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Photobiological safety of lamps and lamp systems in agriculture

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ABSTRACT

Purpose: The article aims to study the photobiological safety of ultraviolet radiation of UV lamps in agriculture.

Design/methodology/approach: The research and analysis of the lighting characteristics of samples of LUF 80 and LE 30 lamps, which are the most widely used in the agrarian complex.

Findings: Experimental studies have shown that the photobiological safety of LUF 80 lamps belongs to the low-risk group RG1, while LE 30 lamps show high risk and are thus assigned to group RG3.

Research limitations/implications: It is advisable to continue studying the characteristics of lamps and lamp systems for various fields of agriculture on the market in Ukraine to assess their compliance with safety requirements.

Practical implications: The application of the proposed approach allows increasing the level of labor safety in commercial greenhouses or any other industry by choosing the suitable lamps for agriculture that at present are not regulated by additional safety measures.

Originality/value: The originality of the article is showing the results of the experimental data of the studies of light-technical characteristics of ultraviolet lamps for agriculture.

Keywords: UV irradiation, Photobiological safety, UV lamp code

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CLEANER PRODUCTION AND BIOTECHNOLOGY

1. Introduction

The working environment includes everything that surrounds a person in the process of work. Often, the body of an employed person is affected by certain factors of the working environment and the labour process, such as radiation during the production process of irradiating the surface with highly concentrated fluxes of femtosecond energy [1] or when using instruments equipped with a xenon lamp in research in the wavelength range from 190 to 1100 nm [2], the presence of fine dust or nanoparticles in the air of the working area [3], elevated temperatures [4], etc. The choice of methods and means of safety should be based on the identification of harmful and hazardous factors inherent in a specific production equipment or process. Algorithms for expert assessment of measures to reduce production risk at an industrial enterprise [5] are being developed, and stochastic models for assessing professional risk [6] are developed and substantiated.

UV radiation has traditionally been regarded as harmful to crops, but recent years have shown that different levels of ultraviolet radiation (UV; 100-400 nm) can provide a number of beneficial effects on seed germination in pre-sowing and the storage quality of many [7,8] fruits, vegetables and ornamental crops [9,10]. UVA (315-400 nm), UVB (280-315 nm), and UVC (100-280 nm) have been shown to influence growth, photosynthesis, as well as affect secondary metabolites of plants and pests such as aphids, whiteflies, and thrips [11]. In addition to bactericidal activity, the UV-C radiation at a wavelength of 254 nm is used for several purposes, including regulation of tomato's ripening [12], stabilization of fruit quality during storage of freshly cut watermelons [13], and delay of decomposition of enzymes in fruits [14].

The results of Bridgen [15] confirm that short periods of UV exposure on young plants in a greenhouse are effective for regulating plant growth. When using ultraviolet light irradiation of plants grown in greenhouses, the doses received by the plants are crucial to control the plants' growth response. Too high a dose of ultraviolet radiation will burn the plants, in contrary, a low dose will not affect. The authors note that UV-C's short-term use can be considered a promoter factor only in the breeding phase [16].

There is also a great positive experience with irradiation facilities for the prophylactic ultraviolet irradiation of animals, birds, and air disinfection [17,18].

Parisi and Wong [19] noted that workers who spend the whole day in the greenhouse still need to take preventative measures to reduce the effects of ultraviolet radiation. The danger of the UV radiation and blue light is governed by the ICNIRP guidelines [20].

The problems of using UV radiation in agriculture and the photobiological safety of lamps and lamp systems (for example, for greenhouses) are given much attention.

UV radiation of the spectral range of 290-400 nm is beneficial for the human body [21]. UV radiation is widely used to treat various skin diseases and other diseases [22]. However, as recent studies show, in addition to the positive effects of UV radiation, it creates several adverse effects for the human body, which can lead to severe structural and functional damage to the skin. Moreover, the weight of negative factors outweighs the positive ones.

The formation of malignant tumours of humans and animals [23,24] and various plant responses [25,26] are directly linked to the effects of UVA. Recent studies have shown that UVA can create mutagenic effects both as a result of direct absorption by DNA cells and indirect damage of the genome by UVA-induced reactive oxygen species [27,28].

