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Original article

IN VITRO RESPONSE OF *COTINUS COGGYGRIA* SCOP. TO THE SPETRAL RADIATION AND LEDS INTENSITY

O.O. Zholobova, I.V. Mogilevskaya

Background. *Modern wide-spectrum LED installations' application under strictly controlled conditions with the correct choice of the quantitative and qualitative light composition helps the microclonal propagation of species Cotinus coggygria Scop., used in agroforestry, landscaping, and pharmaceuticals.*

Purpose. *Choosing the best photomorphogenesis parameters in vitro on a hormone-free medium for C. coggygria as a perspective plant species for commercial uses.*

Materials and methods. *The effect of 15 lighting options, namely 6 ratios of red (R), blue (B), and green (G) spectra, on the composition of LEDs on C. coggygria explants in vitro by methods used in microclonal propagation was studied. The biochemical parameters' content in the samples of the studied leaves was determined using the optical method. Statistical data processing was carried out using the Statistica 12.0 application package (StatSoft, USA).*

Results. *Determining the parameters of regenerants and leaf plates cultivated in vitro, as well as the pigment leaves' composition, made it possible to select the optimal spectral ratio (1R:1B:0.5G) and PPFD values (40–70 μmol m^{-2} s^{-1}) to obtain maximum results at cultivation on a hormone-free medium according to the Murashige and Scoog protocol. During the analysis of C. coggygria biochemical leaf composition, the maximum total chlorophyll amounts (17-21.5 μg cm^2) and NBI (67.8-71.0 c.u.) and the minimum flavonoids and anthocyanins amounts were obtained, which confirms the normal photosynthetic' apparatus work of the studied microshoots.*

Conclusion. *The results obtained can be recommended to be used for optimizing the micropropagation technology of C. coggygria.*

Keywords: *C. coggygria; LEDs; micropropagation; spectrum radiation; regenerants*

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Научная статья

ОТВЕТ *COTINUS COGGYGRIA* SCOP. НА СПЕКТРАЛЬНЫЙ СОСТАВ И ИНТЕНСИВНОСТЬ СВЕТОДИОДОВ В КУЛЬТУРЕ IN VITRO

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Обоснование. *Использование современных светодиодных установок широкого спектра в строго контролируемых условиях при правильном выборе количественного и качественного состава света способствует микроклональному размножению вида Cotinus coggygria Scop., используемого в агролесомелиорации, озеленении и фармацевтике.*

Цель. *Подбор оптимальных параметров фотоморфогенеза для C. coggygria в условиях in vitro на безгормональной среде как перспективного вида растений, используемого в хозяйственной деятельности.*

Материалы и методы. *Исследовано действие 15 вариантов освещения, а именно 6 соотношений красного (R), синего (B) и зеленого(G) спектров в составе светодиодов на экспланты C. coggygria in vitro методами, применяемыми в микроклональном размножении. Определение содержания биохимических показателей в образцах исследуемых листьев проведено оптическим методом. Статистическая обработка данных осуществлялась с помощью пакета прикладных программ Statistica 12.0 (StatSoft, USA).*

Результаты. *Определение показателей регенерантов и листовых пластин, культивируемых in vitro, а также пигментного состава листьев позволило выбрать оптимальное соотношение спектров (1R:1B:0.5G) и значения PPFD (40-70 μmol·m^{-2} s^{-1}) для получения максимальных результатов при культивировании на безгормональной среде по протоколу Murashige и Scoog. В ходе анализа биохимического состава листьев C. coggygria получены максимальные количества хлорофилла общего (17-21,5 мкг см^{2}) и NBI (67,8-71,0 у.е.) и минимальные количества флавоноидов и антоцианов, что подтверждает нормальную работу фотосинтетического аппарата исследуемых микропобегов.*

Заключение. *Полученные результаты можно рекомендовать использовать для оптимизации технологии микроразмножения C. coggygria.*

Ключевые слова: *C. Coggygria; светодиоды; микроразмножение; спектр излучения; регенеранты*

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Introduction

Spectral composition, photosynthetic photon flux density, and photoperiod duration [38] directly affect the successful propagation of plant tissue cultures and their photomorphogenesis [5; 25; 30]. Controlling the light quality and knowing which portions (or combinations) of spectral regions of LEDs are involved in various processes allow one to obtain samples with the desired characteristics [10]. In the researchers works [2] a lighting intensity of 50 μmol·m^{-2} s^{-1} was excessive for optimal growth of birch microshoots, and for sage in vitro [28] on the contrary, three PPFD options were selected: low (50 μmol·m^{-2} s^{-1}), medium (130 μmol·m^{-2} s^{-1}) and high (220 μmol·m^{-2} s^{-1}). At the same time, at high light intensity (200 μmol m^{-2} s^{-1}) a positive reaction was noted in lemon in vitro: observed a high content of chlorophyll and carbohydrates [1]. For example, Park и Runkle [36] grew ornamental plant seedlings at 20 °C using six single-source LED lighting treatments, but at a 160 μmol m^{-2} s^{-1}. The range of optimal light intensity values for a particular plant species is very individual.

In addition to the influence of intensity and spectral composition, researchers pay attention to the pigment composition in plant leaves, which reflects their response to changes in these factors and characterizes the operation of the photosynthetic apparatus [30; 35].

Chlorophylls, carotenoids, and anthocyanins are the major light-absorbing pigments in plants and utilize light wavelengths ranging from 400 to 700 nm for photosynthetic activity [13]. Red light is most effectively absorbed by chlorophyll [39], and blue light is the main morphogenesis component and produces leaves with a high chlorophyll content [1]. Irradiation with light with a wavelength of 730 nm stops plant development processes [5; 14].

The blue spectrum is capable of being absorbed by carotenoids at wavelengths of 448 and 452 nm; photoinhibition and photodamage are neutralized by anthocyanins, which absorb excess radiation [39]. These factors and the LED technologies development have contributed to the photosynthesis process optimization and the regulation of physiological plants characteristics in micropropagation [9; 27; 34]. The functionality, cost-efficiency, durability, low heat, and environmental friendliness of LEDs enable customized lighting patterns that control plant response for optimal performance [39]. Our study is relevant since, among scientific results,

there are more references to the influence of spectral composition on herbaceous plants than on woody plants [30; 32]. Information on the influence of lighting intensity and qualitative spectral composition on the parameters of *Cotinus coggygria* in vitro is not currently presented in the literature.

The genus *Cotinus* (family Anacardiaceae) includes some species of trees or deciduous shrubs native to temperate environments of the northern hemisphere (China, southern USA, southern Europe, Colombia, southern and central Europe, southern Russia, Crimea, Caucasus, Turkey) [18; 23; 40]. *Cotinus coggygria* Scop. (or European Smoketree) is a perennial deciduous shrub, sometimes a small tree up to 5 m tall. *C. coggygria* can be cultivated in dry, rocky soils due to the fact that this plant is resistant to climate conditions with minimal rainfall. It used in various areas of economic activity, including steppe afforestation and the restoration of disturbed lands. The medicinal properties of *C. coggygria* have been studied since useful extracts and essential oils have been isolated from various organs of this plant, which have valuable anticancer [16; 19], antimicrobial [8; 18], anti-inflammatory [12], and antidiabetic [26] actions. Also, *C. coggygria*, according to researchers [11], which is a valuable medicinal raw material, contains a large amount of biologically active substances, and may be used as feed additives for livestock and poultry.

