2}$ and 20 % medium specific flow rate, but those were 1.5–2 times lower than the precalculated ones. In *P. purpureum* cells, protein and B-PE concentrations decreased both with an increase in surface irradiance (by 15–20 %) and with a rise in a specific flow rate (by 1.5 times) for all the variants. The shifts in protein and B-PE concentration in *P. purpureum* culture had a unidirectional character as well; those mainly corresponded to the shift in the culture density. *P. purpureum* B-PE productivity increased by 1.5–1.9 times with a rise in surface irradiance 5 to 25 $W \cdot m^{-2}$. Maximum B-PE productivity (13 $mg \cdot L^{-1} \cdot day^{-1}$) was recorded for the variants of the experiment with a surface irradiance of 25 $W \cdot m^{-2}$ (0.1 and 0.2 day^{-1}). An increase in specific irradiance of *P. purpureum* cells 7 to 26 $W \cdot g^{-1}$ resulted in a rise in biomass productivity by 2.6 times; in B-PE productivity, by 1.8 times; and in protein productivity, by 1.7 times. In the experiment, irradiance was the factor determining the production characteristics of *P. purpureum* culture, and it was confirmed by the data obtained.

Keywords: *Porphyridium purpureum*, culture density, protein, phycobiliproteins, B-phycoerythrin, productivity

The red microalga *Porphyridium purpureum* (Bory) Ross is often considered as an object of both laboratory and mass cultivation (Drobetskaya, 2005 ; Markina & Aizdaicher, 2019 ; Minyuk et al., 2008 ; Tsoglin & Pronina, 2013 ; Fabregas et al., 1998 ; Li S. et al., 2019). The microalgae biomass can serve as a source of several valuable physiologically active substances: extracellular sulfopolysaccharides, unsaturated fatty acids, and pigments of the group of phycobiliproteins (hereinafter PBPs) (Biokhimiia chervonykh vodorostei, 2007 ; Stadnichuk, 1990 ; Borowitzka, 1995 ; Fabregas et al., 1998 ; Li T. et al., 2019). The specific composition of *P. purpureum* pigments is due to the fact that this species is marine: green light penetrates to greater depths and is absorbed by B-phycoerythrin (hereinafter B-PE), which is a part of the light-harvesting complex of chloroplasts (Stadnichuk, 1990 ; Algarra & Ruediger, 1993 ; John et al., 1984).

P. purpureum PBPs (B-PE, R-phycocyanin, and allophycocyanin), which are included in the photosystem II, are proteinaceous pigments, and their content in cells is determined by the level of irradiance and input of nutrients, primarily nitrogen. In terms of the practical use, the red pigment B-PE is of the great interest. Its aqueous solution is pink and has pronounced orange fluorescence; proteinaceous nature of the pigment and no data on its toxicity bring significant opportunities for its use in the food, cosmetic, and healthcare industries. B-PE content can reach 85 % of the total concentration of PBPs. B-PE specific content and production vary in a fairly wide range depending on *P. purpureum* cultivation conditions; the value can be up to 40–50 $mg \cdot L^{-1} \cdot day^{-1}$ (Fabregas et al., 1998 ; Fuentes-Grunewald et al., 2015 ; Gudvilovich & Borovkov, 2014 ; Kathiresan et al., 2006).

Irradiance is one of crucial factors affecting the quantitative composition of microalgae pigments. According to the literature data, microalgae with phycobilisomes and PBPs in their plastids tend to grow better at low irradiance (~ 10 to 50 mol photons$\cdot m^{-2} \cdot s^{-1}$), while other algae species, *e. g.* dinoflagellates and green algae, usually require higher irradiance (~ 60 to 100 mol photons$\cdot m^{-2} \cdot s^{-1}$) (Biokhimiia chervonykh vodorostei, 2007 ; Stadnichuk, 1990 ; Algarra & Ruediger, 1993 ; John et al., 1984 ; Sosa-Hernández et al., 2019). The slowdown in the growth rate of *P. purpureum* cells at excessive irradiance is often considered to result from the chloroplast destruction caused by exposure to high irradiance and by inactivation of enzymes involved in CO_2 fixation (Stadnichuk, 1990 ; Falkowski & Owens, 1980). With a decrease in irradiance, the concentration of PBPs and, first of all, B-PE in *P. purpureum* cells significantly increases (Stadnichuk, 1990 ; Trenkenshu et al., 1981 ; Algarra & Ruediger, 1993 ; John et al., 1984 ; Velea et al., 2011).

