Application of excilamps in agriculture and animal breeding (Review)

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ABSTRACT

The paper provides a review of research data on applications of XeCl excilamps in agriculture and animal breeding. The data demonstrate a favorable effect of radiation produced by the excilamps on the fertility of animals (outbred mice and pigs) and on the growth of plants (flaxes, potatoes, carrots, cucumbers, conifers).
Excilamp models adapted specially for use in stock-raising and grain storage complexes are now available. The research data obtained in 2012–2015 suggest that XeCl excilamps hold promise for prevention of diseases in indoor-housed pigs and for pre-sowing seed preparation.
Key-words: excilamp, narrow-band radiation, dermatology, animal fertility, crop yield.

1. INTRODUCTION

Excilamps are a general name of devices that emit spontaneous ultraviolet (UV) and/or vacuum ultraviolet (VUV) radiation of excimer and exciplex molecules. Now, a great variety of excilamps is available. The devices are classified by the type of working molecules (Table 1), gas excitation method, and design[1–4].

The present paper provides a review of research results obtained in 2012–2015, showing the prospects for excilamp applications in agriculture and animal breeding.

Table 1. Most-used maximum radiation wavelengths for excimer (X_2*, Rg_2*) and exciplex (RgX*) molecules in rare gases Rg, halogens X, and their mixtures Rg-X_2

Rare gas (Rg)			Ar	Kr	Xe
Halogen (X_2)			126 nm	146 nm	172 nm
	Cl	259 nm	175 nm	222 nm	308 nm
	Br	289 nm	165 nm	207 nm	282 nm

2. PHYSIOLOGICAL ACTION OF RADIATION ON ANIMALS

The physiological action of radiation emitted by XeCl excilamps on humans consists in absorption of soft ultraviolet by the skin (epidermis and dermis) with activation of different photochemical processes the most known of which is photosynthesis of group D vitamins. Figure 1 shows how deep the radiation of different wavelengths penetrates the human skin. It is seen that even UVA radiation (λ = 315–400 nm) fails to reach the subcutis, being absorbed in the epidermis and dermis. This is because the photochemical reactions responsible for erythema (skin redness) occur deep in the skin (in the epidermis) and between the epidermis and a radiation source there is a horny layer of flat dead cells which readily absorb UV. Nevertheless, the UV radiation diffused in these layers is sufficient to trigger photochemical processes the most known of which is photosynthesis of group D vitamins. The final stages of synthesis of these vitamins in a human are photochemical.

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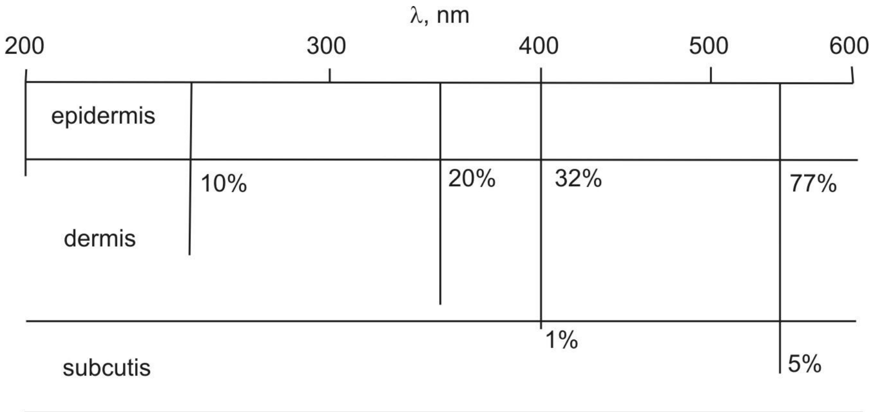

Figure 1. Light penetration depth in the skin layers as a function of radiation wavelength.

In 1980, the UV action on psoriasis was studied. It was found that the UV wavelength for treatment of psoriasis patients was 296–313 nm[5]. The wavelengths 254, 280, and 290 nm failed to provide the so strong therapeutic effect even at an irradiation dose 10–50 times higher than the minimum erythermal dose. The disclosed fact gave grounds for selective phototherapy based on combined action of UV and UVB (λ = 290–320 nm)[6].

Initially, selective phototherapy widely used fluorescent lamps with broad radiation continua and short-wave boundary from 280 to 315 nm (so-called tanning lamps). In 1997, it was proposed to treat psoriasis with a XeCl exciplex laser[6]. The merit of the XeCl laser is minimization of the skin treatment time; among the shortcomings of the laser system is its high cost and maintenance complexity.

T. Oppenländer[8] and E.A. Sosnin[9] independently suggested using a XeCl excilamp for this purpose. The typical radiation spectrum of a dielectric barrier discharge (DBD-driven) XeCl excilamp is the XeCl*(B→X) band with a maximum at 308 nm and short-wave wing at ~ 30 nm. This means that more than 90 % of the radiant energy falls within the active UVB spectrum for psoriasis treatment. The work was not continued, because reliable XeCl excilamps were unavailable at that time.