Objective

The purpose of our study was choosing the best photomorphogenesis parameters in vitro on a hormone-free medium for *C. coggygria* as a perspective plant species for commercial uses.

Materials and methods

All experiments were carried out in the laboratory of biotechnologies of the Federal Scientific Centre for Agroecology, Integrated Reclamation, and Protective Afforestation of the Russian Academy of Sciences (FSC Agroecology RAS), Volgograd, Russia. In this study, conventional plant biotechnology methods were used [3]. During the experiment, we studied the effect of LEDs on the efficiency of *C. coggygria* micropropagation and its photosynthetic potential.

Cotinus coggygria Scop. explants, previously propagated were used for the experiment to study the light intensity and spectral composition influence, it was carried out in 2023. All plant materials were obtained from donor plants located on the territory of FSC Agroecology RAS, Volgograd.

The morphological characteristics of the studied plants were determined in vitro on 15 lighting options at a photoperiod of 16/8 h and a temperature

of 23±2 °C for 42 days (6 weeks) of cultivation. The LEDs were located at a distance of 5–10 cm from the tube top. Lightning options for the cultivation of *C. coggygria* explants with different ratios of red (R), blue (B), and green (G) spectra are presented in tab.1.

Table 1.

Lightning options for cultivation of *C. coggygria* explants

Name of LED installation		Types of LED used (R: B: G)	PPFD, μmol m^{-2} s^{-1}
STELLAR ФИТО LINE (C)		1:1:0.5	40, 70, 125, 170
Gauss Basic, LED (L)		0.9:1:0.8	20
Multi-tiered vegetation plant (M)	option A	0.7:1:0.5	70, 125
	option B	2:1:0.5	40, 70, 125
Growth chamber TPL 500 (TPL)		0.5:1:0.03	125
Climate chamber VeFarm – Clima 2 (V)		2.5:1:0.4	70, 125, 170, 225

To set the illumination level (required photosynthetic photon flux density (PPFD)), a compact JI600D touch-screen photon flux spectral sensor (RoHS Compliant, Taiwan) was used. 15 lighting options were configured using it, UspectrumX 1.00 software (UPRtek, Taiwan).

After 6 weeks of in vitro cultivation, shoot length, average root length, fresh shoot and root masses, number of roots per explant, as well as characteristics of leaf plates (length (L) and width (D), area, and L/D ratio) were assessed. The content of biochemical parameters of the studied leaves (total chlorophyll, flavonoids, anthocyanins, and nitrogen balance index) was determined by the optical method using an analyzer of plants Dualex+ (Force A, France). Morphological indicators were taken using the generally accepted method [3]. Measurement of the mass of the shoot and root was carried out by the gravimetric method on an analytical balance VL-120 C (Gosmetr, Russia).

Explants (~2.5–3.0 cm) with one or two nodes, grown in vitro, were transferred under aseptic conditions in a laminar box NEOTERIC (Lamsystems, Russia) into 50 ml glass tubes with 12–15 ml of MS medium according to the Murashige and Scoog protocol [3] with 7.0 g L^{-1} Plant agar (Dia-m, Russia) and 30 g L^{-1} sucrose, without adding growth regulators to eliminate the growth regulators influence on the studied samples. The medium pH was adjusted to 5.8 with a 1M KOH solution before the experiment. The prepared medium was sterilized in an autoclave (GKa-PZ 25) using saturated steam under pressure (P = 101 kPa) at 121°C for 20 min. At the cultivation stage, the explants were at 23±2°C and a 16-hour photoperiod under the conditions (tab.1) for 42 days.

The experiment was carried out in 10-fold biological and two-fold analytical replicates. After 6 weeks, the regenerants were carefully removed from the culture tubes, and parameters were measured. Experimental data were carried out using software for image analysis and processing, ImageJ (USA).

All data were expressed as mean ± SE. Statistical analysis was performed using STATISTICA software (Stat Soft Inc., USA) and Microsoft Office Excel 2019. Differences between the means of several groups were determined using ANOVA, one-way analysis of variance, and Fisher's test. All differences were considered to be statistically significant at $p < 0.05$.

Results of the Research and Discussion

The results showed that plants in studied lighting conditions responded differently to the variable experimental parameters. Both positive and negative effects were observed when cultured under controlled conditions (fig.1, 2).

The maximum shoot lengths were recorded in the lighting options, with R: B=0.5–1 in a wide range of lighting intensity (up to 170 μmol m^{-2} s^{-1} at the ratio R: B=1) (fig.1).

A comparison of the regenerated shoot lengths under different conditions showed that with an increase of the red wave in the spectrum to R: B = 2.0–2.5 and intensity to 125 μmol m^{-2} s^{-1}.

The values are statistically significant with the data obtained at R: B=1:1. The positive effect of R: B=1:1 spectrum on shoot length and fresh weight was mentioned in research by Huimin and Zhigang [20] studied *Gossypium hirsutum* L. in vitro. The authors believe that blue and red LEDs, when used together, can offset each other's shortcomings. Combining them can promote growth, but the best blue and red LED ratio depends on the plant species and cultivar [31].

When analyzing the data, it was noticed the root length does not have statistical differences at R:B ratios=0.7–2 and PPFD = 70 – 125 μmol m^{-2} s^{-1}. A decrease in root length was observed with an increase in illumination intensity to 170 – 225 μmol m^{-2} s^{-1} and the spectral composition of LEDs to 2.5R:1B:0.5G. The root number on the explant after cultivation for 6 weeks is at its maximum at an intensity of 70 μmol m^{-2} s^{-1} (1R:1B:0.5G) (fig.2, a). With this value, the indicators of the roots number at PPFD = 40 (1R:1B:0.5G) and 70 (2.5R:1B:0.5G) are not statistically significant. A sharp decrease in the root number to 0.1–0.9 (2.5 times or more) was observed even with an increase in PPFD to 125 μmol m^{-2} s^{-1} and higher (fig.1, fig.2 (g, h)). A decrease in rhizogenesis was also noted, including regenerants with second-order roots or even their absence at the spectral ratios (PPFD= 40, 125 μmol m^{-2} s^{-1}) и 2.5R:1B:0.4G (PPFD более 125 μmol m^{-2} s^{-1}) (fig. 3).

