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EFFECTS OF LIGHT OF DIFFERENT WAVELENGTHS, PRODUCED BY LIGHT-EMITTING DIODES (LEDS), ON THE GERMINATION OF SEEDS OF *PINUS NIGRA* ARN., AND ON THE GROWTH OF THE PLANTLETS RESULTED FROM THEIR EMBRYOS

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ABSTRACT:
After **21 days** of exposure of the black pine seeds (*Pinus nigra* Arn.), putted to germinate - and ulterior - of the plantlets resulted from their embryos, at ***white*** *fluorescent light*, or at light produced by *Light-Emitting Diodes* (LEDs), in regime 16 hours / day, with a light intensity of 1200 lux, comparative with similar samples maintained at *natural light*, in a laboratory with northern exposition, it was found that the ***white*** light of LEDs has largely increased the germination of the seeds, while the ***yellow*** or ***green*** light of LEDs caused a reduction to almost a half of the percentage of seeds germination. On the other hand, the ***white*** light, emitted by fluorescent tubes, has stimulated with 45.3% the growth in size of the plantlets, and with 50.7 the dry weight of them. The ***white*** light of LEDs grew with just 18.7% the growth of the plantlets and with 24.2% their dry weight. At the plantlets exposed to the ***red*** light of LEDs, the size of the plantlets has been increased with 39.8%, and their dry weight with 47.1%; the ***blue*** light of LEDs has enhanced only with 10% the growth of the plantlets, respectively with 16.7% the dry weight of them. Instead, the plantlets illuminated with ***yellow*** or ***green*** light emitted by LEDs have presented values close to those of the control variant, regarding both the size and the dry weight of the plantlets.
Keywords: *Pinus nigra*, LEDs, light, colour, germination

INTRODUCTION

Light is one of the most important environmental factors, which exercises various influences on plants, being not only a source of energy in photosynthesis, but it also acting and on the germination, the growth and the development of the vegetal organisms. In the plant's reaction, it matters not only the quantity and the quality of incident radiations, but also the length of illumination period, respective the photoperiod.

One of the most convenient light sources, used in the forced cultures and *in vitro* cultures was - until recently – the fluorescent light. From the year 1962, there have been introduced the Light-Emitting Diodes (LEDs) that emit light of different wavelengths (see the part of methods, from the present paper) not only across the visible spectrum, respectively: ***red***, ***yellow***, ***green***, ***blue*** or ***white*** light, but also and in the ultraviolet or infrared spectra. These lighting sources present a very high brightness, even if their dimensions are very small, of only 3-5 mm in diameter.

Such lighting devices have a long lifespan (at least 12-18 years of operation), are easy to install, are economical, generate low heat, present a very reduced risk of fire, have a small fragility, reduced weight and they are ecological (*Bula* et al., 1991; *Barta* et al, 1992).

Goins and his collaborators (1997), from the Kennedy Space Center, U.S.A., had grown - time for 70 days - wheat plants (*Triticum aestivum* L., cv. „USU-Super Dwarf") in the ***red*** light emitted by LEDs, that had a photosynthetic photon flux (PPF) of 350 μmol $m^{-2}s^{-1}$, with or without simultaneous combination of this light with a ***blue*** light, emitted by fluorescent tubes. The authors cited concluded that the size of plants subjected to illumination with ***red*** LEDs had increased by 2.6 cm, compared to that of similar plants illuminated with ***white*** fluorescent tubes, the reference group (control).

Investigations concerning the effects exerted by LED's light on the growing process of plants were also performed by the researchers from the European Space Agency from Noordwijk (Holland) (*Brinckmann*, 2005) and by those from the Russian State Research Centre from Moscow (Russia) (*Erokhin*, 2006), whose results confirmed the appropriateness of the plants growing (for example, of salad) in the space shuttles, under conditions of lighting of the cultures with LEDs, combining the LEDs issuing the ***red*** light (660 nm) with those that generate ***blue*** light (470 nm). Productivity of salad leaves increased by 30%, compared to that recorded at the batch of the plants illuminated with ***white*** light, produced by fluorescent tubes.

