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Grafička priprema: Ančica Sečan, mag. act. soc.
Objavljeno: 30. prosinca 2025. godine.
Časopis izlazi u elektroničkom izdanju dva puta godišnje, krajem lipnja i prosinca, a predviđena su i dva specijalna izdanja tijekom godine iz biotehničkog područja.
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Riječ gostujuće urednice

Poštovani čitatelji Glasila Future,

Iznimno mi je zadovoljstvo predstaviti Vam ovo posebno izdanje časopisa „Glasilo Future“ koji donosi znanstvene i stručne radove na temu ljekovitog i samoniklog bilja te povrća, kao i njihove uloge u prehrani, zdravlju i održivom razvoju. Posebna vrijednost ovog broja ogleda se u interdisciplinarnom pristupu koji povezuje poljoprivredu, prehranu, okoliš i tradicionalna znanja, naglašavajući njihovu važnost u kontekstu suvremenih izazova.

Rad autorice Šukalić i suradnika koji se bavi procjenom potencijalnog nekarcinogenog rizika unosa teških metala putem konzumacije blitve (*Beta vulgaris* subsp. *cicla*) na području Mostara donosi značajan doprinos razumijevanju sigurnosti hrane i javnog zdravlja. Rezultati ukazuju na to da su koncentracije ispitivanih metala unutar zakonski dopuštenih granica, no ističu i potrebu za kontinuiranim praćenjem, osobito kada je riječ o osjetljivim skupinama poput djece.

Utjecaj dopunskog osvjetljenja na razvoj presadnica rajčice u zaštićenom prostoru prikazan je u radu (Bogevska et al.) koji naglašava važnost svjetlosti kao ključnog čimbenika u formiranju kvalitetnog sadnog materijala. Rezultati istraživanja jasno ukazuju na prednosti LED rasvjete u odnosu na druge izvore svjetla, čime se otvara prostor za daljnja istraživanja i unapređenje tehnologija kontroliranog uzgoja.

Istraživanje o utjecaju hidrolata aromatičnog bilja na klijavost sjemenki višegodišnjeg ljulja (Franin et al.) ističe potencijal hidrolata kao ekološki prihvatljivih bioherbicida. Dobiveni rezultati ukazuju na mogućnost njihove primjene u integriranoj i ekološkoj poljoprivredi, čime se doprinosi smanjenju uporabe sintetskih sredstava i zaštiti okoliša.

Inventarizacija samoniklog bilja na području Dube Pelješke (Dujmović Purgar et al.) donosi sveobuhvatan pregled flore ovog mediteranskog područja, s posebnim naglaskom na uporabnu vrijednost biljnih svojti. Analiza prehrambenih, ljekovitih, začinskih i drugih korisnih vrsta, kao i identifikacija endemičnih, ugroženih i invazivnih biljaka, predstavlja vrijedan temelj za očuvanje bioraznolikosti i održivo upravljanje lokalnim ekosustavima.

Etnobotaničko istraživanje provedeno u ruralnoj okolici Senja (Šimunović i Vitasović-Kosić) pruža vrijedan uvid u bogatstvo tradicionalnog znanja o korištenju ljekovitog i aromatičnog te drugog samoniklog bilja. Dokumentiranjem uporabe 93 biljne svojte i 6 vrsta gljiva, rad naglašava važnost prijenosa znanja između generacija te njegov potencijal u očuvanju kulturne baštine, razvoju održivog ruralnog turizma i lokalnih proizvoda.

Završno, rad autorice Židovec i suradnika, posvećen ljekovitim svojstvima i uporabi mirisave ljubice (*Viola odorata* L.) prikazuje ovu biljku kao iznimno vrijednu samoniklu vrstu bogate povijesti primjene u prehrani i narodnoj medicini. Pregled njene morfologije, fitokemijskog sastava i širokog spektra primjene dodatno potvrđuje njezin značaj u suvremenom i tradicionalnom kontekstu.

Vjerujem da će ovaj broj Glasila Future potaknuti daljnja istraživanja, razmjenu znanja i interdisciplinarni dijalog te biti koristan i inspirativan kako znanstvenicima i stručnjacima, tako i široj čitateljskoj publici.