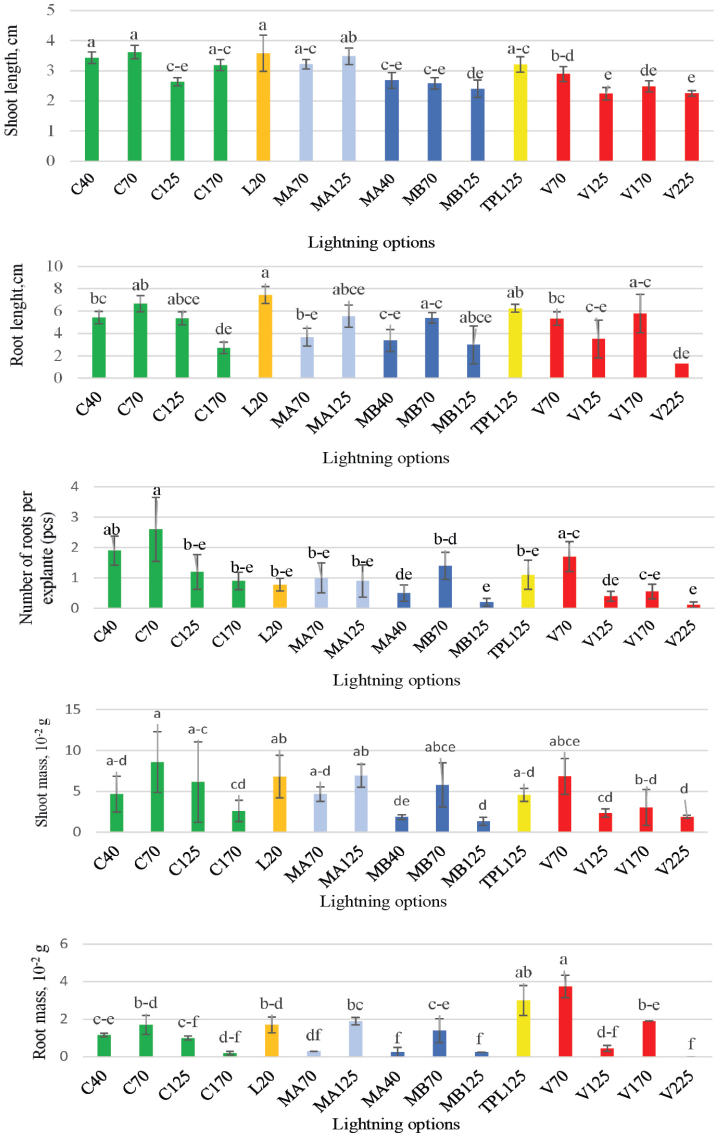

Fig. 1. Characteristics of *C. coggygria* microshoots after 6 weeks of cultivation. Column means followed by different letters are significantly different at the 5% level of Fisher LSD ANOVA.

Fig. 2. Regenerants of *C. coggygria* after cultivation in different lighting options (R: B: G, μmol $m^{-2} s^{-1}$): 1:1:0.5, 70 (a); 0.7:1:0.5, 70 (b); 2:1 :0.5, 70 (c); 2.5:1:0.4, 70 (d); 1:1:0.5, 125 (e); 0.7:1:0.5, 125 (f); 2:1B:0.5G, 125 (g); 2.5:1.0:0.4, 125 (h); 0.5:1:0.03, 125 (i). Scales correspond to 1 cm.

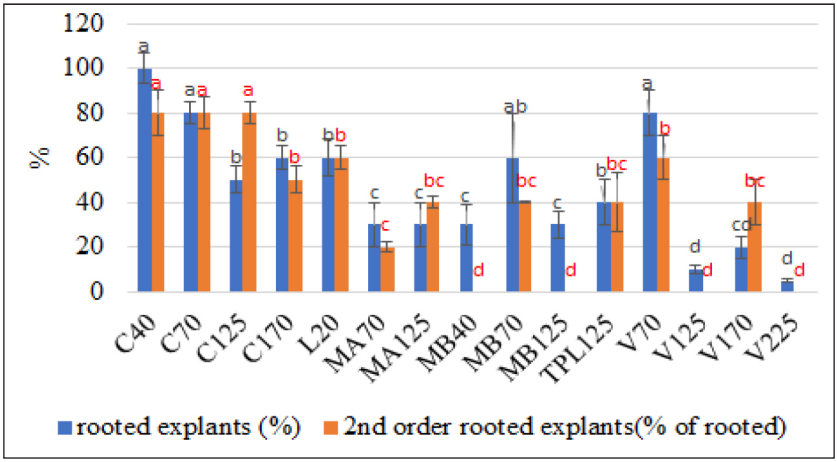

Fig. 3. Number of rooted explants and with 2nd order roots (% of rooted). Column means followed by different letters are significantly different at the 5% level of Fisher LSD ANOVA.

Thus, when cultivating *C. coggygria* under controlled conditions, increasing the proportion of the red spectrum does not produce a positive effect. A similar effect was obtained by Galdiano et al. [24] in *Cattleya loddigesii* Lindley, where red color reduced root length.

The maximum values of the fresh shoot mass (fig. 1) were observed at an intensity of 40–125 μmol m^{-2} s^{-1} (1R:1B:0.5G), in other spectral variants, with an increase of the red spectrum to 2 – 2.5R, a decrease in mass escape occurred already at an intensity of 125 μmol m^{-2} s^{-1}. Therefore, the ratio (0.9–1) R:1B and the illumination intensity of no more than 125 μmol m^{-2} s^{-1} are advantageous compared to other spectral options, which is consistent with the data [15, 34, 35].

During the studies, the maximum root mass was noted with a spectral ratio 2.5R:1B:0.4G and PPFD=70 μmol m^{-2} s^{-1} (3.75) and 0.5R:1B:0.03G and 125 μmol m^{-2} s^{-1} (3.00), but it was not possible to identify any dependence of the value of this indicator on the intensity and spectral composition.

Analysis of the morphometric parameters of *C. coggygria* showed the table 2.

Table 2.

Morphometric characteristics of leaves of *C. coggygria* in vitro with different variants of spectral composition and PPFD

Types of LED used (R: B: G)	PPFD, μmol m^{-2} s^{-1}	Leaf plate area, cm^2	L/D ratio	Increase in the leaves' number per explant, pcs.
1:1:0.5	40	0.36±0.05 c-f	1.56±0.07 c	3.90±0.82a
	70	0.52±0.06 ab	1.60±0.06 bc	4.60±0.94a
	125	0.50±0.08 a-c	1.58±0.07 bc	2.80±0.93a-d
	170	0.20±0.04 fg	1.45±0.08 c	1.80±0.53b-d
0.9:1:0.8	20	0.62±0.04 a	1.66±0.07 bc	3.60±0.95ab
0.7:1:0.5	70	0.43±0.08 b-d	1.95±0.07 a	4.20±0.68a
	125	0.62±0.05 a	1.59±0.07 bc	2.80±0.8a-d
2:1:0.5	40	0.24±0.03 e-g	1.80±0.09 ab	2.70±0.59a-d
	70	0.44±0.07 a-e	1.57±0.07 bc	2.80±0.69a-d
	125	0.16±0.02 g	1.72±0.06 a-c	1.40±0.27cd
0.5:1:0.03	125	0.33±0.02 d-g	1.60±0.06 bc	3.60±0.7ab
2.5:1:0.4	70	0.62±0.06 a	1.59±0.09 bc	3.10±0.82a-c
	125	0.30±0.06 c-g	1.72±0.09 a-c	1.70±0.33b-d
	170	0.35±0.04c-g	1.72±0.13 bc	2.89±0.67a-d
	225	0.26±0.07d-g	1.85±0.18 ab	0.89±0.45d

Column means followed by different letters are significantly different at the 5% level of Fisher LSD ANOVA.

Leaf plates parameters (area and ratio of length to width (L/D)) are influenced by the PPFD parameter, since a decrease in leaf area was observed with an increase in PPFD>125 μmol $m^{-2} s^{-1}$ and reducing it to 40 μmol $m^{-2} s^{-1}$. The optimal value for different spectral ratios for leaf area is a range of 70 -125 μmol $m^{-2} s^{-1}$ (tab. 2).