Experimenting with dried seeds, of radish, of carrot and of cress, exposed just for several seconds to powerful LEDs, emitting ***green*** light (with wavelength of 526 nm and light intensity of 37.2 Wm^{-2}), after the germination and their growth, outdoor in ***natural*** light, with diurnal variations specific to late summer in Germany, for 14, 26 and 71 days, *Sommer* and *Franke* (2006) had found that this procedure determined the increase by 5.9% of the fresh weight of the cress plants, with 23.3% of the roots of radish, and with 97% of the carrot roots, as against to

seeds that had not undergone any exposure – dried being - to the ***green*** light of LEDs (control batch).

Pop and *Cachiță* (2009), testing on *in vitro* cultures of *Sequoia sempervirens* illuminated with LEDs emitting ***white*** or ***green*** light, noticed that – comparative to similar vitrocultures illuminated with ***white*** light, emitted by fluorescent tubes, lot considered as reference, respectively 100% - the ***white*** light of LEDs had stimulated the basal ramification of vitroplantlets, while the ***green*** light had enhanced with 33% the growth in length of the stalks of the plantlets regenerated from explants.

Recent studies, performed in this direction, by *Vîdican* and *Cachiță* (2010), revealed the fact that, the illumination of the vitrocultures of the yellow cactus (*Echinopsis chamaecereus* F. Lutea) – for 90 days – with LEDs emitting light, ***red*** or ***green***, had enhanced the callogenesis with 77%, respective with 100%, in relation with the situation recorded to the similar samples which were been illuminated with ***white*** light emitted by fluorescent tubes, reference values, considered 100%.

In the present study, we have proposed to analyse the exercised influence of the light, with different wavelengths, respective of various colours, produced by LEDs, on the germination of black pine seeds (*Pinus nigra* Arn.), and on the growth of seedlings resulted from their embryos.

MATERIALS AND METODS

As biological material, we used black pine seeds (*Pinus nigra* Arn.) imbibed – in dark - with tap water, for 12 hours, after that they were put to germinate on filter paper wetted with tap water, too. The germination process has been performed in uncoloured and transparent boxes, made from plastic material. During the germination, the seeds were illuminated with LEDs (super bright Zextar), diodes that had 5 mm in diameter, which were fixed on some plates. The plates with LEDs have had the dimension of 30 cm in length and 20 cm in width, and the density of LEDs was of 40/600 cm^2. The LEDs were located at a distance of 20 cm from the seeds. In function of the wavelength emitted by LEDs, we organised the following experimental variants:

V_0 – seeds germinated in ***natural*** light (control lot);
V_{00} – seeds germinated in ***white*** fluorescent light (380-760 nm);
V_1 – seeds germinated in ***white*** LEDs light (380-760 nm);
V_2 – seeds germinated in ***blue*** LEDs light (465 nm);
V_3 – seeds germinated in ***green*** LEDs light (520 nm);
V_4 – seeds germinated in ***yellow*** LEDs light (590 nm);
V_5 – seeds germinated in ***red*** LEDs light (650 nm).

In the **7th day** after the seeds were put to germinate, was assessed their germination percentage and was determined the growth of the plantlets originated from their embryos, measurements that were continued in the **14th** and the **21st day** from the assembling of the experiment.

In the whole period of the experiment, the photoperiod consisted of 16 hours of light / 24 hours; the temperature in the germination and growth chamber was maintained constant, at 20±2°C, over day and night; the relative humidity from the growth room was at 50-60%. The light intensity – measured at the seeds level – was of 1200 lx, parameter adjusted with the aid of a potentiometer, in such a way that the tension applied to LEDs to be equivalent at each experimental variant.

The control variant consists of black pine seeds, germinated in a laboratory with northern orientation, exposed to ***natural*** light (Fig. 1).

Fig.1. *Pinus nigra* var. Arn. plantlet, after 21 days from the moment when seeds were put to germinate, (consisting in root, hypocotyl and 5-7 cotyledons), illuminated with ***natural*** light, the control variant – V_0.