The progress in excilamp research made possible reliable XeCl excilamps and successful treatment of other skin diseases such as vitiligo, eczema, and atopic dermatitis[10–16].

The possibility of using a DBD-driven nitrogen lamp for treatment of skin diseases was demonstrated; Its spectra includes useful ultraviolet range of wavelengths (part of UVA)[17,18].

In 2012, E.A. Sosnin proposed to extend the research in the physiological action of radiation produced by a DBD-driven XeCl excilamp to animals. The reasoning behind the study was that animals in stockbreeding farms are kept indoors throughout their life and this, while preventing the spread of epidemic diseases, deprive the animals of sunlight, including short-wavelength solar UV (λ ~ 290–320 nm), which stimulates the physiological activity of animals in natural conditions via complex photochemical and physiological reactions. In particular, the latter processes increase the immunity and productivity of animals. Because the radiation spectrum of a XeCl excilamp corresponds to this physiologically active range of solar radiation, it was reasonable to pursue the study.

First, the physiological action of radiation was studied on outbred white mice to investigate its effect on the motion and smooth muscle activity of intestines (Figure 2). On the 30th day after completion of the experiment, anatomical examination was conducted. The study did not reveal any toxic, embryotoxic, skin irritative, and allergic action of the radiation. The live mass was physiologically increased by 2.6–3.1 %; enhancement and improvement was found in the motion activity, respiratory function, and gastric peristalsis; the radiation was shown to predispose to *multiple pregnancy* of the animals[19].

In 2012–2013, in collaboration with Tomsk Agricultural Institute and Siberian Agrarian Group, the physiological action of a DBD-driven XeCl excilamp on sows was studied. The arrangement of excilamps for irradiation of sows is shown in Figure 3.

Figure 2. Photo of a white mouse doe with a brood. The doe during pregnancy was exposed to radiation

In tests, six sows were used; three were a control group and three were a test group. Before testing, the animals were subjected to biochemical blood analysis. After two-week testing, the analysis was repeated. The irradiation schedule included daily exposure of artificially inseminated sows to UVA radiation sudozes during one week.

It was shown that small irradiation doses decreased the death rate of newborn piglets more than two times.

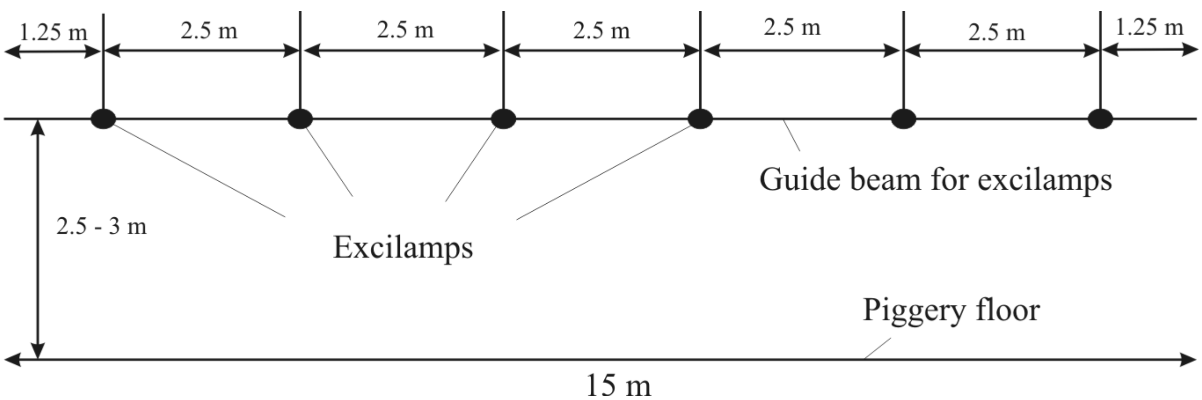

Figure 3. Arrangement of excilamps rated at irradiation of about 25–30 animals.

In should be noted that the operating conditions of devices in stockbreeding complexes are "aggressive"; the air is saturated with dust and biological gases. This makes impossible long-term operation of conventional air-cooled excilamps. Therefore, for solving the problem, we specially developed a protected XeCl excilamp operating with no cooling but ensuring the desired irradiation doses. The operation of this type of excilamps is based on the effect of working mixture convection [20–22].

The results obtained require not only practical implementation but also reconsiderations based on photochemical and photophysical research. However, it is clear even now that DBD-driven XeCl excilamps give hope for their wide application in the future, in particular to assist technological processes in animal breeding [23].

3. PHOTOREGULATION OF AGRICULTURAL PLANTS

The potential of excilamps is still far from being unveiled in full, as evidenced by research in UV photoregulation of plants.

Radiation sources can provide efficient control of photosynthesis and growth of plants. One of the ways of increasing the photosynthetic activity of plants is to use a light source emitting at $\lambda \sim 300–800$ nm and ideally such that its radiation is concentrated at 400–510 and 610–720 nm. Another way is to use UV radiation. In plants, this radiation changes the activity of enzymes and hormones and influences the synthesis of pigments as well as the rates of photosynthesis and photoperiodic reaction[24]. Our earlier laboratory research in the effect of UV radiation on photocontrol of plants suggested the following[25].