Želim Vam ugodno i poticajno čitanje.

izv. prof. dr. sc. Sanja Radman

Glasilo Future

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SADRŽAJ:

Influence of artificial light on tomato seedling development in the protected environment

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Abstract

Seedling quality is a critical determinant of overall crop productivity, as it directly influences subsequent plant growth and yield. Various factors affect seedling quality, among which light plays a crucial role due to its significant impact on photosynthesis and biomass accumulation. An experiment was conducted in a closed, protected facility (basement) in an individual producer in Ilinden, Skopje, to evaluate the impact of different light sources on the quality of tomato seedlings (morphological characteristics, cv. Marglobe). Three treatments were applied: natural daylight in a closed environment, LED light (80W), and infrared light (250W). Seedlings were grown from seeds in pots over two months in an uncontrolled environment (no additional heating or humidity), with each treatment including 90 seedlins in three replications (30 seedlings per replication). Fifty days after sowing, the seedlings were removed from the substrate, washed, and allowed to dry on standard filter paper for 30 minutes. Several parameters were measured destructively: total seedling weight (g), seedling height (mm), stem thickness (mm), root length (mm), root weight (g), number of leaves, and leaf weight (g). Data were analyzed using One-Way ANOVA and tested with a t-test at 1% and 5% probability levels. Results revealed highly significant differences in all parameters for seedlings grown under LED light, indicating its superior effect on seedling quality assessed through morphological indicators. Although the current protected environment posed some challenges, the findings highlight the potential of controlled-environment cultivation and underscore the need for further research and modification on environmental conditions and experiment design.

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Key words: *Lycopersicon esculentum* Mill., infrared light, LED light, plantlets, morphological characteristics.

Introduction

Although the total production of tomatoes in North Macedonia has decreased over the last decade, tomatoes remain the leading crop after potatoes and peppers (MakStat, 2015/2024). The production of tomatoes is carried out using seedlings in protected areas. The quality of seedlings determines the total production and development (Hazarika et al., 2022; Nkurunziza et al., 2022; Liu et al., 2023; Bae et al., 2025). Many factors influence the quality of tomato seedlings. The most investigated one is the growing media (Zaller et al., 2007; Sönmez et al., 2010; Gama et al., 2015; Atif et al., 2016; Vivek and Duraisamy, 2017; Yilmaz et al., 2017; Chiomento et al., 2020; Nkurunziza et al., 2022; Hazarika et al., 2022) following different production methods (greenhouse as control, plant factory and then a nursery and a plant factory) (Bae et al., 2025), traditional and floating systems (Özer, 2018), and bio products (Lumbrikal, Baikal EM, Biolan and Bioglobin) (Boteva, 2014) on the quality of seedlings.

Light serves as both a vital energy source and a key signal regulating plant growth and development (Song et al., 2024). The quality of tomato seedlings is highly influenced by light conditions (Um et al., 2009; Liu et al., 2011; Almansa et al., 2018; Meiramkulova et al., 2021; Zheng et al., 2023; Song et al., 2024) and future development (Liu et al., 2023). Appropriate light quality plays a crucial role in effectively regulating the photosynthetic capacity of plants and thereby significantly influences their overall growth, development, and physiological performance. (Meiramkulova et al., 2021). Ligh-quality lighting is undeniably linked to enhanced photosynthesis, as the process fundamentally depends on the intensity and quality of light reaching the chloroplasts (Yang et al., 2018). Otherwise, a progressive decrease in solar radiation under shading conditions (35%, 50% and 75%) resulted in a significant decline in photosynthetic rate, stomatal conductance, and electron transport rate, indicating that reduced light intensity adversely affected the photosynthetic efficiency of the plants (Jumrani et al., 2024). Improvement of the efficiency of photosynthesis is key to increasing agricultural production (Yang et al., 2018). Currently, light-emitting diode (LED) technology has emerged as a highly energy-efficient and versatile artificial lighting system that can be effectively applied in the agricultural sector, where it has been proven to enhance the productivity of various crops, particularly horticultural commodities (Arif et al., 2024). LED lighting offers growers' precise control over light spectrum, intensity, and timing while reducing heat loss and energy consumption by about 20–35% compared with conventional HPS or other traditional lighting systems (Gupta, 2017; Stamford et al., 2023). Red (600–700 nm) and blue (400–500 nm) wavelengths are predominantly utilized in most LED-based lighting systems, as these ranges are most efficiently absorbed by plant pigments, particularly chlorophylls, to drive photosynthesis (Stamford et al., 2023). LED lighting, particularly with nanoparticle coating, positively influenced tomato seedlings by enhancing photosynthetic pigment levels and promoting better growth compared with those grown under HPS control conditions (Meiramkulova et al., 2021). LED lamps AP673L and FL are suitable for cucumber seedling production, producing compact, chlorophyll-rich plants, while in tomato seedlings, the FL lamp showed the best performance (Tymoszuk et al., 2023). Considering the beneficial effects of artificial lighting on seedling production, the aim of this study was to evaluate how commercially available light sources influence the morphological quality parameters of tomato seedlings.