After one, two and three weeks from the moment when seeds were put to germinate, while these and the plantlets originated from their embryos were exposed to light of different colours, emitted by LEDs, or to the ***white*** light produced by fluorescent tubes (corresponding to the proposed experimental variants), or to the ***natural*** light, biometrical measurements were performed, determining: the median size of the *roots*, of the *hypocotyls*, and in the **21st day** of germination, also the length of the *cotyledons*; by summing the numbers referring to the mean length of each organ, in part, the average size of the *entire plantlet* was obtained. Also, in the **21st day** from the moment when seeds were put to germinate, has been determined the weight – fresh and dry – of each organ, individually, respective of the *root*, of the *hypocotyl* and of the *cotyledons*. In order to determine the dry weight of the vegetal material, the samples were maintained in a drying oven, set at a constant temperature of 105°C, for three days, moment in which was registered a stability of the dry weight of samples. By summing the dry weight of

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each organ, in part, has been obtained the *whole plantlet* dry average weight.

The resulted data from the performed measurements were statistically processed with the aid of the GraphPad Software, using independent groups „Student's" ***t*** test (two-tailed P value). The arithmetic mean of the realised measurements and the standard deviation from the mean – in the case of each experimental variant – were individually reported to the respective values of the control variant, at the confidence level of 95% ($p \leq 0.05$) and 98 degrees of freedom (DF), so, resulting the statistical signification of the means (the statistical probability that the means of the experimental variants to be significant different from the mean of the control variant).

The average data obtained at the parameters measured, in part, at each experimental variant, were expressed in percentage values, which were graphically represented in figures 2-4. These data had originated from reporting the obtained results at each parameter, measured individually at the various experimental variants, to the similar data registered at the control lot, samples which were illuminated during the experiments with ***natural*** light, values considered as reference, respectively of 100%.

RESULTS AND DISCUSSIONS

If at the control variant (V_0), lot of black pine seeds exposed to ***natural*** light, the ***germination percentage*** (determined in the **7th day** after the seeds were put to germinate), was 36%, at the V_{00} variant – seeds illuminated with ***white*** fluorescent tubes - it was 40%, and at the V_1 variant – lot of seeds germinated at ***white*** light emitted by LEDs – this parameter being the highest of 56% (Table 1), data statistically significant ($p \leq 0.05$).

In comparison with the control lot (V_0), these values indicate us the fact that, at the V_{00} variant (samples exposed to the ***white*** light of the fluorescent tubes) the germination was enhanced with 4%, and at the V_1 variant – seeds and plantlets of black pine illuminated with LEDs of ***white*** colour – the germination percentage increased by 20% (Table 1).

The percentage of germination of the seeds exposed to the ***blue*** light of LEDs (V_2) was 33%, which by comparison with the values obtained in the case of this parameter analysed at the control group (V_0) - seeds germinated in ***natural*** light (values reference, considered 100%) – has represented a minus of 3%, and that of the seeds germinated in the ***green*** light of LEDs (V_3) was of minus 9%. In the case of the seeds germinated at the ***yellow*** light of LEDs (V_4), the germination percentage was of only 24%, registering a minus of 12% as against to the values of this parameter obtained at the control variant (V_0); at the seeds germinated in the ***red*** light of LEDs (V_5), this parameter situated at 30%, germination percentage that was with 6% lower than at the control lot (Table 1).

Table 1. The *percentage of germination* of the black pine seeds (*Pinus nigra* Arn.), determined in the **7th day** from the moment when these were put to germinate, in regime 16 hours of light / 24 hours, illuminated with LEDs emitting light of different wavelengths, or with fluorescent ***white*** tubes - 380 – 760 nm (V_{00}), or with ***natural*** light - the control variant (V_0).