As shown (Fabregas et al., 1998 ; Fuentes-Grunewald et al., 2015 ; Gudvilovich & Borovkov, 2014), B-PE content in *P. purpureum* cells depends on nitrogen concentration in the culture medium. After the depletion of this mineral nutrition element, B-PE concentration sharply decreases.

When comparing the growth rate, as well as biomass, exopolysaccharide, and B-PE production in batch and semi-continuous *P. purpureum* cultures, the advantage of the latter one in terms of all the analyzed parameters was observed (Fuentes-Grunewald et al., 2015 ; Gudvilovich & Borovkov, 2014). Therefore, *Porphyridium* cultivation for obtaining PBPs-enriched biomass has to be carried out in a semi-continuous mode: it allows maintaining both the culture irradiance and nitrogen concentration at a level given. Nevertheless, even in this mode, variation in cultivation parameters (medium specific flow rate and irradiance) significantly alters the metabolism and direction of biosynthetic pathways in *P. purpureum* culture (Upitis et al., 1989 ; Fabregas et al., 1998 ; Fuentes-Grunewald et al., 2015 ; Gudvilovich & Borovkov, 2014).

The effects of irradiance and nitrogen concentration on the growth and PBPs accumulation in *P. purpureum* have been studied in detail, but these effects were mainly assessed separately. Moreover, most investigations on the effect of irradiance and nitrogen concentration on B-PE synthesis in *P. purpureum* cells were carried out for batch cultures. There are little data on productivity of semi-continuous *Porphyridium* cultures when varying these parameters (Fabregas et al., 1998 ; Fuentes-Grunewald et al., 2015 ; Gudvilovich & Borovkov, 2014). So, the aim of this work was to study *P. purpureum* growth and B-PE accumulation and production in a semi-continuous culture at low surface irradiance, with minimal rates of the pigment photodestruction.

MATERIAL AND METHODS

The work was carried out on the basis of the IBSS biotechnology and phytoresources department (Sevastopol). The object of the study was the culture of the red microalga *Porphyridium purpureum* (Bory de Saint-Vincent, 1797) Drew et Ross, 1965 (synonym: *Porphyridium cruentum* (S. F. Gray) Nägeli, 1894) (Rhodophyta): IBSS-70 strain from the IBSS core facility "Collection of Hydrobionts of the World Ocean". Cultivation was carried out on a nutrient medium for marine red algae according to (Trenkenshu et al., 1981). The composition was as follows ($g \cdot L^{-1}$): $NaNO_3$, 1.2; $NaH_2PO_4 \times 2H_2O$, 0.45; EDTA-Na_2, 0.037; $FeC_6H_5O_7 \times 3H_2O$, 0.0265; $MnCl_2 \times 4H_2O$, 0.004; $Co(NO_3)_2 \times 6H_2O$, 0.0031; $(NH_4)_6Mo_7O_{24} \times 4H_2O$, 0.0009; and $K_2Cr_2(SO_4)_2 \times 4H_2O$, 0.0017. The medium was prepared using sterilized seawater.

P. purpureum culture was grown in a setup uniting four plane-parallel photobioreactors and three systems: for supplying an air/gas mixture, thermal stabilization, and lighting. Each photobioreactor was a glass container, with a size of 5 cm × 25 cm × 50 cm and a working thickness of 5 cm. The photobioreactors were manufactured by staff of the IBSS biotechnology and phytoresources department. Into the gas distribution system, CO_2 was supplied from a cylinder with a dosing system (rotameter); CO_2 ratio in the mixture was of 2–3 % v/v (volume percent). For the culture barbotage, the resulting air/gas mixture entered the photobioreactor. The mean blowdown rate for this mixture was of 0.5 $L \cdot min^{-1} \cdot L^{-1}$ culture. Throughout the experiment, medium pH was maintained at 8–9; the temperature, at +26…+28 °C. DRL-700 lamps were used for lighting. The mean surface irradiance for two cultivators was 5 $W \cdot m^{-2}$; for the other two, 25 $W \cdot m^{-2}$.