In WHO [24], an analysis of more than a hundred scientific research about the effect of natural UV radiation and radiation from artificial sources used in various types of tanning salons on human health was carried out. Most importantly, UVA and UVB contribute to DNA damage, and therefore the IARC (International Agency for Research on Cancer) has classified the entire spectrum of UV radiation as carcinogenic to humans [29]. Also, UV radiation from artificial light sources, regardless of natural radiation, can pose risks for melanoma formation [30]. The danger is also presented by blue light [31].

A favourable direction for the investigation of the photobiological safety of lamps and lamp systems is the analysis of tanning salons since the availability of regulatory documentation and the necessary equipment allows a number of studies in this direction. The WHO [24] provides evidence that all the benefits of tanning salons advertised in various sources of information are not valid. A number of studies have shown that irradiation is higher than the safety limits and the ratio of UVB/UVA fluxes is significantly different from natural solar in most tanning salons.

The harmful nature of UV radiation to the eye must also be taken into account [32]. The emission requirements for lamps used in photobiological systems and tanning salons are established in EN 60335-2-27:2013; IEC 61228:2008 [33,34].

The effective irradiance, weighted against the CIE erythemal action spectrum in the spectral ranges (250-320) nm and (320-400) nm, is given in Table 1.

Table 1.
Limits of effective irradiance of tanning appliances according to IEC 60335-2-27

Type of UV device	Effective irradiance, W/m^2	
	$250nm<\lambda\leq320nm$	$320nm<\lambda\leq400nm$
1	< 0.001	≥ 0.15
2	0.001-0.15	≥ 0.15
3	< 0.15	< 0.15
4	≥ 0.15	< 0.15
5	≥ 0.15	≥ 0.15

Table 2.
Characteristics of tanning lamps from different manufacturers

№	Lamp type	UV code	Length/ diameter, mm
1	HAVELLS-SYLVANIA PBO 180 W 2.6 R	180-R-103/8.0	2016/38
2	LIGHHTECH SR 32/80 W	80-R-100/3.2	1500/32
3	NEW TECHNOLOGY 160 W 3.5	160-R-132/10.3	1760/38
4	COSMEDICO COSMOUS 160 W 36 R	160-R-150/1.8	1760/38

For EU countries, according to EN 60335-2-27, the erythemal irradiance in the spectral range 280-400 nm should be no more than 0.3 W/m^2. Devices for domestic use should have an erythemal irradiance, not exceeding 0.15 W/m^2.

UVB radiation in large doses causes burns, so it should be limited. The ratio of UVB/UVA for tanning lamps is in the range of 1-12. Erythema-weighted irradiation and E_{UVB}/E_{UVA} ratios, estimated by the Carcinogenic Radiation Safety Function, are the main parameters of tanning lamps and lamps used in agriculture communicated to consumers by UV marking (IEC 61228: 2008).

In most cases, low-pressure discharge lamps are used. The parameters of some types of tanning lamps are given in Table 2.

In the works [35,36], studies of the parameters of tanning salons of various types showed that a significant part of them produced an erythemal irradiance over 0.3 W/m^2, which is a maximum value established by the European standard. In England, measurements showed that 9 out of 10 tanning salons exceeded irradiation limit [37,38]. Very low compliance of tanning salons with European requirements was also noted in Longo [36].

The inconsistency of lamps in tanning salons makes it necessary to check ultraviolet lamps used in different areas in agriculture.

Current requirements for actinic UV radiation lamps' photobiological safety are established in EN 62471:2008 [39].