Experimental variants	Percentage of germinated seeds (%)
V_0 – ***natural*** light	36
V_{00} – ***white*** fluorescent light	40
V_1 – ***white*** LEDs light	56
V_2 –***blue*** LEDs light	33
V_3 – ***green*** LEDs light	27
V_4 – ***yellow*** LEDs light	24
V_5 – ***red*** LEDs light	30

In the following, we will analyse the results regarding the ***growth*** of the organs of black pine plantlets, in the case of all experimental variants, in comparison with the growth recorded at the control lot seedlings, samples exposed to the ***natural*** light (the control variant – V_0): at the plantlets illuminated with fluorescent ***white*** tubes (V_{00}), in the **7th day** of germination (Fig. 2 A), the *roots* have marked an enhancement of the growth in length of 4.4%, at the *hypocotyls* the increase being of 61.5%, and at the *entire plantlet* the growth marked an increase of 28.2%. We must point out the fact that, in the case of all experimental variants, in the **7th day** and the **14th** day of germination, the size of the *whole plantlet* has consisted only from the *root* and the *hypocotyl*, because – at that "age" - the *cotyledons* were embedded in the seminal tegument. Thus, only in the **21st day** of germination, the *entire plantlet* dimension has included not only the lengths of the *root* and of the *hypocotyl* but also of the *cotyledons* (Fig. 1).

In the **14th day** of germination (Fig. 2 B), at the lot of pine plantlets illuminated with fluorescent ***white*** tubes (V_{00}), it has been remarked an increase of the size of the *roots* with 96.4%, and of the *hypocotyls* with 60%, as against to the respective parameters recorded at the germination and growth of the control lot seedlings (V_0), samples which were grown in ***natural*** light.

In the **21st** day of germination (Fig. 2 C), the size of the *roots* of the plantlets lighted with ***white*** fluorescent tubes (V_{00}) grew with 68%, that of the *hypocotyls* with 9%, of the *cotyledons* with 86%, respectively, that of the *whole plantlet* with 45.3%, as against to the size registered at the seedlings exposed to ***natural*** light (V_0).

At the variant illuminated with ***white*** LEDs (V_1), versus to the values of the growth parameters recorded at the control lot – cultures exposed to ***natural*** light

(V_0 variant) – in the **7th day** of germination, the size of the *roots* was increased with 7.4%, that of *hypocotyls* with 58.7%, respectively, that of the *entire plantlet* with 28.8%; in the **14th day** after the seeds were put to germinate, in the conditions of exposure of samples at LEDs emitting ***white*** light (V_1), the growth in length of the *roots* was risen with 36.3% and of the *hypocotyls* with 35.4%, respective, of the *whole seedling* with 50.4%; in relation with the growth values that had been marked at the control batch plantlets (V_0), in the **21st day** of germination, at the plantlets illuminated with ***white*** LEDs (V_1), the *roots* showed an increase of the growth in length by 34.4% as against to the respective parameter measured at the control group, while the growth of the *hypocotyls* was inhibited with 8.6, and the *cotyledons* size was increased with 51.3%; summing the growing values of all organs and reporting the data obtained at this variant in relation to those marked at the plantlets grown at ***natural*** light (control batch), we found that the length of the *entire seedling* was increased with 18.7%. Therefore, although, largely, the lot of seedlings lighted with LEDs emitting ***white*** light was stimulated in growth, in the **21st day** of germination, at these plantlets it was registered a lowering of the differences in growth of the *entire plantlet* of about 50%, in the first **14 days** from the initiation of the experiment, to 18.7% in the **21st day** of germination (Fig. 2 C). The growing differences noticed in relation with the control variant – in all cited cases – were statistically significant.