P. purpureum semi-continuous (quasi-continuous) cultivation was carried out in the experimental cultivators at a medium specific flow rate of 0.1 and 0.2 day^{-1}. A semi-continuous (quasi-continuous) culture was obtained by regular replacing of a portion of microalgae suspension with an equivalent volume of fresh medium. Specifically, every 24 hours, 10 or 20 % of the culture volume ($\omega = 0.1$ day^{-1} and $\omega = 0.2$ day^{-1}, respectively) was removed from the cultivators and replaced. The inoculum was introduced into the cultivators so that the initial density in all the variants of the experiment was equal. Dry matter content in the culture was determined by volumetric weight calculations (Trenkenshu & Belyanin, 1979) and by weight method (Metody fiziologo-biokhimicheskogo issledovaniya, 1975). *P. purpureum* productivity was quantified by daily culture harvesting (10 and 20 % of the cultivator volume, respectively). Samples for calculating the concentration of pigments and protein were taken when the culture reached the steady state.

P. purpureum culture suspension obtained in the experiment was centrifuged for 10 minutes, a supernatant was removed, and a precipitated biomass was used to determine PBPs. B-PE content was estimated by the spectrophotometry (Stadnichuk, 1990); protein concentration, according

to (Lowry et al., 1951). To quantify B-PE in *P. purpureum* biomass, it was extracted with a phosphate buffer (0.05 M; pH 7–7.5). The spectra of pigment extracts were recorded on a SF-2000 spectrophotometer at a wavelength range 400 to 800 nm, with a step of 0.1 nm. The optical density of the obtained extracts was recorded in the area of the characteristic absorption maximums of B-PE (545 nm), R-phycocyanin (615 nm), and allophycocyanin (650 nm), as well as at 750 nm (to consider the nonspecific absorption of the solution). Pigment content in the aqueous solution was calculated according to (Stadnichuk, 1990) by the optical density values for the corresponding wavelengths.

The arithmetic mean ($\bar{x}$), standard deviation (*SD*), standard error of the mean, and confidence interval for the mean ($\Delta\bar{x}$) were calculated using the LibreOffice and SciDAVis software (significance level $\alpha = 0.05$). The table and graphs show the mean values and calculated confidence intervals ($\bar{x} \pm \Delta\bar{x}$) for triplicate.

RESULTS AND DISCUSSION

Under semi-continuous cultivation, *P. purpureum* culture density stabilized according to the specified irradiance and medium specific flow rate. The steady state was reached on the 3rd or 4th day (Fig. 1A).

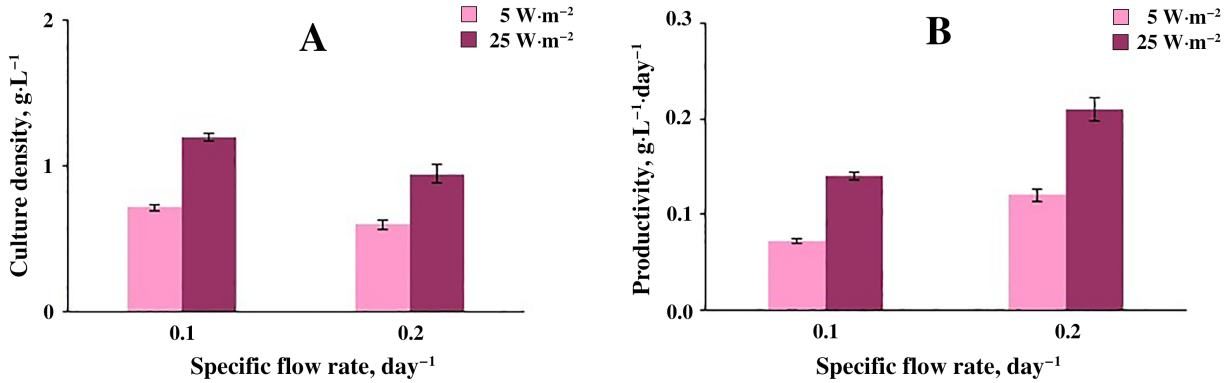

Fig. 1. *P. purpureum* semi-continuous culture density (A) and productivity (B) under different irradiance conditions