Materials and methods

The experiments were conducted at two distinct locations. One required a protected environment, which was provided by a designated room (basement) of individual producer in the municipality of Ilinden - Skopje, where three separate and adequately sized spaces were prepared for the trials. The second location was dedicated to laboratory analyses, which were carried out in the laboratories of the Faculty of Agricultural Sciences and Food at the "Ss. Cyril and Methodius University" - Skopje, Republic of North Macedonia.

Experiments conducted in a controlled environment

The private producer of the municipality of Ilinden in Skopje was selected as the location for conducting the first phase of the planned experiments. The setup included three treatment variants: the first was placed in a room with one-sided natural daylight and served as the control. The remaining two variants were established in a basement room under artificial lighting. The setup process took two days. On the first day, a 4 m² space (200 cm × 200 cm was constructed within the basement using a wooden frame and plasticized foil to create a controlled environment. Concurrently, lighting installations were completed, including LED and infrared lamps.

The characteristics of the LED lamp used (model AK56488) include a power rating of 80 W, white light emission at 6500 K, a voltage range of 160–240 V, a frequency of 50 Hz, and dimensions of 120 cm × 8 cm. The red lamp used was an infrared model R125, with a power of 250 W, operating at 220 V, and classified in energy class E. Following lamp installation, the next step involved setting up the surface base for the seedling pots, measuring 140 cm × 80 cm × 70 cm. To prevent light interference between the white and red light sources, the area was physically divided in half, resulting in two separate growing sections, each measuring 70 cm × 80 cm × 70 cm. This setup ensured a lamp-to-surface distance of 100 cm for the LED lamp and 90 cm for the infrared lamp. The selection of these lamps was based on their broad commercial availability and cost-effectiveness, as they represent affordable lighting options that are readily accessible on the market, making them suitable for practical application and potential adoption by producers. Tomato seeds were sown on October 28, 2024, using the Marglobe variety - a traditional cultivar originating from the United States. This variety is characterized by a plant height of 100–150 cm, round to slightly flattened fruits weighing between 120 and 200 grams, vivid fruit coloration, and a rich flavor. Marglobe tomatoes thrive in well-drained soils with a pH of 6.0–6.8 and require a warm, moderately humid climate for optimal growth.

A total of 270 plastic pots, each with a volume of 370 ml, were used for sowing. These were filled with approximately 85 liters of substrate from the brand 'PROFISUPSTRAT,' characterized by a fine structure, a pH ($CaCl_2$) ranging from 5.2 to 6.0, a nutritional composition of 1 kg/m^3, and enrichment with gramoMICRO-DEPOT at 50 g/m^3. The substrate consisted of 20% white and 80% black peat. Sowing was done manually, with one seed placed in each pot. Germination time varied across the three lighting treatments. The earliest germination occurred under infrared light at 4 days, followed by LED light at 6 days. The slowest germination was observed under natural daylight conditions at 9 days. Owing to delayed development under natural daylight conditions, the corresponding plants were additionally exposed to LED light for 15 days to support their growth.