To protect against the eye or skin injury from ultraviolet radiation exposure produced by a broadband source, two hazards are considered, the actinic UV hazard to skin and eye and the UVA eye hazard. With regards to the actinic UV hazard, the effective integrated spectral irradiance E_{uv}, of the light source shall not exceed the levels defined by:

$$E_{uv} \cdot t = \sum_{200}^{400} \sum E_{\lambda}(\lambda, t) \cdot S_{uv}(\lambda) \cdot \Delta t \cdot \Delta\lambda \leq 30 \text{ J/m}^2 \quad (1)$$

where E_{uv} is the total actinic UV irradiance in the range 200-400 nm, W/m^2; $E_{\lambda}(\lambda, t)$ – spectral irradiance produced by the source at a given distance in the range 200-400 nm, W · m^{-2} · nm^{-1}; $S_{uv}(\lambda)$ – hazard weighting function; Δλ – the wavelength interval, nm; Δt – the exposure time, s.

The hazard weighting function for assessing actinic UV radiation's danger to the skin and eyes is presented in EN 62471:2008 [39].

The function for different wavelengths differs by several orders of magnitude; it is provided on a logarithmic scale.

The permissible time for exposure to ultraviolet radiation incident upon the unprotected eye or skin shall be computed by:

$$t_{\max} = \frac{30}{E_{uv}} \frac{\text{J}/\text{m}^2}{\text{W}/\text{m}^2} \quad (2)$$

Regarding the UVA hazard, for exposure times of less than 1000 s, the dose of UVA (320-400 nm) should not exceed 10,000 J/m^2. If the eyes are irradiated for longer than 1000 s, the UVA exposure level should not exceed 10 W/m^2.

In EN 62471:2008 [39], exposure limit values (EL) of irradiation are established, which should not be exceeded when using lamps. ELs' values determine conditions under which each person can be exposed repeatedly to radiation without irreversible health effects. They were not considered as an exact boundary between safe and dangerous levels but are indicative values only. Safety classifications of optical emissions established four main risk groups: The general group (RG0) carries no photobiological risks; Group 1 (RG1) – insignificant risk, carries neither the actinic hazard (EUV) for 1000 s nor the hazard of UVA (E_{UVA}) for 300 s; Group 2 (RG2) – medium risk, does not bear the photo-biological hazards of actinic radiation (E_{UV}) for 0.25 s, as well as the hazards of UVA (E_{UVA}) for 100 s; Group 3 (RG3) – high risk, carries danger even with short exposures [40].

For UV lamps, exposure limits for various groups of photobiological risks are given in Table 3.

Table 3.
Emission limits for various photobiological risk groups

Risk	Units of measurement	Emission limits values		
		Overall Group	Low risk	Average risk
Actinic UV (E_{UV})	mW/m^2	1	>3	>30
UV (EU_{UVA})	W/m^2	10	33	100

Although these data no longer correspond to the latest concepts on the safety of UV radiation, this document is the only one by which it is possible to evaluate lamps' UV radiation.

2. Material and methods

This work aimed to study the photobiological safety of lamps and determine the risk group for their radiation in accordance with EN 62471:2008 [39].

Ultraviolet lamps of the LUF 80 type (GRL Plant, Ukraine) and erythema lamps LE30 (Lisma Plant, Russia) were taken as the object of study. In Figure 1 shows samples of the studied lamps.

Measurement of spectral irradiance and calculation of the total actinic UV irradiance of E_{UV} in the wavelength range 200-400 nm and spectral irradiance of E_{UVA} in the UVA range (320-400 nm) was carried out according to the methods given in IEC 61228:2008 [34], EN 62471:2008 [39].

Fig. 1. Samples of the investigated lamps

The measurements were carried out using the OST-300 optical radiation test system (Fig. 2), which contains a spectroradiometer for measuring irradiance in the wavelength range of 200-400 nm and software for calculating the total actinic UV irradiance and integrate irradiance in individual spectral ranges. The program also allows one to calculate the maximum exposure time and risk group to which the tested radiation source belongs.