The nutrient medium used in the experiment was designed to obtain 3–4 g of *P. purpureum* biomass from 1 L of culture (Trenkenshu et al., 1981 ; Upitis et al., 1989). With a rise in the medium specific flow rate 0.1 to 0.2 day^{-1}, there was a proportional increase (by 2 times) in the content of biogenic elements inputted into *P. purpureum* culture every day; it resulted in a rise in precalculated productivity (Table 1).

Table 1. *P. purpureum* productivity under semi-continuous cultivation

Specific flow rate, day $^{-1}$	Daily nitrogen input, mg·L^{-1}	Precalculated productivity, g·L^{-1}·day^{-1}	Registered productivity, g·L^{-1}·day^{-1}
0.1	19.8	0.3–0.4	0.07–0.14
0.2	39.6	0.6–0.8	0.12–0.21

With a 2-fold increase in the flow rate (0.1 to 0.2 day^{-1}), *P. purpureum* culture density decreased for irradiance of 5 and 25 $W \cdot m^{-2}$ by 12 and 20 %, respectively (Fig. 1A). With a rise in surface irradiance, the culture density increased: with a daily specific flow rate of 10 %, by 1.8 times; with 20 %, by 1.6 times (Fig. 1A). *P. purpureum* culture productivity increased by 1.6–1.7 times both with a rise in surface irradiance 5 to 25 $W \cdot m^{-2}$ and an increase in the medium specific flow rate 0.1 to 0.2 day^{-1} (Fig. 1B).

Importantly, *P. purpureum* culture productivity did not reach the precalculated values in any of the variants of the experiment. The maximums were recorded in the variant with the highest irradiance and medium specific flow rate, but those were 1.5–2 times lower than the precalculated ones as well. For other variants of the experiment, observed productivity was 2.5–4 times lower than the precalculated one (see Table 1 and Fig. 1B).

With a rise in the medium specific flow rate 0.1 to 0.2 day^{-1} and a decrease in *P. purpureum* culture density, the specific irradiance of the cells increased for all the variants. This resulted in a significant rise in *P. purpureum* productivity, which indicates that the culture growth is precisely limited by irradiance conditions. Thus, *Porphyridium* growth rate did not depend on the content of biogenic elements inputted into culture every day, but was determined by the level of irradiance of the cells.

In addition to the stabilization of *P. purpureum* culture density, we observed the stabilization of B-PE concentration in the culture under semi-continuous cultivation (Fig. 2B). This is due to low variability in both the content of mineral nutrition elements and irradiance of the cells when the culture reaches the steady state (Trenkenshu, 2017). In *P. purpureum* cells, B-PE concentration decreased for all the variants both with a rise in surface irradiance by 15 % and a decrease in the culture density, *e. g.*, an increase in the medium specific flow rate, by 1.5 times (Fig. 2A). Apparently, a significant rise in the culture density under irradiance increase 5 to 25 $W \cdot m^{-2}$ negated the effect of the factor of irradiance on photoacclimation processes in microalgae cells. Therefore, the shift in B-PE content was less pronounced. The nature of the shifts in B-PE concentration and production in *P. purpureum* culture with an increase in irradiance and medium flow rate was largely consistent with the nature of the shifts in the culture density and productivity (Figs 1, 2B, and 2C). Specifically, B-PE content in the culture increased by 1.5–1.9 times with a rise in surface irradiance 5 to 25 $W \cdot m^{-2}$ and decreased by 1.6–2 times with an increase in the growth rate. B-PE productivity of *P. purpureum* increased by 1.5–1.9 times as well with a rise in surface irradiance. With a rise in the medium specific flow rate 0.1 to 0.2 day^{-1}, B-PE productivity increased by 1.25 times at 5 $W \cdot m^{-2}$ and did not change at 25 $W \cdot m^{-2}$.