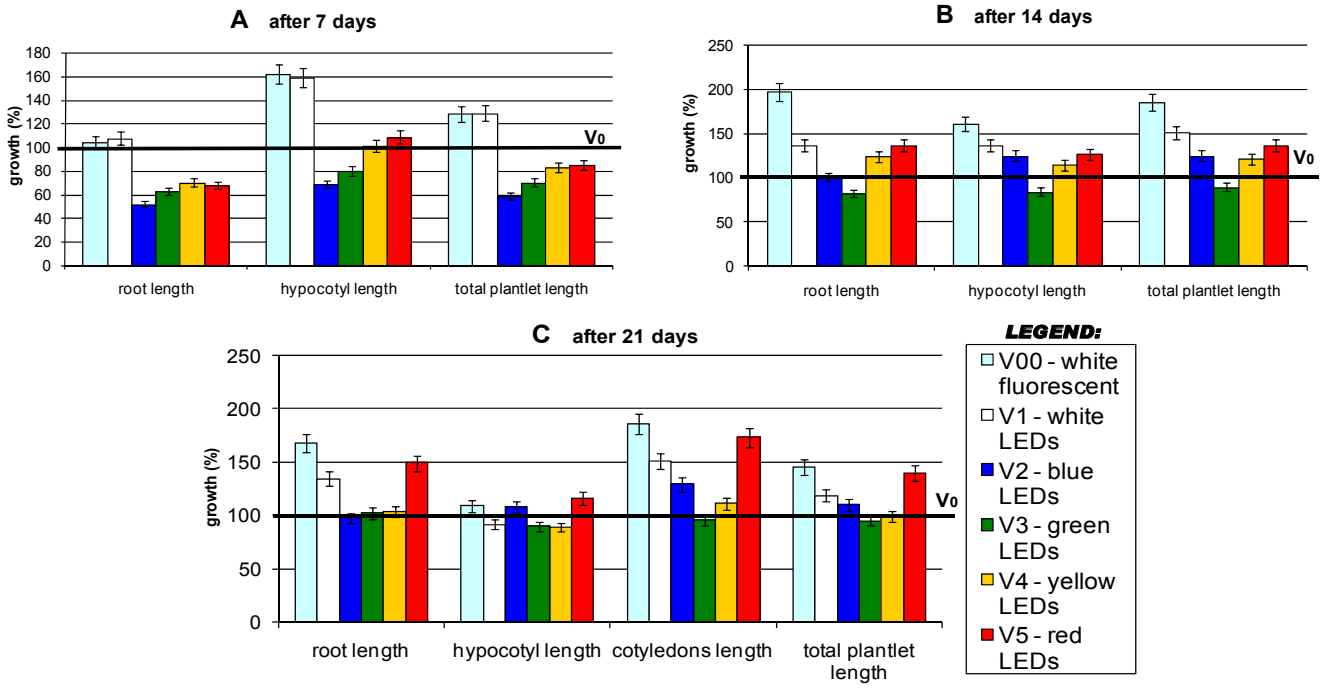

Fig. 2. The ***growth*** of the black pine plantlets (*Pinus nigra* Arn.), respective the size of their organs, in the **7th day (A)**, in the **14th day (B)** and in the **21st day (C)** from putting the seeds to germinate, being illuminated with *LEDs* of different colours, respectively, with ***white*** *fluorescent tubes* (V_{00}), values reported to those of the control batch, exposed to *natural* light, reference values, considered 100% (V_0).

Reporting the data of growing recorded at the plantlets exposed to the ***blue*** LEDs light (V_2) (Fig. 2 A), to those of the similar parameters determined at the organs of the control lot plantlets (V_0), variant grown in ***natural*** light - in the **7th day** of germination (moment when the *cotyledons* were not yet developed), the plantlets have presented *roots* whose size was smaller with 40% than there were marked at the control lot; also, in relation to the seedlings from the control group (V_0), the size of *hypocotyls* was reduced with 31.3%; consequently, the average size of the *entire* black pine *plantlet* - at cultures exposed at ***blue*** light - was more reduced with 41% than the size of the plantlets from the control lot (V_0); in the **14th day** from the assembling of the experiment (Fig. 2 B), the seedlings grown in the ***blue*** light emitted by LEDs (V_2) have had *roots* that presented a similar length with the plantlets grown in ***natural*** light (V_0); but, the *hypocotyls* have marked an increase in growth by 24.2% against to the control batch; accordingly, the size of the *entire plantlet*, which at this phase of germination had taken into account only the size of the *root* and of the *hypocotyl*, was greater with 23.8% than that of the seedlings from the control variant – V_0; in the **21-day** of germination (Fig. 2 C), at the plantlets grown in the ***blue*** LEDs light, the *roots* presented a size close to that of the control batch plantlets (V_0) (differences which,

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but, were statistically insignificant at p≤0.05), and the *hypocotyls* have had the size higher, with just 8.6%, than the dimension of the *hypocotyls* from the control lot; in the case of the *cotyledons* the medium increase of growth was of 29.4%; by summing these values it can say that the ***blue*** light of LEDs had stimulated – in average - with 10% the growth in length of the *entire plantlet* (inclusive *cotyledons*), differences which were statistically significant.