Our data are consistent with the studies [31], where the leaf area of elite clones of *Populus euramericana* plants in vitro was greatest under high exposure to monochrome red light or a combination of R: B=70/30 (%) and 60μmol $m^{-2}s^{-1}$.

In studies [22], combined treatment with red and blue spectrum in various combinations improved the leaves number. In our experiment, a statistically significant decrease of leaves number was noted at R: B = (2–2.5):1 and high light intensity values, with a ratios R: B=0.5–1 the leaves number increase over 6 weeks fluctuated in the range of 3.6 – 4.2 (tab.2).

The state of the pigment complex affects the plant organism's resistance to unfavorable environmental factors [6]. In micropropagation, plants are often exposed to high relative humidity within culture containers, reduced gas exchange, low CO_2 concentrations during the photoperiod, and high concentrations of carbohydrates, nitrogen, and growth regulators in the growing media. It directly affects the photosynthesis process in plants in vitro. Therefore, the selection of spectral ratios and photosynthetic photon flux density can be used to improve it [15, 32].

When studying the influence of different lighting options on *C. coggygria* leaves photosynthetic parameters, it was noted the maximum values of total chlorophyll were observed at a lighting intensity of 40–125 μmol $m^{-2} s^{-1}$ (1R:1B:0.5G) and 40 μmol $m^{-2} s^{-1}$ (2R:1B:0.5G) (tab. 3).

These values (17.26–21.5 μg cm^{-2}) correspond to the normal operation of the photosynthetic apparatus of *C. coggygria* in vitro with a sufficient number of nutritional components in the medium [4].

When using R:B ratios, many researchers have confirmed the positive effect of R: B= 1:1 on the accumulation of chlorophyll compared to the monochromatic effect of only red or only blue spectra, while the response of chlorophyll content in vitro to different illumination may vary in different plant species [21, 29, 17]. Changing the R:B ratio down to 0.5 or up to 2.5 results in a decrease in total chlorophyll, which is consistent with studies [39].

PPFD is measured μmol $m^{-2} s^{-1}$. Column means followed by different letters are significantly different at the 5% level of Fisher LSD ANOVA.

The lowest values of this indicator were obtained when the photosynthetic photon flux density increased to 170 μmol $m^{-2} s^{-1}$. At 225 μmol $m^{-2} s^{-1}$, there was

no possibility of taking results using the optical method due to the drying out of the regenerants. Thus, the amount of total chlorophyll in leaf samples decreased by 2 times when increased to 170 μmol m^{-2} s^{-1}. According to the study of Huimin and Zhigang [20], *Gossypium hirsutum* L. seedlings can utilize chlorophyll more efficiently under red LED light than under blue LED light and 50 μmol m^{-2} s^{-1}, which is consistent with our results on total chlorophyll since a decrease in its content occurs precisely with an increase in the proportion of the red spectrum.

Table 3.

Pigment composition of *C. coggygria* leaves after cultivation for 6 weeks under different lighting conditions

Types of LED used	PPFD*	Total Chlorophyll, μg cm^{-2}	NBI, c.u	Flavonoids, μg cm^{-2}	Anthocyanins, μg cm^{-2}
1:1:0.5	40	17.26±1.1 b-d	70.99±6.2a	0.27±0.02f	0.4±0.01b
	70	21.41±1.5 a	67.85±4.2a	0.34±0.02ef	0.39±0.01de
	125	18.6±1.5 a	48.62±5.8b-d	0.45±0.04cd	0.46±0.03b
	170	9.91±1.2 fi	12.36±1.4f	0.8±0.05a	0.67±0.04a
0.9:1:0.8	20	17.53±0.9 bc	66.09±3.6a	0.28±0.02f	0.39±0.01e
0.7:1:0.5	70	16.37±0.8 c-f	48.94±4.6b-d	0.36+0.02e	0.42±0.01b-e
	125	13.52±0.7 fi	39.42±3.0c-e	0.33±0.02ef	0.44±0.01bc
2:1:0.5	40	21.50±1.4 a	61.9±5.2ab	0.37±0.03de	0.38±0.02e
	70	14.75±1.4 b-d	50.63±6.5bc	0.33±0.03ef	0.43±0.02b-e
	125	11.51±1.1 b-f	24.31±5.5ef	0.54±0.06bc	0.44±0.02b-e
0.5:1:0.03	125	14.12±0.9 fi	46.16±3.4cd	0.33±0.02ef	0.42±0.01b-e
2.5:1:0.4	70	17.27±0.9 b-d	40.23±4.1c-e	0.46±0.03cd	0.44±0.01bce
	125	15.18±1.4 b-f	29.6±5.3d-f	0.57±0.08bc	0.45±0.02b-e
	170	9.34±1.13 i	18.97±4.4f	0.59±0.06b	0.61±0.04a

The maximum flavonoids (0.8 μg cm^{-2}) and anthocyanins (0.67 μg cm^{-2}) content was observed at a light intensity of 170 μmol m^{-2} s^{-1}. These values are 2.5 and 1.7 times greater, respectively, than the amounts of the studied pigments at lower PPFD (40 – 70 μmol m^{-2} s^{-1}). Anthocyanins are known to prevent photoinhibition and photodamage by absorbing excess radiation. To cope with stress caused by excessive light intensity, plants accumulate phenolic compounds (flavonoids and anthocyanins) in the leaf epidermis, which shield excessive radiation [37]. Minimum values of anthocyanins (0.38–0.4 μg cm^{-2}) and flavonoids (0.28–0.33 μg cm^{-2}) were observed at low PPFD (20–70 μmol m^{-2} s^{-1}) due to the absence of increased light intensity.

Changes in the chlorophyll content that occur in plant leaves are accompanied by changes in the plant nitrogen balance index NBI, which is an indicator of changes in the carbon to nitrogen ratio in formed leaves [7]. The NBI nitrogen balance index characterizes the ratio of chlorophylls and flavonoids in the leaf blade. The maximum values of the indicator were observed in the intensity range 40–70 μmol m^{-2} s^{-1} in different variants of the spectra (~62–71 c.u.). A sharp decrease in NBI by almost 6 times (tab.3) at light intensity up to 170 μmol m^{-2} s^{-1} characterizes a lack of nitrogen in the leaves. When a plant is in optimal shape, it uses basal metabolism and synthesizes proteins that determine the nitrogen balance index, and when plants lack nitrogen, they direct their metabolism to the synthesis of flavonoids [6]. This is due to the response of *C. coggygria* regenerants at high light intensities.

When cultivated in vitro for 6 weeks and using different ratios of spectra and lighting intensities, the combined influence of these factors on the performance of *C. coggygria* microshoots can be noted. With close ratios R:B:G=1:1:0.5 and 0.9:1:0.8 and a PPFD range of 20–70 μmol m^{-2} s^{-1}, maximum shoot and root lengths and leaf growth were obtained, indicating a positive effect on the biochemical composition of leaf plates in the absence of excess radiation. For other spectral ratios with a red component predominance, a negative effect was already noted at an intensity of 125 μmol m^{-2} s^{-1}. Thus, we can note the positive effect of the blue component of the spectrum in equal shares with the red one or its prevalence over the red one (R: B = (0.5 - 0.9):1). These results are consistent with the studies of Batista et al. [32]. At an intensity < 125 μmol m^{-2} s^{-1} and an increase in the proportion of the red component to R=2–2.5, a response was noted in the of *C. coggygria* microshoots, manifested in the reddening of the leaves and a change in their biochemical composition (a decrease in the total chlorophyll content and an increase in the flavonoids and anthocyanins amount), a reduction in fresh shoot and root masses, a decline in the rhizogenesis ability, a decrease in the leaf plate area, and an increase in the leaves' number.