PBPs production is known to depend on both the culture growth rate and their content in microalgae cells (Fabregas et al., 1998 ; Gudvilovich & Borovkov, 2014). The highest B-PE productivity of *P. purpureum* semi-continuous culture was recorded for the variants of the experiment with a surface irradiance of 25 $W \cdot m^{-2}$ (0.1 and 0.2 day^{-1}). As shown, a 5-fold rise in surface irradiance for two variants of daily specific flow rate resulted in a significant increase in both B-PE concentration in *P. purpureum* culture and pigment productivity. At the same time, an increase in the medium specific flow rate 0.1 to 0.2 day^{-1} had a less pronounced effect on this parameter at 5 $W \cdot m^{-2}$ and did not result in any noticeable shift in B-PE productivity at 25 $W \cdot m^{-2}$.

In the publication (Fabregas et al., 1998), at a comparable level of total daily irradiance of *P. purpureum* cells, it was shown as follows: B-PE content in the culture depends on the shift in limiting factors. Up to a flow rate of 0.1 day^{-1}, this factor is nitrogen input resulting in an increase in PBPs concentration. With further rise in the medium flow rate, the cell metabolism is controlled entirely by irradiance

conditions. In the latter case, with an increase in the medium flow rate, B-PE content in the culture decreases markedly. This negative relationship between irradiance level and B-PE concentration in the cells is characteristic of *P. purpureum*, as well as other Rhodophyta species.