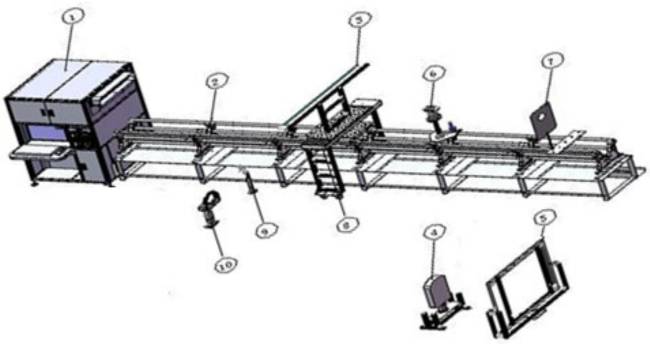

Fig. 2. OST-300 installation diagram: 1 – mobile operational platform; 2 – optical rails and their equipment; 3, 4, 5, 9, 10 – variable lamp holders; 6 – movable trolley for laser measurement; 7 – movable diaphragm of the field of view; 8 – a movable platform for research lamps

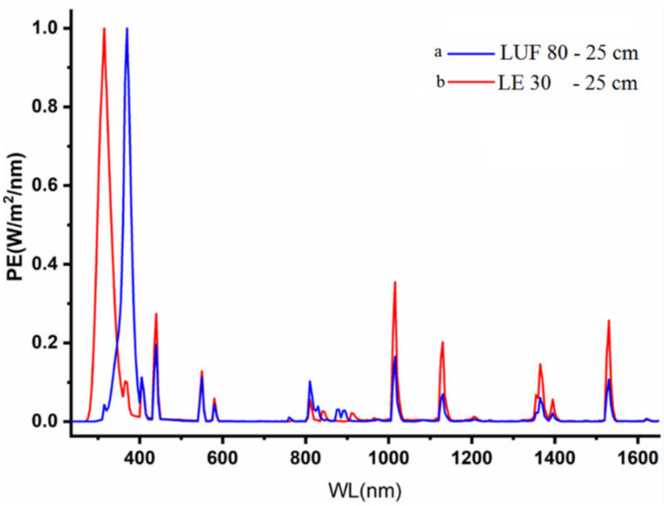

Fig. 3. Spectral irradiance of a lamp of the type LUF 80 (a) and LE 30 (b)

The results of measuring the spectral irradiance (in W/m^2nm) of LUF 80 and LE 30 lamps in the wavelength range of 200-550 nm are presented in Figure 3.

3. Results and discussion

3.1. Determination of the UV code of LUF 80 and LE 30 lamps

In the studied LUF 80 and LE 30 lamps, on the marking and in the additional information provided in the technical specifications for the LUF 80 and LE 30 lamps, there is not enough information to determine the equivalence code (UV code) according to IEC 61228-2008 [34].

To determine the codes, it was necessary to carry out measurements and calculations of the following indicators:

- The erythemal irradiance in the spectral range of 250-400 nm;
- Effective irradiance weighted against the non-melanoma skin cancer (NMSC) hazard weighting function in the UVA, E_{UVA} (λ> 320 nm) and UVB, E_{UVB} (λ< 320 nm).
- Determination of the ratio of effective irradiation (energy illuminance) of the E_{UVB}/ E_{UVA}.

To find these indicators, we used the measurement data obtained with the OST-300 spectroradiometer. The calculations were carried out in accordance with the requirements of IEC 61228: 2008 [34]. The calculation results are summarized in Table 4.

Table 4.
The calculation results of the erythemal irradiance for determining the lamps' UV code according to IEC 61228-2008 [34]

Type of lamps	Distance from lamps, m	E_{UV}, mW/m^2	E_{UVB}, mW/m^2	E_{UVA}, mW/m^2	E_{UVB}/E_{UVA}
LUF 80	0.25	6.2	7.6	2.0	3.8
LE 30	0.25	2936.2	1238.0	7.3	170.0

UV-LUF lamp code 80 (for 80 W power): 80-O-6.2/3.8, where 80-O is a lamp without reflector, 80 W power 8 – erythemal irradiance at a distance of 0.25 m spectral range of 250-400 nm; 3.8 – E_{UVB}/ E_{UVA}.

UV code of the LE 30 lamp: 30-O-2936/170, where 30-O is a lamp without a reflector, with a power of 30 W, 2936 is the effective erythemal irradiance at a distance of 0.25 m in the spectral range of 250-400 nm; 170 – E_{UVB}/E_{UVA}.