Analysis of data from the literature and our research made it possible to select optimal PPFD values and qualitative composition for cultivating *C. coggygria* under in vitro conditions. The study results can be used to optimize the protocol for micropropagation of C. coggygria explants in artificial lighting conditions.

Conclusion

Our research made possible to select the optimal spectral composition and the light intensity for cultivating *C. coggygria* regenerants. With these param-

eters, the upper part of the shoot developed well, and maximum rooting of regenerants was observed. Analysis of the pigment composition of leaves under the selected conditions showed the maximum chlorophyll content and nitrogen balance index with minimal amounts of anthocyanins and flavonoids, which indicates the normal functioning of the photosynthetic apparatus of *C. coggygria* microshoots.

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References

1. Vliyanie spektral'nogo sostava svetodiodnogo izlucheniya na rost i razvitie rasteniy [Influence of the spectral composition of led radiation on plant growth and development]. Lyakh P.A., Koloshina K.A., Popova K.I., Lyakh, A.A. *Innovatsii i prodovol'stvennaya bezopasnost',* 2022, no. 1, pp. 108-120. https://doi.org/10.31677/2311-0651-2022-35-1-108-120
2. Vozdeystvie svetodiodnykh obluchateley razlichnogo spektral'nogo sostava na rost i razvitie Betula pubescens Ehrh. i Rubus idaeus L.v kul'ture in vitro [Effect of different led spectrum regimens on growth and development of *Betula pubescens* Ehrh. and *Rubus idaeus* L. in culture in vitro]. Evlakov P.M., Grodetskaya T.A., Fedorova O.A., Shestakov R.A., Baranov O.Yu. *Lesotekhnicheskiy zhurnal,* 2022, vol. 12, no. 4(48), pp. 14-30. https://doi.org/10.34222/issn2222-7962/2022.4/2.
3. Ditchenko T.I. *Kul'tura rastitel'nykh kletok, tkaney i organov* [Culture of plant cells, tissues and organs]. Minsk, Belarus': BGU, 2007, 46 p. http://www.bio.bsu.by/fbr/files/plant_cell_cultures.pdf (accessed March 4, 2024).
4. Zholobova O.O., Tereshchenko T.V. Optimizatsiya uglevodnogo sostava pitatel'noy sredy pri mikroklonal'nom razmnozhenii Cotinus coggygria Scop. [Optimization of the carbohydrate composition of the nutrient medium for microclonal propagation of *Cotinus coggygria* Scop.]. *Tavricheskiy vestnik agrarnoy nauki,* 2023, no. 4(36), pp. 102-112. https://doi.org/10.5281/zenodo.10279273
5. Opredelenie optimal'nogo spektral'nogo sostava izlucheniya svetodiodnoy fitolampy dlya stimulyatsii razvitiya semyan morkovi i tomata [Optimal Spectral

Radiation Composition of a LED Phytolapm for Stimulating Carrot and Tomato Seed Development] / Gubina A.A., Levin E.V., Romanovich M.M., Degterev A.E., Patokov N.O., Lamkin I.A., Tarasov S.A. *Izvestiya vysshikh uchebnykh zavedeniy Rossii. Radioelektronika,* 2022, vol. 25, no. 3, pp. 62-72. https://doi.org/10.32603/1993-8985-2022-25-3-62-72

6. Otsenka vliyaniya uglekislotnykh ekstraktov pikhty sibirskoy na indeks azotnogo balansa zernovykh kul'tur [Evaluation of the effect of carbon dioxide extracts of siberian fir on the nitrogen balance index of grain crops] / Kovaleva A.L., Zinner N.S., Nekratova A.N., Shchukina A.V. *Vestnik Altayskogo gosudarstvennogo agrarnogo universiteta,* 2021, no. 2 (196), pp. 20-26. http://vestnik.asau.ru/index.php/vestnik/article/view/178/170 (accessed March 4, 2024).
7. Soderzhanie fotosinteticheskikh pigmentov v list'yakh «zdorovykh» i «oslablennykh» derev'ev topolya bal'zamicheskogo (Populus balsamifera L.), proizrastayushchikh v usloviyakh promyshlennogo zagryazneniya (Respublika Bashkortostan, Sterlitamakskiy promyshlennyy tsentr [The content of photosynthetic pigments in the leaves of «healthy» and «weakened» balsam poplar trees (*Populus balsamifera* L.) growing under conditions of industrial pollution (Republic of Bashkortostan, Sterlitamak industrial center)] / Giniyatullin R.Kh., Ivanov R.S., Tagirova O.V., Kulagin A.Yu. *Samarskiy nauchnyy vestnik,* 2022, vol. 11, no. 1, pp. 43-48. https://doi.org/10.55355/snv2022111104
8. Antimicrobial screening of *Cotinus coggyggria* Scop leaves extract for its application in endodontics / Nizharadze N., Shavadze T., Mamaladze M., Shalashvili K. *Experimental and Clinical Medicine Georgia,* 2022, vol. 8. https://doi.org/10.52340/jecm.2022.08.01.
9. Application of wide-spectrum light-emitting diodes in micropropagation of popular ornamental plant species: A study on plant quality and cost reduction / Miler N., Kulus D., Woźny A., Rymarz D., Hajzer M., Wierzbowski K., Szeffs L. *In Vitro Cellular & Developmental Biology-Plant,* 2019, vol. 55, pp. 99-108. https://doi.org/10.1007/s11627-018-9939-5
10. Bantis F., Ouzounis T., Radoglou K. Artificial LED lighting enhances growth characteristics and total phenolic content of *Ocimum basilicum*, but variably affects transplant success. *Scientia Horticulturae,* 2016, vol. 198, pp. 277–283. https://doi.org/10.1016/j.scienta.2015.11.014
11. Chemical Composition and Content of Biologically Active Substances Found in *Cotinus coggygria, Dactylorhiza maculata*, *Platanthera chlorantha* Growing in Various Territories / Sukhikh S., Asyakina L., Korobenkov M., Skrypnik L., Pungin A., Ivanova S., Babich O. *Plants,* 2021, vol. 12, pp. 2806, 2021. https://doi.org/10.3390/plants10122806