At the samples exposed to the ***green*** light of LEDs (V_3), in the **7th day** of germination (Fig. 2 A), it has been marked an inhibition with 37.4% of the growth in length of the embryonary *roots* and a reduction with 19.6% of the *hypocotyls* length, which made the size of the *entire plantlet* (*root* + *hypocotyl*) to be smaller with 30% than that of the seedlings from the samples exposed to ***natural*** light; in the **14th** day of germination (Fig. 2 B), the *roots* of the plantlets exposed to the ***green*** LEDs light were decreased with just 18.6% than those of the control lot (V_0), and the length of the *hypocotyls* was more reduced with 16.5% comparatively with that of the similar organs from the plantlets grown in ***natural*** light, which did that the *entire plantlet* size (*root* + *hypocotyl*), in the **14th day** of germination, to mark – at this parameter – a minus of just 11% versus the control. In the **21st** day of germination (Fig. 2 C), the length of the *roots* was close to that of the seedlings from the control batch, and the *hypocotyls* size was slightly lower – with 10.3% - than of the respective parameter measured at the control lot; in the same time, the growth in length of the *cotyledons* had marked a 4% inhibition; consequently, the dimension of the *whole seedling* (*root* + *hypocotyl* + *cotyledons*), comparatively with the size of the plantlets originated from the control lot, was diminished with 5%. But, the majority of these data were not validated statistically.

In the **7th day** of germination, at the lot of seeds exposed to LEDs emitting ***yellow*** light (V_4), in relation to the values recorded at the control lot (seeds, respective seedlings generated by these, illuminated with ***natural*** light – V_0), was remarked a decrease of the *roots* size with 30%, and with 17% of the *entire plantlet*, while the *hypocotyls* size was close to that of the control batch (V_0) (Fig. 2 A); in the **14th day** of germination, at the lighting variant with ***yellow*** LEDs (Fig. 2 A) was registered an increase with 23.2% of the growth in length of the *roots* and with 13.6% of the *hypocotyls* size, respective the *whole plantlet* (not taking into account the *cotyledons*, because these were underdeveloped) presented an increase of the growth in length of 20.3% as against to the size marked at the control variant plantlets, illuminated with ***natural*** light; in the **21st day** of germination (Fig. 2 C), the growing of seedlings exposed to ***yellow*** LEDs light (V_4) was slightly slower: so, the *roots* size was just with 3.8% greater than it was marked at the plantlets grown in ***natural*** light (V_0), and the *hypocotyls* height was more reduced with 11% versus to that of the similar organ measured at the seedlings of the control lot, exposed to **natural** light, instead, the *cotyledons* size was higher with 11.5% than that recorded to the control lot (V_0); however, the differences concerning the size of the *entire plantlet* (inclusive *cotyledons*) were statistically insignificant.

At the samples exposed to the ***red*** LEDs light (V_5), in the **7th day** of germination (Fig. 2 A), it was marked an inhibitory influence on the growth in length of the *roots* - with 32%, at this variant being noticed the presence of a slightly positive effect on the *hypocotyls* elongation, with an increase of 8.6%; the size of the *whole plantlet* (without *cotyledons*, these being incorporated in the seminal tegument) was more reduced with 15% in relation to that of the seedlings illuminated with ***natural*** light (V_0); in the **14th day** of germination the general picture – regarding the growing processes – has radically changed, the ***red*** light emitted by LEDs increasing with 36% the growth in length of the *roots* and with 26% of that of *hypocotyls*, fact that enhanced by 36.5% the size of the *entire plantlet* (Fig. 2 B); in the **21st day** after the seeds were putted to germinate, the stimulatory influence exercised on the growth by the ***red*** light of LEDs had been maintained, showing it still, a positive effect not only on the growth in length of the *roots* (+49.3%) and of the *hypocotyls* (+16.2%), but also of the *cotyledons* (+73.2%), recording an increase with 39.8% of the *whole seedling* size (inclusive, *cotyledons*), values which were significant from statistical point of view.