1) Broadband irradiation simulative of solar radiation fails to provide exact information on how the growth of plants is disturbed;

2) Besides hazardous effects, UVB radiation can likely to produce photocontrol effects but they are "damped" by radiation at other wavelengths and affected by greatly differing doses.

Thus, the research in the UVB effect required a narrow-band source that would allow wide variation in the irradiation dose. This concept was tested [26]. The photocontrol effect of narrow-band UV radiation produced by DBD-driven KrBr and XeCl excilamps on accumulation of photosynthetic pigments was studied in 50-day germs grown in laboratory conditions: *Siberian cedar* (*Pinus sibirica Du Tour*), Ajan spruce (*Picea ajanensis Lindl. et Gord.* (*Fisch. ex Carr.*)), and *Cajander larch* (*Larix cajanderi Mayr* (*Worosch*)). The research results showed that irrespective of the radiation wavelength, exposure time, and plant type, UVB radiation stimulated the synthesis of chlorophyll. This suggests that narrow-band UVB radiation displays photocontrol effects, which is of interest in terms of increasing the plant productivity, and that further research in UVB excilamps can provide their use in photobiology of plants.

Another line of our studies concerns the application of excilamps for pre-sowing treatment of seeds. For tests, we chose a DBD-driven XeCl excilamp with an intense emission band at 290–320 nm corresponding to short-wave UV light transmitted through atmosphere. The irradiated materials were seeds of different varieties of flaxes, potatoes, carrots, and cucumbers. The radiation action on different varieties was found to be differential. However, in all cases, an increase was observed in germinating power, leaf coverage, and stem length, which increased the crop yield.

Several examples of how a XeCl excilamp influences the plant characteristics are given below.

Example 1. Figure 4 presents two flax beds (TOST K cultivar).

LEFT ROW **RIGHT ROW**

Figure 4. Flax growth: UVA-irradiated seeds (left row) and non-irradiated seeds (right row); Krivosheino Farm Field, Tomsk Region, 2013

It is seen that the irradiated seeds (left row) demonstrate better growth of sprouts than the non-irradiated seeds (right row). In both rows, the time of planting, soil composition, and growing conditions are the same.

Example 2. After harvesting (Krivosheino Farm Field, Tomsk Region, 2014), the iodine number X* of flax seeds (TOST cultivar) was identified by analytical chemistry. The iodine number is the number of grams of iodine that can join double bonds to 100 grams of fat. The higher the value of X*, the more the unsaturated acids are contained in seed fat. It was shown that the iodine number in control plants was $X^* = 0.45 \pm 0.06$, whereas that in test plants (irradiated seeds) was $X^* = 0.6 \pm 0.07$.

Example 3. Table 2 presents measured morphometric parameters of hothouse cucumbers. It is evident that irradiation of seeds ensures a 27% increase in the stem height and up to 40% increase in the assimilating surface area compared to the control crops.

Table 2. Morphometric parameters of hothouse cucumbers (Konkurent cultivar); Tomsk Agricultural College, 2013[27]

Variants	**Stem height**		**Assimilating surface area**	
	cm	**%**	**cm^2**	**%**
June 17, 2013				
Control	7.8 ± 0.2	100	7.55 ± 0.07	100
49-sec irradiation	8.4 ± 0.2	108	6.44 ± 0.22	85
98-sec irradiation	9.2 ± 0.3	118	7.90 ± 0.18	105
June 24, 2013				
Control	12.3 ± 0.6	100	15.09 ± 0.2	100
49-sec irradiation	12.4 ± 0.7	100	19.25 ± 0.1	127
98-sec irradiation	15.6 ± 0.5	127	21.80 ± 0.2	144
July 1, 2013				
Control	15.9 ± 0.3	100	19.12 ± 0.4	100
49-sec irradiation	16.3 ± 0.7	102	22.23 ± 0.3	116
98-sec irradiation	18.5 ± 0.4	116	24.85 ± 0.3	130

The research results were patented [28]. The observed effects bring up the question of what photochemical processes are responsible for them. We hope that an answer to this question will be found in the future.

4. CONCLUSION

Animals in stockbreeding complexes spend the entire life cycle indoors to prevent the spread of epidemic diseases. At the same time, they are deprived of sunlight, including short-wavelength solar UV (~290–320 nm), which stimulates the physiological activity of animals in natural conditions via complex photochemical and physiological reactions. It is shown that irradiation with excilamps provides good physiological states and pregnancy of outbred white mice. Small irradiation doses decrease the death rate of newborn piglets more than two times.

The use of DBD-driven XeCl excilamps for pre-sowing treatment of seeds of different varieties (flaxes, potatoes, carrots, cucumbers) demonstrates differential irradiation effects. However, in all cases, an increase is observed in germinating power, leaf coverage, and stem length, which increases the crop yield.

The research data obtained in 2012–2015 suggest good prospects for application of excilamps in agriculture and animal breeding.

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