12. *Cotinus coggygria* Scop. Attenuates Acetic Acid-Induced Colitis in Rats by Regulation of Inflammatory Mediators/ Sen A., Ertaş B., Çevik Ö., Yıldırım A., Kayalı D.G., Akakın D., Şener G. *Applied Biochemistry and Biotechnology,* 2023, vol. 195(11), pp. 7021-7036. https://doi.org/10.1007/s12010-023-04474-1
13. Davis P.A. Burns C. Photobiology in protected horticulture. *Food and Energy Security,* 2016, vol. 5(4), pp. 223-238. https://doi.org/10.1002/fes3.97
14. Degtereva M.M., Roshina N.V., Aleksandrova A.A., Tarasov S.A., Lamkin I.A. et al. The Optoelectronic Semiconductor Device Based of the Leds to Improve Plant Growth. *IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus),* 2020, pp. 1123-1125. https://doi.org/10.1109/EIConRus49466.2020.9039256
15. Dutta Gupta S., Jatothu B. Fundamentals and applications of light-emitting diodes (LEDs) in in vitro plant growth and morphogenesis. *Plant biotechnology reports,* 2013, vol. 7, pp. 211-220. https://doi.org/10.1007/s11816-013-0277-0
16. Effect and mechanism of total flavonoids extracted from *Cotinus coggygria* against glioblastoma cancer in vitro and in vivo / Wang, G., Wang, J., Du, L., & Li, F. *BioMed Research International,* 2015. https://doi.org/10.1155/2015/856349
17. Effects of light-emitting diodes on tissue culture plantlets and seedlings of Rice (*Oryza sativa* L.) / Yu L.L., Song C.M., Sun L.J., Li L.L., Xu Z.G., Tang C. *Journal of Integrative Agriculture,* 2020, vol. 19, pp. 1743–1754. https://doi.org/10.1016/S2095-3119(19)62793-0
18. Goncagül G., Güceyü C., Günaydin E. Investigation of In-Vitro Antibacterial Activity of *Cotinus coggygria* Scop. Extracts. *Van Veterinary Journal,* 2020, vol. 31(3), pp. 127-132. https://doi.org/10.36483/vanvetj.742535
19. Gospodinova Z., Nikolova M., Antov G. In vitro Antiproliferative Effects of *Cotinus coggygria* Scop. on human non-melanoma and melanoma skin cancer cells. *American Journal of Pharm and Health Research,* 2021, vol. 9(7). https://doi.org/10.46624/ajphr.2021.v9.i7.001
20. Huimin L., Zhigang X. Effect of light-emitting diodes on growth and morphogenesis of upland cotton (*Gossypium hirsutum* L.) plantlets in vitro. *Plant Cell, Tissue and Organ Culture (PCTOC),* 2010, vol. 103, pp. 155–163. https://doi.org/10.1007/s11240-010-9763-z
21. Iacona C., Muleo R. Light quality affects in vitro adventitious rooting and ex vitro performance of cherry rootstock Colt. *Scientia Horticulturae,* 2010, vol. 125(4), pp. 630-636. https://doi.org/10.1016/j.scienta.2010.05.018
22. Impact of LED light sources on morphogenesis and levels of photosynthetic pigments in *Gerbera jamesonii* grown in vitro / Pawłowska B., Żupnik M.,

Szewczyk-Taranek B., Cioć M. *Horticulture, Environment, and Biotechnology,* 2019, vol. 59, pp. 115-123. https://doi.org/10.1007/s13580-018-0012-4

23. In vitro antidiabetic activity of *Cotinus coggygria* Scop. / Gozcu S., Yuca H., Dursunoglu B., Demirezer L.O., Guvenlap Z. *Planta med.,* 2016, vol. 81(S01), pp. S1-S381. https://doi.org/10.1055/s-0036-1596544
24. In vitro growth and acclimatization of *Cattleya loddigesii* Lindley (Orchidaceae) with actived charcoal in two light spectra / Galdiano R.F.Jr., Mantovani C., Pivetta K.F.L., de Macedo Lemos E.G. *Ciência Rural*., 2012, vol. 42(5), pp. 801-808. https://doi.org/10.1590/S0103-84782012005000019
25. Influence of light-emitting diodes on the efficiency of valuable woody plants micropropagation / Djangalina E.D, Kapytina A.I, Kaigermazova M.A, Mamirova A.A, Shadenova E.A. *International Journal of Biology and Chemistry,* 2023, vol. 16(1), pp. 49-57. https://doi.org/10.26577/ijbch.2023.v16.i1.05
26. Integrating Ethnobotany, Phytochemistry, and Pharmacology of *Cotinus coggygria* and *Toxicodendron vernicufluum* / Antal D.S., Ardelean F., Jijie R., Pinzaru I., Soica C., Dehelean C. *Ethnopharmacology of Eastern European Countries,* 2022, vol. 12, pp. 662852. https://doi.org/10.3389/fphar.2021.662852
27. Kim H.J., Lin M.Y., Mitchell C.A. Light spectral and thermal properties govern biomass allocation in tomato through morphological and physiological changes. *Environmental and experimental botany,* 2019, vol. 157, pp. 228-240. https://doi.org/10.1016/j.envexpbot.2018.10.019
28. Kozłowska W., Matkowski A., Zielińska S. Light Intensity and Temperature Effect on *Salvia yangii* (BT Drew) Metabolic Profile in vitro. *Frontiers in Plant Science,* 2022, vol. 13, pp. 888509. https://doi.org/10.3389/fpls.2022.888509
29. Li H., Tang C., Xu Z. The effects of different light qualities on rapeseed (*Brassica napus* L.) plantlet growth and morphogenesis in vitro. *Scientia Horticulturae,* 2013, vol. 150, pp. 117-124. https://doi.org/10.1016/j.scienta.2012.10.009
30. Light and plant growth regulators on in vitro proliferation / Cavallaro V., Pellegrino A., Muleo R., Forgione I. *Plants,* 2022, vol. 11(7), pp. 844. https://doi.org/10.3390/plants11070844
31. Light quality affects shoot regeneration, cell division, and wood formation in elite clones of *Populus euramericana* / Kwon A.R., Cui H.Y., Lee H., Shin H., Kang, K.S., Park, S.Y. *Acta physiologiae plantarum,* 2015, vol. 37, pp. 1-9. https://doi.org/10.1007/s11738-015-1812-0
32. Light quality in plant tissue culture: does it matter? / Batista D.S., Felipe S.H.S., Silva T.D., de Castro K.M., Mamedes-Rodrigues T.C., Miranda, N.A., Otoni, W.C. *In Vitro Cellular and Developmental Biology-Plant,* 2010, vol. 54, pp. 195-215. https://doi.org/10.1007/s11627-018-9902-5

33. Light quality on growth and phenolic compounds accumulation in *Moringa oleifera* L. grown in vitro / da Silva R.R., de Souza R.R., Coimbra M., Nery F., Alvarenga A., Paiva R. *Comunicata Scientiae,* 2020, vol. 11, pp. e3313-e3133. https://doi.org/10.14295/cs.v11i.3313
34. Light-emitting diodes: Progress in plant micropropagation / Bello-Bello J.J., Perez-Sato J.A., Cruz-Cruz C.A., Martínez-Estrada E. In: Jacob-lopes E., Zepka L. Q., Queiroz M. I. (ed.). *Chlorophyll*. BoD–Books on Demand. 2017, vol. 6(1), pp. 93-103. https://dx.doi.org/10.5772/67913
35. Lotfi M., Mars M., Werbrouck S. Optimizing pear micropropagation and rooting with light emitting diodes and trans-cinnamic Acid. Plant Growth Regulation, 2019, vol. 88, pp. 173–180. https://doi.org/10.1007/s10725-019-00498-y
36. Park Y., Runkle E. Spectral effects of light-emitting diodes on plant growth, visual color quality, and photosynthetic photon efficacy: White versus blue plus red radiation. *Plos One,* 2018, vol. 13(8), pp. e0202386. https://doi.org/10.6084/m9.figshare.6946136
37. Takahashi S., Badger M.R. Photoprotection in plants: a new light on photosystem II damage. *Trends in Plant Science,* 2011, vol. 16, pp. 1-10. https://doi.org/10.1016/j.tplants.2010.10.001
38. The effects of photoperiod and light spectrum on stock plant growth and rooting of cuttings of *Cotinus coggygria* 'Royal Purple' / Cameron R.W.F., Harrison-Murray R.S., Judd H.L, Marks T.R, Ford Y.Y, Bates C.H.A. *The Journal of Horticultural Science and Biotechnology,* 2005, vol. 80(2), pp. 245-253. https://doi.org/10.1080/14620316.2005.11511925
39. Zheng L., He H., Song W. Application of Light-emitting Diodes and the Effect of Light Quality on Horticultural Crops: A Review. *Hortscience*, 2019, vol. 54(10), pp. 1656–1661. https://doi.org/10.21273/HORTSCI14109-19
40. Zholobova O.O., Mogilevskaya I.V., Melnik S.V. Screening Smoke Tree (*Cotinus coggygria* Scop.) on Osmotic Stress using Polyethylene Glycol 6000 in vitro. *Indian Journal of Agricultural Research,* 2024, vol. 58(1), pp. 36-42. https://doi.org/10.18805/IJARe.AF-781