In the **21st day** of germination, the most effective light regarding the ***dry weight*** accumulation of the organs of the black pine plantlets, comparatively with the control variant, exposed to ***natural*** light (V_0), was the ***white*** one, emitted by fluorescent tubes (V_{00}) (Fig. 3). Thus, in the case of the dry weight of *roots*, at this experimental variant, the increase recorded was of 50.8%; regarding the dry mass of *hypocotyls* the increase was of 10.3%, and the *cotyledons* gain in dry weight has situated at 82.3%; overall, at this type of lighting, the dry weight of *entire plantlet* has risen with 50.7%, in relation to the same parameter analysed at the reference lot (V_0) (Fig. 3).

Black pine plantlets lighted with LEDs issuing ***white*** light (V_1), have recorded an increase with 27% of the *roots* dry mass, and with 43.8% of the dry weight of the *cotyledons*, instead, the dry weight of the *hypocotyls* was more lowered with 2.2% versus the similar determinations performed at the control batch seedlings (V_0), statistically insignificant data (Fig. 3); in consequence, the dry mass of *whole plantlet* was increased by 24.2%, compared with the respective parameter measured at the control sample (V_0).

Dry weight of the *roots* of the seedlings exposed to the ***blue*** LEDs light (V_2), showed a slight decrease of -1.6% of this parameter, data proven not to be statistically significant; however, the dry mass of the *hypocotyls* of

the seedlings exposed to ***blue*** LEDs grew with 18.5% (compared with that registered at seedlings grown in ***natural*** light – V_0), and, that of *cotyledons* has enhanced with 20.3%; consequently, at the lot lighted with ***blue*** LEDs the dry weight of the *whole plantlet* has marked a rise of 16.7% (statistically significant data) as against to the reference values of the control sample (V_0) (Fig. 3).

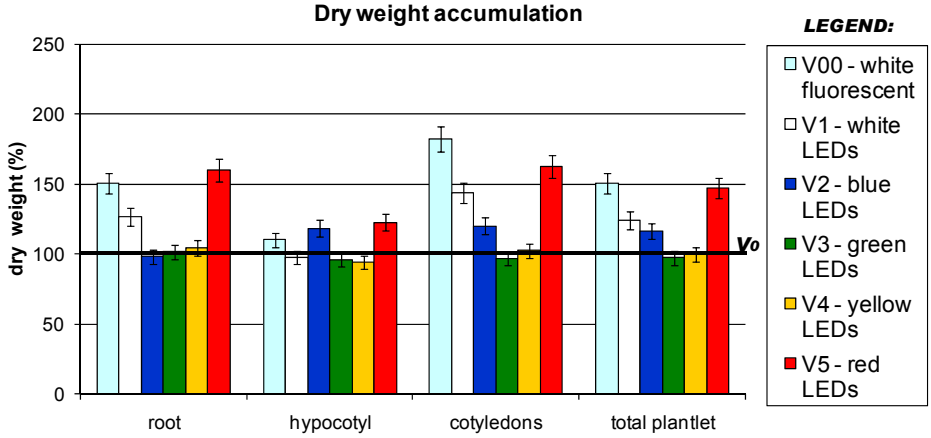

Fig. 3. *Dry weight* of the black pine seedlings (*Pinus nigra* Arn.), respectively of their organs, expressed in percents, values resulted from reporting the partial data to the values of the similar samples of the control variant – *natural* light (V_0) reference values, considered 100%); determination which were performed in the **21st day** of germination, in the conditions of illumination of seeds and plantlets with light of different colours, emitted by *LEDs*, or with ***white*** light emitted by *fluorescent tubes* (V_{00}).