3.2. Research of photobiological safety of lamps

Based on the measurements $E(\lambda)$, the values of E_{UV}, E_{UVA} for distances from the lamp 0.25 m, and the time of safe exposure and the risk group, were calculated and presented below.

1. Ultraviolet lamp LE 30: The total E_{UV} value at a distance of 0.25 m is 62.7 mW/m^2. The energy illumination of the E_{UVA} at a distance of 0.25 m is 427.9 mW/m^2. Under these conditions, the emission of lamps belongs to the group of insignificant risk. Under these conditions, the lamp belongs to a high-risk group (RG3).
2. Lamp LUF 80: E_{UV} =2.9 mW/m^2; E_{UVA} =4912 mW/m^2. The emission of lamps belongs to the group of insignificant risk (RG1).

3.3. Discussion of results

As can be seen from the above results (Tab. 4), in the spectral composition of LUV 80 lamps, there is less radiation in the UVB range, and it creates significantly less erythema UVA irradiance.

Therefore, the LUF 80 lamps are more safe than the LE 30 lamps, as their use will not lead to structural and functional damage to the skin [41] and will not create a mutagenic effect [42].

When obtaining the ratio of the E_{UVB}/E_{UVA} equal to 3.8, it is not forbidden to use the LUF 80 lamps in various photobiological systems, as well as in tanning salons, the requirements for which are given in [33,34]. It is necessary to take into account the effect of UV radiation on the retina and other components of the organs of sight, because this radiation can lead to significant damage to the visual apparatus [43].

The obtained results (Tab. 4) showed that efficiency of the LE 30 lamps against erythema is in 45 times higher than efficiency of the LUF 80 lamps. It is known that the action of UVB radiation is directly related to the formation of malignant tumours in humans and mammals [44,45], as well as various undesirable reactions in plants [46,47].

UVB radiation contributes to DNA damage in the same way as UVA radiation, and therefore the entire spectrum of UV radiation is carcinogenic to humans [48]. It should not be forgotten that most of the studies described in the dermatological literature [49] warn about the risk of non-melanoma skin damage in humans during using the UV nail polish curing lamps. Even the duration of using these lamps does not exceed several hours per month.

When using the LE 30 lamps in various systems of ultraviolet exposure during irradiation of plants [46], animals [45], as well as people [44] providing the proper exploitation of the UV systems the following parameters should be taken into account: E_{UV}, E_{UVA}, E_{UVB} and the E_{UVB}/E_{UVA} ratio. UVB radiation at high doses causes burns, so it should be limited, which applies more to the LE 30 lamps compared to the LUF 80 lamps.

The maximum UV exposure time is defined as follows:

$$t_{max} = \frac{30}{E_{UV}} \frac{J/_{m^2}}{W/_{m^2}} [39].$$

The maximum exposure time, estimated by the weight function of the actinic hazard of UV radiation, should not exceed 15 J/m^2 within a 4-hour period.

Limits of maximum UVA exposure: dose should be no more than 10^3 mJ/cm^2 at t<1000 s; at t>1000 s – $E_{UVA} \leq 10$ W/m^2, the maximum UVA exposure time is defined as follows:

$$t_{max} \leq \frac{10^4}{E_{UVA}} \left(\frac{J/_{m^2}}{W/_{m^2}}\right) \tag{3}$$

The recommended exposure time for the first action should not exceed a dose of 10 mJ/cm^2. For the second action, the dose should not exceed 25 mJ/cm^2, and the total dose should not exceed $3 \cdot 10^3$ J/m^2. The maximum annual dose should not exceed $15 \cdot 10^3$ J/m^2.

4. Conclusions

1. The photobiological safety of LUF 80 lamps belongs to the low-risk group RG1, and the LE 30 lamps to the high-risk group RG3.
2. The UV code of the LUF 80 lamps is 80-O-6.2/3.8, and the UV code of the LE lamps is 30-O-2936/170. The erythema efficiency of LE 30 lamps is 45 times greater than LUF 80, which requires additional safety measures.
3. It is advisable to continue studying the characteristics of lamps and lamp systems for various fields of agriculture on the market in Ukraine to assess their compliance with safety requirements.

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