Environmental conditions

During the examined period, temperature and relative humidity were measured twice daily — once during the light period and once during the dark period. At the end of the experiment, average values for both periods were calculated. Measurements were taken using a combined thermometer and hygrometer (model HTC-2) with measurement accuracy temperature: ±1°C and humidity: ±5% RH.In both cases, the lighting period was maintained at 16 hours per day (Tymoszuk et al., 2023).

Laboratory experiments

Laboratory measurements were conducted 50 days after sowing in two separate facilities: the Laboratory of Irrigation and the Seed Quality Control Laboratory at the Faculty of Agricultural Sciences and Food - Skopje. The equipment used included two digital scales, a caliper, and a ruler. Measurements were taken from 30 plants, with three repetitions per treatment. Fifty days after sowing, the seedlings were removed from the substrate, washed, and allowed to dry on standard filter paper (64g/m^2) for 30 minutes. To assess seedling quality, the following parameters were evaluated: total seedling weight (g), seedling height (mm), stem diameter measured above root neck below cotyledons (mm), root length under root neck till the end of the root tips (mm), root weight (g), number of leaves, and leaf weight (g).

Data analysis

The research data were statistically analyzed using analysis of variance (One-Way ANOVA). Statistical analysis of the mean values of the examined morphological parameters was conducted using the Least Significant Difference (LSD) test, followed by a t-test to determine significance at the 1% and 5% probability levels.

Results and discussion

Environmental conditions

During the vegetation period, the average daytime temperature in the room exposed to natural daylight was approximately 18.5 °C, while the nighttime temperature averaged 15.5 °C, with a relative humidity of around 70%. In the treatments with artificial lighting (LED and infrared light), the average daytime temperature was 17 °C, and the nighttime temperature was 14.5 °C. However, the infrared light treatment exhibited a slightly higher temperature, approximately 0.5 °C above that of the LED light treatment. The average relative humidity in both artificially lit treatments was 80%. According to the literature, the optimal daytime temperature for tomato seedling growth ranges between 18 and 21°C, while the optimal nighttime temperature is between 10 and 18°C (Balliu et al., 2017). The optimal relative humidity for the production of most commonly cultivated vegetable seedlings is reported to be within the range of 50–70% (Moravćević and Todorović, 2022).

Laboratory measurements

Based on laboratory measurements of the evaluated parameters, the results illustrating the effects of different light treatments on seedling vegetative growth as presented below in Table 1.

Table 1. *Morphological characteristics of tomato seedling quality*

Total seedling weight (g)				
Treatment	Mean ± SE	Difference from Natural daylight	Difference from Infrared light	Difference from LED light
Natural daylight	0.2943±0.0096	-	-0.8918**	-10.7154**
Infrared light	1.1861±0.0682	0.8918**	-	-9.8236**
LED light	11.0097±0.0884	10.7154**	9.8236**	-
Seedling height (mm)				
Treatment	Mean ± SE	Difference from Natural daylight	Difference from Infrared light	Difference from LED light
Natural daylight	104.00±6.11010	-	-155.33**	-310.67**
Infrared light	259.33±13.0171	155.33**	-	-155.34**
LED light	414.67±5.6075	310.67**	155.34**	-
Stem thickness (mm)				
Treatment	Mean ± SE	Difference from Natural daylight	Difference from Infrared light	Difference from LED light
Natural daylight	0.12± 0.0058	-	-0.09	-4.69**
Infrared light	0.21±0.0361	0.09	-	-4.60**
LED light	4.81±0.1054	4.69**	4.60**	-