Список литературы

1. Влияние спектрального состава светодиодного излучения на рост и развитие растений / Лях П.А., Колошина К.А., Попова К.И., Лях, А.А // Инновации и продовольственная безопасность. 2022. №. 1. С. 108-120. https://doi.org/10.31677/2311-0651-2022-35-1-108-120
2. Воздействие светодиодных облучателей различного спектрального состава на рост и развитие *Betula pubescens* Ehrh. и *Rubus idaeus* L.в культуре in

vitro/ Евлаков П.М., Гродецкая Т.А., Федорова О.А., Шестаков Р.А., Баранов О.Ю // Лесотехнический журнал. 2022. Т. 12. №. 4(48). С. 14-30. https://doi.org/10.34222/issn2222-7962/2022.4/2

3. Дитченко Т.И. Культура растительных клеток, тканей и органов. Минск, Беларусь: БГУ, 2007, 46 с. http://www.bio.bsu.by/fbr/files/plant_cell_cultures.pdf (дата обращения: 04.03.2024).
4. Жолобова О.О., Терещенко Т.В. Оптимизация углеводного состава питательной среды при микроклональном размножении *Cotinus coggygria* Scop. // Таврический вестник аграрной науки. 2023. № 4(36). С. 102-112. https://doi.org/ 10.5281/zenodo.10279273
5. Определение оптимального спектрального состава излучения светодиодной фитолампы для стимуляции развития семян моркови и томата / Губина А.А., Левин Е.В., Романович М.М., Дегтерев А.Э., Патоков Н.О., Ламкин И.А., Тарасов С.А. // Известия высших учебных заведений России. Радиоэлектроника. 2022. Т. 25. №. 3. С. 62-72. https://doi.org/10.32603/1993-8985-2022-25-3-62-72
6. Оценка влияния углекислотных экстрактов пихты сибирской на индекс азотного баланса зерновых культур / Ковалева А.Л., Зиннер Н.С., Некратова А.Н., Щукина А.В. Вестник Алтайского государственного аграрного университета. 2021. №. 2 (196). С. 20-26. http://vestnik.asau.ru/index.php/vestnik/article/view/178/170 (дата обращения: 04.03.2024).
7. Содержание фотосинтетических пигментов в листьях «здоровых» и «ослабленных» деревьев тополя бальзамического (*Populus balsamifera* L.), произрастающих в условиях промышленного загрязнения (Республика Башкортостан, Стерлитамакский промышленный центр / Гиниятуллин Р.Х., Иванов Р.С., Тагирова О.В., Кулагин А.Ю. // Самарский научный вестник. 2022. Т. 11. №. 1. С. 43-48. https://doi.org/10.55355/snv2022111104
8. Antimicrobial screening of *Cotinus coggyggria* Scop leaves extract for its application in endodontics / Nizharadze N., Shavadze T., Mamaladze M., Shalashvili K. // Experimental and Clinical Medicine Georgia. 2022. Vol. 8. https://doi.org/10.52340/jecm.2022.08.01
9. Application of wide-spectrum light-emitting diodes in micropropagation of popular ornamental plant species: A study on plant quality and cost reduction / Miler N., Kulus D., Woźny A., Rymarz D., Hajzer M., Wierzbowski K., Szeffs L. // In Vitro Cellular & Developmental Biology-Plant. 2019. Vol. 55. P. 99-108. https://doi.org/10.1007/s11627-018-9939-5
10. Bantis F.; Ouzounis T.; Radoglou K. Artificial LED lighting enhances growth characteristics and total phenolic content of *Ocimum basilicum*, but variably

affects transplant success // Scientia Horticulturae. 2016. Vol. 198. P. 277–283. https://doi.org/10.1016/j.scienta.2015.11.014
11. Chemical Composition and Content of Biologically Active Substances Found in *Cotinus coggygria, Dactylorhiza maculata, Platanthera chlorantha* Growing in Various Territories / Sukhikh S., Asyakina L., Korobenkov M., Skrypnik L., Pungin A., Ivanova S., Babich O. // Plants. 2021. Vol. 12. P. 2806. https://doi.org/10.3390/plants10122806
12. *Cotinus coggygria* Scop. Attenuates Acetic Acid-Induced Colitis in Rats by Regulation of Inflammatory Mediators/ Sen A., Ertaş B., Çevik Ö., Yıldırım A., Kayalı D.G., Akakın D., Şener G. // Applied Biochemistry and Biotechnology. 2023. Vol. 195(11). P. 7021-7036. https://doi.org/10.1007/s12010-023-04474-1
13. Davis P.A. Burns C. Photobiology in protected horticulture // Food and Energy Security. 2016. Vol. 5(4). P. 223-238. https://doi.org/10.1002/fes3.97
14. Degtereva M.M., Roshina N.V., Aleksandrova A.A., Tarasov S.A., Lamkin I.A. et al. The Optoelectronic Semiconductor Device Based of the Leds to Improve Plant Growth. IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus) 2020, pp. 1123-1125. https://doi.org/10.1109/EIConRus49466.2020.9039256
15. Dutta Gupta S., Jatothu B. Fundamentals and applications of light-emitting diodes (LEDs) in in vitro plant growth and morphogenesis // Plant biotechnology reports. 2013. Vol. 7. P. 211-220. https://doi.org/10.1007/s11816-013-0277-0
16. Effect and mechanism of total flavonoids extracted from *Cotinus coggygria* against glioblastoma cancer in vitro and in vivo / Wang, G., Wang, J., Du, L., & Li, F. // BioMed Research International. 2015. https://doi.org/10.1155/2015/856349
17. Effects of light-emitting diodes on tissue culture plantlets and seedlings of Rice (*Oryza sativa* L.) / Yu L.L., Song C.M., Sun L.J., Li L.L., Xu Z.G., Tang C. // Journal of Integrative Agriculture. 2020. Vol. 19. P. 1743–1754. https://doi.org/10.1016/S2095-3119(19)62793-0
18. Goncagül G., Güceyü C., Günaydin E. Investigation of In-Vitro Antibacterial Activity of *Cotinus coggygria* Scop. Extracts // Van Veterinary Journal. 2020. Vol. 31(3). P. 127-132. https://doi.org/10.36483/vanvetj.742535
19. Gospodinova Z., Nikolova M., Antov G. In vitro Antiproliferative Effects of *Cotinus coggygria* Scop. on human non-melanoma and melanoma skin cancer cells // American Journal of Pharm and Health Research. 2021. vol. 9(7). https://doi.org/10.46624/ajphr.2021.v9.i7.001
20. Huimin L., Zhigang X. Effect of light-emitting diodes on growth and morphogenesis of upland cotton (*Gossypium hirsutum* L.) plantlets in vitro // Plant Cell, Tissue and Organ Culture (PCTOC). 2010. Vol. 103. P. 155–163. https://doi.org/10.1007/s11240-010-9763-z