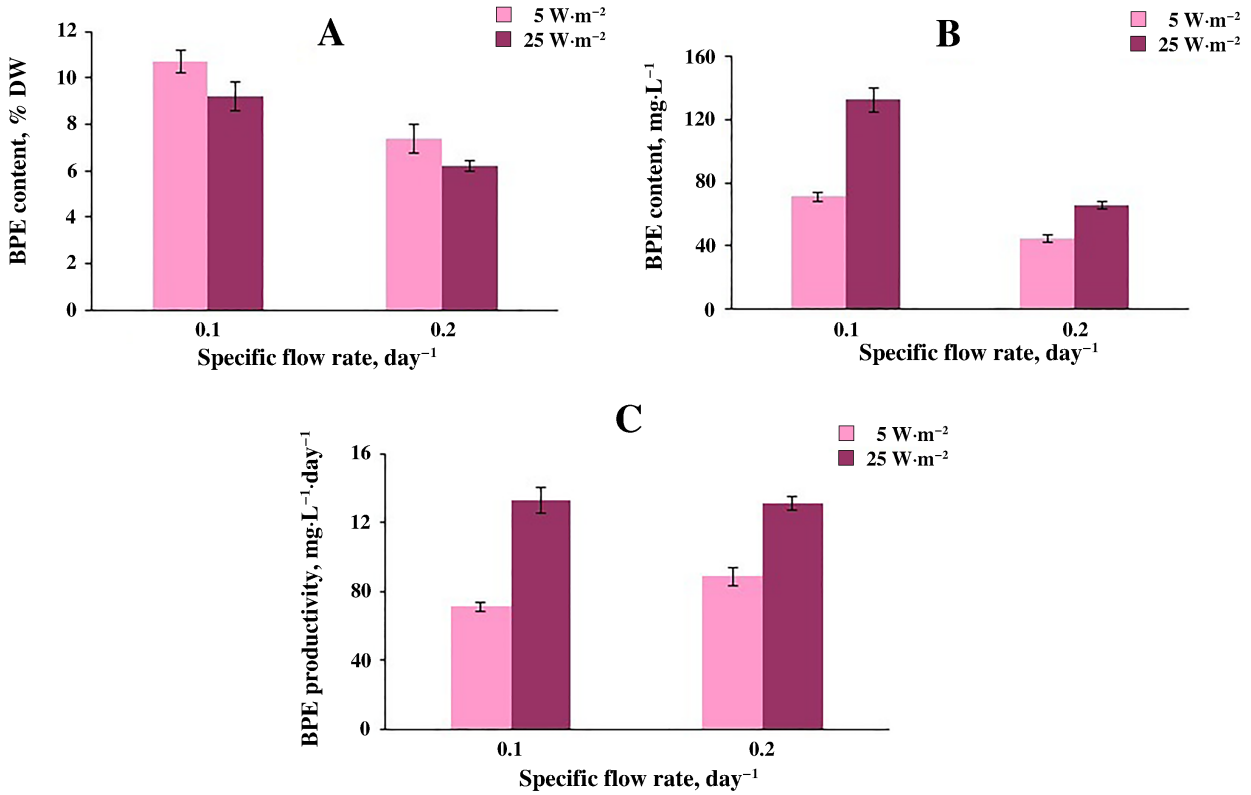

Fig. 2. B-phycoerythrin content in *P. purpureum* biomass (A) and culture (B), as well as B-phycoerythrin productivity of *P. purpureum* semi-continuous culture (C) under different irradiance conditions

Thus, an increase in the medium specific flow rate in the experiment 0.1 to 0.2 day^{-1} at a surface irradiance of 25 $W \cdot m^{-2}$ led to a rise in biomass productivity and a decrease in B-PE concentration in *P. purpureum* cells. As a result, the shift in specific content did not have a pronounced effect on B-PE production since it was compensated by an increase in the culture growth rate.

Protein concentration in *P. purpureum* cells decreased by 15–20 % with an increase in surface irradiance 5 to 25 $W \cdot m^{-2}$; by 1.3–1.4 times, with a rise in the medium specific flow rate 0.1 to 0.2 day^{-1} (Fig. 3A). In general, the nature of the shift in protein content in *P. purpureum* culture correlated with the shift in B-PE concentration. This tendency is consistent with the existing concepts on the correlation between the content of total protein and pigments forming protein complexes (Drobetskaya, 2005).

Based on the experimental data obtained, it was shown that an increase in the specific irradiance of the cells (7 to 26 $W \cdot g^{-1}$) significantly affected the productivity of *P. purpureum* semi-continuous culture, with the unidirectional shifts in biomass, B-PE, and protein productivity. Specifically, with a rise in irradiance, biomass productivity increased by 2.6 times; with a rise in B-PE productivity, by 1.8 times; and with a rise in protein productivity, by 1.7 times (Fig. 4).

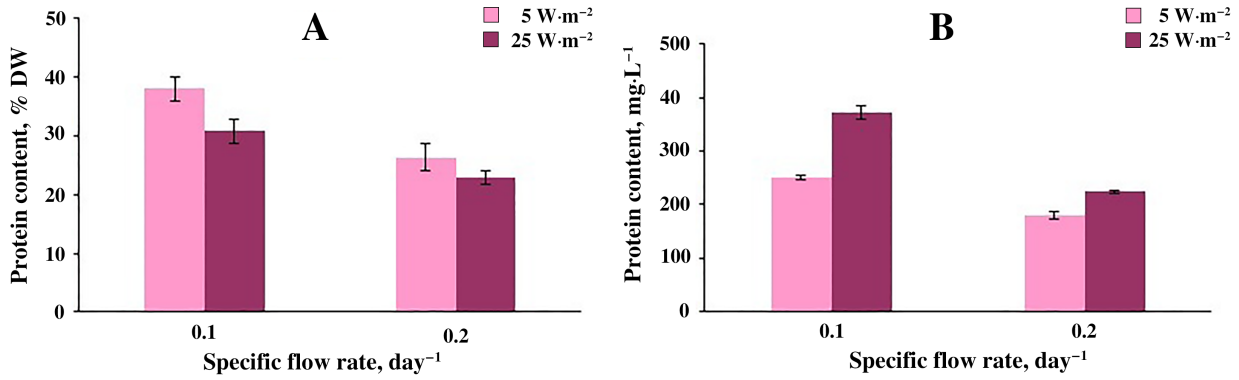

Fig. 3. Protein content in *P. purpureum* biomass (A) and culture (B) under different irradiance conditions