Root length (mm)				
Treatment	Mean ± SE	Difference from Natural daylight	Difference from Infrared light	Difference from LED light
Natural daylight	26.00±1.3229	-	-6.43	-130.00**
Infrared light	32.43±6.0378	6.43	-	-123.57**
LED light	156.00±4.1633	130.00**	123.57**	-
Root weight (g)				
Treatment	Mean ± SE	Difference from Natural daylight	Difference from Infrared light	Difference from LED light
Natural daylight	0.0310±0.0090	-	-0.0063	-0.6537**
Infrared light	0.0373±0.0040	0.0063	-	-0.6474**
LED light	0.6847±0.0231	0.6537**	0.6474**	-
Number of leaves				
Treatment	Mean ± SE	Difference from Natural daylight	Difference from Infrared light	Difference from LED light
Natural daylight	1.50±0.1155	-	-0.80*	-3.40**
Infrared light	2.30±0.0333	0.80*	-	-2.60**
LED light	4.90±0.1000	3.40**	2.60**	-
Leaf weight (g)				
Treatment	Mean ± SE	Difference from Natural daylight	Difference from Infrared light	Difference from LED light
Natural daylight	0.0889±0.0117	-	-0.1338**	-4.6794**
Infrared light	0.2227±0.0146	0.1338**	-	-4.5456**
LED light	4.7683±0.0429	4.6794**	4.5456**	-
* significance at the 5%, **significance at the 1%				

According to Table 1, the average seedling weight was 0.2943 g under natural daylight, 1.1861 g under infrared light, and 11.0097 g under LED light. These values represent statistically significant differences among the three light treatments. The results indicate a substantially higher biomass accumulation in plants grown under LED light compared to those grown under natural daylight and infrared light, confirming the superior effectiveness of LED light in promoting vegetative growth (Song et al., 2024).

The results obtained for the average height of tomato seedlings in the three light treatments are given in Table 1. The average height of tomato seedlings under natural daylight is 104.00 mm, the average height of seedlings under infrared light is 259.33 mm, while for seedlings under LED light it is 414.67 mm. The results are significant at the 0.01 level.

Table 1 presents the average stem thickness of tomato seedlings: 0.12 mm under natural daylight, 0.09 mm under infrared light, and 4.69 mm under LED light. Seedlings grown under LED light showed the greatest stem thickness, while those under infrared light had the smallest. The difference between LED and infrared light treatments was statistically significant at the 0.01 level. No significant difference was observed between infrared light and natural daylight.

Seedlings with well-developed root systems that meet high morphological (i.e., root mass, fibrosity, volume, first-order laterals, area, and length) and physiological (i.e., root growth potential) standards have a greater ability to rapidly produce new roots after planting, resulting in a positive relationship between root mass and root growth potential (Grossnickle and MacDonald, 2017). As shown in Table 1, average root length varied across treatments: 26.00 mm under natural daylight, 32.43 mm under infrared light, and 156.00 mm under LED light. LED light significantly increased root length, with statistical significance at the 0.01 level. Similarly, root weight was highest under LED light (0.6847 g), compared to natural daylight (0.0310 g) and infrared light (0.0373 g), again confirming the positive effect of LED light based on statistical analysis.

According to Table 1, the average number of leaves per plant was 1.50 under natural daylight, 2.30 under infrared light, and 4.90 under LED light. The difference between LED light and the other treatments was statistically significant at the 0.01 level, while infrared light showed a significant advantage over natural daylight at the 0.05 level. Leaf mass followed a similar trend: 0.0889 g (natural daylight), 0.2227 g (infrared light), and 4.7683 g (LED light), further confirming the positive effect of LED light on plant biomass.

According to Kula-Maximeno et al. (2021), all growth and morphological parameters improved under white LED light 30 days after germination. In our study, measured after 50 days, similar trends were observed—plants grown under LED light consistently outperformed those under infrared and natural daylight conditions. Kula-Maximeno et al., (2021) also noted that dry mass accumulation is a key indicator of lamp efficiency, with significantly higher values under white (LED) light compared to high pressure sodium lamps (HPS). Our findings support this, as LED light resulted in greater total plant mass, further confirming the superior efficiency of LED lighting.