21. Iacona C., Muleo R. Light quality affects in vitro adventitious rooting and ex vitro performance of cherry rootstock Colt. // Scientia Horticulturae. 2010. Vol. 125(4). P. 630-636. https://doi.org/10.1016/j.scienta.2010.05.018
22. Impact of LED light sources on morphogenesis and levels of photosynthetic pigments in *Gerbera jamesonii* grown in vitro / Pawłowska B., Żupnik M., Szewczyk-Taranek B., Cioć M. / Horticulture, Environment, and Biotechnology. 2019. Vol. 59. P. 115-123. https://doi.org/10.1007/s13580-018-0012-4
23. In vitro antidiabetic activity of *Cotinus coggygria* Scop. / Gozcu S., Yuca H., Dursunoglu B., Demirezer L.O., Guvenlap Z. // Planta med. 2016. Vol. 81(S01). P. S1-S381. https://doi.org/10.1055/s-0036-1596544
24. In vitro growth and acclimatization of Cattleya loddigesii Lindley (Orchidaceae) with actived charcoal in two light spectra / Galdiano R.F.Jr., Mantovani C., Pivetta K.F.L., de Macedo Lemos E.G. Ciência Rural. 2012. Vol. 42(5). P. 801-808. https://doi.org/10.1590/S0103-84782012005000019
25. Influence of light-emitting diodes on the efficiency of valuable woody plants micropropagation / Djangalina E.D, Kapytina A.I, Kaigermazova M.A, Mamirova A.A, Shadenova E.A. // International Journal of Biology and Chemistry. 2023. Vol. 16(1). P. 49-57. https://doi.org/10.26577/ijbch.2023.v16.i1.05
26. Integrating Ethnobotany, Phytochemistry, and Pharmacology of *Cotinus coggygria* and *Toxicodendron vernicufluum* / Antal D.S., Ardelean F., Jijie R., Pinzaru I., Soica C., Dehelean C. // Ethnopharmacology of Eastern European Countries. 2022. Vol. 12. P. 662852. https://doi.org/10.3389/fphar.2021.662852
27. Kim H.J., Lin M.Y., Mitchell C.A. Light spectral and thermal properties govern biomass allocation in tomato through morphological and physiological changes // Environmental and experimental botany. 2019. Vol. 157. P. 228-240. https://doi.org/10.1016/j.envexpbot.2018.10.019
28. Kozłowska W., Matkowski A., Zielińska S. Light Intensity and Temperature Effect on *Salvia yangii* (BT Drew) Metabolic Profile in vitro // Frontiers in Plant Science. 2022. Vol. 13. P. 888509. https://doi.org/10.3389/fpls.2022.888509
29. Li H., Tang C., Xu Z. The effects of different light qualities on rapeseed (*Brassica napus* L.) plantlet growth and morphogenesis in vitro // Scientia Horticulturae. 2013. Vol. 150. P. 117-124.
30. Light and plant growth regulators on in vitro proliferation / Cavallaro V., Pellegrino A., Muleo R., Forgione I. // Plants. 2022. Vol. 11(7). P. 844. https://doi.org/10.3390/plants11070844. https://doi.org/10.1016/j.scienta.2012.10.009
31. Light quality affects shoot regeneration, cell division, and wood formation in elite clones of *Populus euramericana* / Kwon A.R., Cui H.Y., Lee H., Shin H., Kang, K.S., Park, S.Y. // Acta physiologiae plantarum. 2015. Vol. 37. P. 1-9. https://doi.org/10.1007/s11738-015-1812-0

32. Light quality in plant tissue culture: does it matter? / Batista D.S., Felipe S.H.S., Silva T.D., de Castro K.M., Mamedes-Rodrigues T.C., Miranda, N.A., Otoni, W.C. // In Vitro Cellular and Developmental Biology-Plant. 2010. Vol. 54. P. 195-215. https://doi.org/10.1007/s11627-018-9902-5
33. Light quality on growth and phenolic compounds accumulation in *Moringa oleifera* L. grown in vitro / da Silva R.R., de Souza R.R., Coimbra M., Nery F., Alvarenga A., Paiva R. // Comunicata Scientiae. 2020. Vol. 11. P. e3313-e3133. https://doi.org/10.14295/cs.v11i.3313
34. Light-emitting diodes: Progress in plant micropropagation/ Bello-Bello J.J., Perez-Sato J.A., Cruz-Cruz C.A., Martínez-Estrada E. In: Jacob-lopes, E.; Zepka, L. Q.; Queiroz, M. I. (ed.). Chlorophyll. BoD–Books on Demand. 2017. Vol. 6(1). P. 93-103. https://dx.doi.org/10.5772/67913
35. Lotfi M., Mars M., Werbrouck S. Optimizing pear micropropagation and rooting with light emitting diodes and trans-cinnamic Acid // Plant Growth Regulation. 2019. Vol. 88. P. 173–180. https://doi.org/10.1007/s10725-019-00498-y
36. Park Y., Runkle E. Spectral effects of light-emitting diodes on plant growth, visual color quality, and photosynthetic photon efficacy: White versus blue plus red radiation // Plos One. 2018. Vol. 13(8). P. e0202386. https://doi.org/10.6084/m9.figshare.6946136
37. Takahashi S., Badger M.R. Photoprotection in plants: a new light on photosystem II damage // Trends in Plant Science. 2011. Vol. 16. P. 1-10. https://doi.org/10.1016/j.tplants.2010.10.001
38. The effects of photoperiod and light spectrum on stock plant growth and rooting of cuttings of *Cotinus coggygria* 'Royal Purple' / Cameron R.W.F., Harrison-Murray R.S., Judd H.L, Marks T.R, Ford Y.Y, Bates C.H.A. // The Journal of Horticultural Science and Biotechnology. 2005. Vol. 80(2). P. 245-253. https://doi.org/10.1080/14620316.2005.11511925
39. Zheng L., He H., Song W. Application of Light-emitting Diodes and the Effect of Light Quality on Horticultural Crops: A Review // Hortscience. 2019. Vol. 54(10). P. 1656–1661. https://doi.org/10.21273/HORTSCI14109-19
40. Zholobova O.O., Mogilevskaya I.V., Melnik S.V. Screening Smoke Tree (*Cotinus coggygria* Scop.) on Osmotic Stress using Polyethylene Glycol 6000 in vitro // Indian Journal of Agricultural Research. 2024. Vol. 58(1). P. 36-42. https://doi.org/10.18805/IJARe.AF-781

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