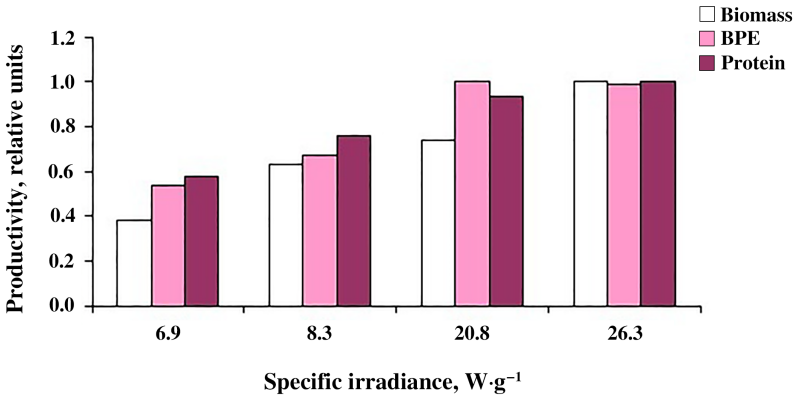

Fig. 4. Dependence of *P. purpureum* semi-continuous culture productivity (normalized to maximum values) on specific irradiance

In the semi-continuous mode, biogenic elements are systematically inputted into the culture medium. With a rise in a specific flow rate, the content of nitrogen and phosphorus inputted into the culture increases proportionally; this allows maintaining the cells in the vegetative state. The content of biogenic elements inputted into *P. purpureum* culture at the medium specific flow rate of 0.2 day^{-1} was sufficient to ensure a high culture growth rate and B-PE synthesis (see Table 1), but irradiance conditions at the level specified in the experiment did not allow reaching biomass and B-PE productivity values obtained earlier (0.5 $g \cdot L^{-1} \cdot day^{-1}$ and 40 $mg \cdot L^{-1} \cdot day^{-1}$, respectively) (Gudvilovich & Borovkov, 2014). The maximum productivity values for the experimental conditions (0.21 $g \cdot L^{-1} \cdot day^{-1}$) were recorded for the variant with irradiance of 25 $W \cdot m^{-2}$ and 20 % medium specific flow rate. Maximum B-PE productivity (13 $mg \cdot L^{-1} \cdot day^{-1}$) was registered for the variants with surface irradiance of 25 $W \cdot m^{-2}$ (0.1 and 0.2 day^{-1}). By efficiency of the expended resources, to obtain *P. purpureum* biomass enriched in B-PE, the optimal growth mode was that with surface irradiance of 25 $W \cdot m^{-2}$ and 10 % medium specific flow rate. A further increase in the content of mineral nutrition elements in *P. purpureum* culture is ineffective since the main factor determining its production characteristics was irradiance, which was confirmed by the experimental data obtained.

Nevertheless, B-PE productivity of *P. purpureum* at 25 $W \cdot m^{-2}$ recorded in the experiment correlates with similar productivity at a comparable level of total daily irradiance of *P. purpureum* cells, which was registered in the semi-continuous mode as well (13 and 15 $mg \cdot L^{-1} \cdot day^{-1}$, respectively) (Fabregas et al., 1998). Maximum *P. purpureum* productivity registered in the experiment was also comparable with the data obtained at 2-fold higher irradiance; both biomass and B-PE productivity values (0.29 and 17.5 $mg \cdot L^{-1} \cdot day^{-1}$, respectively) were close to the experimental data (Li T. et al., 2019).

Conclusion. The nature of the shifts in the production characteristics of *P. purpureum* semi-continuous culture was determined, with varying its specific growth rate and surface irradiance. An increase in irradiance 5 to 25 $W \cdot m^{-2}$ caused a rise in both biomass and B-phycoerythrin productivity of the culture by 1.5–2 times, while an increase in the medium specific flow rate 0.1 to 0.2 day^{-1} resulted in a similar rise in biomass productivity alone. The maximum values of biomass and B-PE productivity of *P. purpureum* (0.21 $g \cdot L^{-1} \cdot day^{-1}$ and 13 $mg \cdot L^{-1} \cdot day^{-1}$, respectively) were recorded for the variant of the experiment with irradiance of 25 $W \cdot m^{-2}$ and 20 % medium specific flow rate. However, the precalculated level of *P. purpureum* culture productivity, corresponding to the content of nitrogen inputted, was not recorded in any of the variants. The maximum values of productivity under the experimental conditions were 1.5–2 times lower than the precalculated ones. Protein and B-PE concentrations in *P. purpureum* cells decreased both with a rise in surface irradiance (by 15–20 %) and an increase in the medium specific flow rate (by 1.5 times). In general, the shifts in protein and B-PE content in *P. purpureum* culture were unidirectional, which is consistent with the existing concepts. In the experiment, a rise in specific irradiance of the cells 7 to 26 $W \cdot g^{-1}$ resulted in an increase in biomass, B-PE, and protein productivity: biomass productivity increased by 2.6 times; B-PE productivity, by 1.8 times; and protein productivity, by 1.7 times. Thus, the photobiosynthesis of *P. purpureum* cells was determined by the level of the cell irradiance. Surface irradiance was the main factor determining the production characteristics of *P. purpureum* culture; it should be taken into account during intensive cultivation.