In addition to biomass, seedling height is a key quality standard. According to Đurovka, (2008), a quality tomato seedling should reach 30 cm for early seedlings or 20–25 cm for medium-early seedlings. In our study, seedlings grown under white light reached an average height of 41.46 cm, indicating elongation. Song et al. (2024) also reported that supplemental LED lighting significantly affects tomato seedling morphology, with greater heights observed at a PPFD of 300 $\mu mol \cdot m^{-2} \cdot s^{-1}$ compared to lower intensities (100–200 $\mu mol \cdot m^{-2} \cdot s^{-1}$). Although light intensity was not measured in our study, noticeable morphological changes particularly in seedling height were observed under both LED and infrared light. According to Song et al. (2024), average plant heights ranged from 6.9 to 10.6 cm, which differs significantly from our results. Regarding red light, Fylladitakis (2023) reported that it generally promotes growth rate and dry mass but may also cause excessive elongation in some plants, as confirmed in our study. Tomato seedlings grown under 100% red light exhibit reduced photosynthesis and abnormal stem elongation (Arif et al., 2024). Fard red light significantly inhibited lateral branch elongation in cucumber seedlings by increasing auxin (IAA) levels, reducing cytokinin (CTK; zeatin) content, and downregulating CTK synthesis-related genes (IPTs) (S. Li et al., 2024). In another study through a series of external pharmacological manipulations of gibberellins, auxin, and brassinosteroids, it was shown that gibberellins and brassinosteroids are both sufficient and necessary to induce internode elongation in tomato plants under low red-to-far-red light conditions, while auxin alone has limited effects but, in combination with gibberellins, produces significant elongation, indicating a complex hormonal interplay (L. Li et al., 2024). In tomato seedlings, the auxin balance was influenced by the LED light spectrum, with higher accumulation of active IAA under blue/red light, increased levels of the auxin degradation form (oxIAA) under white light, and light-dependent variation in brassinosteroid content, as 28-homocastasterone accumulated most under LED-generated white light, while far-red light reduced BR levels in the leaves (Kula-Maximenko et al., 2021).

Stem thickness is a key morphological trait reflecting seedling vigor, mechanical stability, and potential for successful establishment and growth in the field.. According to Đurovka, (2008), optimal stem thickness should be 10 mm. In our study, the average stem thickness under LED light was 4.81 mm, indicating a notable deviation from the standard. According to Song et al. (2024), the use of supplemental LED lighting resulted in an average stem diameter of 3.09 to 4.55 mm, which is comparable to our findings under LED light. Zheng et al. (2023) reported that light intensity derived from the LED red-blue ratio is 7:3 significantly affects tomato seedling development. The greatest stem diameter (4.23 mm) was observed at 240 $\mu mol \cdot m^{-2} \cdot s^{-1}$, while both lower and higher intensities resulted in reduced stem thickness. Additionally, at a low intensity of 60 $\mu mol \cdot m^{-2} \cdot s^{-1}$, seedlings exhibited excessive elongation.

The root system plays a vital role in the early growth and development of tomato seedlings. Zhang et al., (2025) found that increasing Daily Light Integral (DLI) within a certain range could visibly promote the growth of both the shoot and root of the seedlings. Similarly, Song et al., (2024) reported increased underground biomass with 1–2 hours of supplemental evening LED lighting at 200–300 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Zheng et al., (2023) also confirmed that the greatest root mass occurred at 240 $\mu mol \cdot m^{-2} \cdot s^{-1}$. The current study indicates that LED light produced the most favorable results in terms of root growth and biomass accumulation.

The number and mass of leaves are also key indicators of healthy, high-quality tomato seedling development. Under the influence of LED light, the best results were achieved, with an average of nearly five leaves per plant and a leaf mass of 4.7683 g. These findings are consistent with those of Song et al. (2024), who reported similar outcomes (3.5-4.9) when nocturnal supplemental lighting was used.

Although the seedlings did not fully meet standard quality requirements, future research should consider optimizing the lamp-to-surface distance below 50 cm and maintaining a consistent light intensity of 240 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (Zheng et al., 2023) or 300 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (Kula-Maximenko et al., 2021).

Conclusion

Based on the influence of artificial lighting on tomato seedling quality, it can be concluded that seedlings grown under LED lighting exhibited the highest quality morphological characteristics. Additionally, optimized environmental conditions, including slightly higher day and night temperatures and reduced air humidity, should be maintained to promote optimal seedling development. Furthermore, the experimental design should be refined by ensuring an appropriate lamp-to-surface distance with incorporating precise light intensity measurements.

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