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ПРОДУКЦИОННЫЕ ХАРАКТЕРИСТИКИ ПОЛУПРОТОЧНОЙ КУЛЬТУРЫ *PORPHYRIDIUM PURPUREUM* (BORY) DREW ET ROSS ПРИ НИЗКОЙ ОСВЕЩЁННОСТИ

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Красная микроводоросль *Porphyridium purpureum* (Bory de Saint-Vincent, 1797) Drew et Ross, 1965 вызывает интерес у исследователей как источник разнообразных биологически ценных веществ, количество которых в её клетках определяется условиями культивирования. Содержание фикобилипротеинов в клетках *P. purpureum* непосредственно зависит от концентрации азота в культуральной среде и от уровня освещённости клеток. Полупроточный способ культивирования позволяет легко поддерживать эти параметры на заданном уровне. Целью работы было изучить рост культуры *P. purpureum*, накопление и продукцию пигмента B-фикоэритрина (B-ФЭ) при низкой поверхностной освещённости, когда скорости процессов фотодеструкции пигментов минимальны. *P. purpureum* выращивали методом полупроточного (квазинепрерывного) культивирования при удельной скорости протока среды 0,1 и 0,2 сут$^{-1}$ и средней поверхностной освещённости 5 и 25 Вт·м$^{-2}$. Продуктивность культуры *P. purpureum* увеличивалась в 1,6–1,7 раза как с ростом поверхностной освещённости с 5 до 25 Вт·м$^{-2}$, так и с увеличением удельной скорости протока среды с 0,1 до 0,2 сут$^{-1}$. Максимальные значения продуктивности для условий эксперимента (0,21 г·л$^{-1}$·сут$^{-1}$) отмечены в варианте с освещённостью 25 Вт·м$^{-2}$ и 20%-ной

скоростью обмена среды, однако они были ниже расчётных в 1,5–2 раза. Содержание белка и B-ФЭ в клетках *P. purpureum* снижалось как с ростом поверхностной освещённости (на 15–20 %), так и с увеличением скорости обмена среды (в 1,5 раза) для всех вариантов. Изменения содержания белка и B-ФЭ в культуре *P. purpureum* также имели однонаправленный характер, и в основном он соответствовал характеру изменения плотности культуры *P. purpureum*. Продуктивность порфиридиума по B-ФЭ увеличивалась в 1,5–1,9 раза с ростом поверхностной освещённости с 5 до 25 Вт·м$^{-2}$. Максимальная продуктивность *P. purpureum* по B-ФЭ (13 мг·л$^{-1}$·сут$^{-1}$) зарегистрирована для вариантов эксперимента с поверхностной освещённостью 25 Вт·м$^{-2}$ (0,1 и 0,2 сут$^{-1}$). Повышение удельной освещённости клеток порфиридиума в эксперименте с 7 до 26 Вт·г$^{-1}$ вызывало увеличение продуктивности по биомассе в 2,6 раза, по B-ФЭ — в 1,8 раза, по белку — в 1,7 раза. Показано, что фактором, определявшим продукционные характеристики исследованной культуры в опыте, являлся световой, что подтверждено полученными экспериментальными данными.

Keywords: *Porphyridium purpureum*, culture density, protein, phycobiliproteins, B-phycoerythrin, productivity