Concerning the gravimetrical values recorded at the dry weight determination of the black pine plantlets exposed to the ***green*** light of LEDs (V_3) (Fig. 3), these were not presented statistically remarkable differences ($p \leq 0.05$) as against to the control samples (V_0), which were exposed to ***natural*** light, thus, by comparison with the same parameters determined at the reference samples (V_0), the dry mass of the *roots* showed an insignificant growing, of +1.6%, while that of the hypocotyls had marked a slightly minus of 3.8%, and the *cotyledons* mass has lowered with 3%, the negative increase in dry weight of the *entire seedling* being of 2.7%.

At the black pine seedlings exposed to the ***yellow*** LEDs light (V_4) comparative with the seedlings grown in ***natural*** light (V_0), the dry weight of the *roots* was slightly higher (+4.8%), and that of the *hypocotyls* a little lowered (-5.4%); from determinations resulting the fact that the dry mass of the *cotyledons*, respective of the *whole seedling*, was similar to the samples derived from the control batch (V_0). But, the noticed differences were not significant from a statistical point of view (Fig. 3).

The most intensive stimulatory effect, provoked by LEDs light, was marked at the samples exposed to the ***red*** light (V_5), at which the gain in dry weight of the *radicle* mass was of 60.3%, in relation to the *radicle* mass harvested from the black pine seedlings exposed to ***natural*** light (V_0), while the dry weight of the *hypocotyls* of plantlets grown in the ***red*** LEDs light was risen with 22.8% in report to this parameter measured at the control lot (V_0); the gain in dry weight of the *cotyledons* was 62.5%, versus the similar parameter values determined at the reference samples, the control (V_0); therefore, the *whole plantlet* dry weight, at the black pine plantlets exposed to the ***red*** LEDs light (V_5) was increased with 47.1% (Fig. 3). In all the cases described in this paragraph, the signalled differences were statistically significant.

Comparing the effects of the three types of ***white*** lights (Fig. 4), used in the experiments which have made the object of this work, on the growth and the dry weight of the black pine plantlets risen from germinated seeds and subsequently exposed to ***white*** light, of various origin, respective: V_0 – ***natural*** light, V_{00} – ***white*** light produced by fluorescent tubes and V_1 – ***white*** light emitted by LEDs, for 21 days, in regime of 16 hours light / 24 hours, after determining not only of the growth in length of their organs, but also of their dry weight, it has been found that, at the seedlings lighted with ***white*** fluorescent tubes (V_{00}) there were registered the highest values both of the plantlets size – with 45.3% - and of their dry mass – with 50.7% - in relation to the recorded values at the similar parameters determined at the black pine plantlets grown in ***natural*** light, reference values, considered 100%; regarding the experimental variant lighted with ***white*** LEDs, the size of the seedlings exposed to ***white*** fluorescent light showed values greater with 26.5%, respectively, the dry weight of these was with 26.6% higher than those of the lot exposed to light issued by ***white*** LEDs (Fig. 4).

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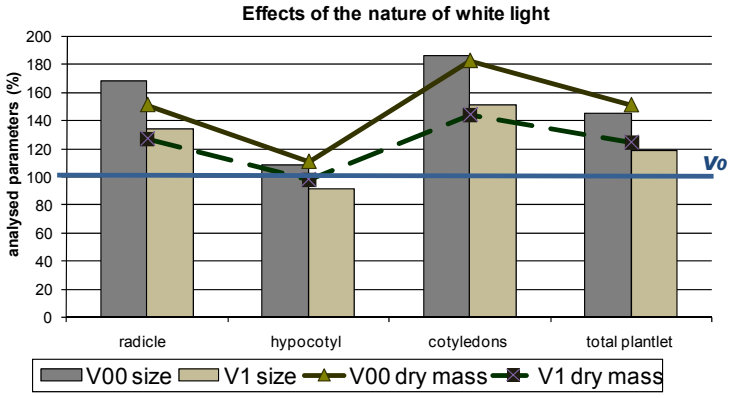

Fig. 4. Comparison between the growth in length and the dry weight accumulation of the black pine plantlets illuminated with ***white*** light of different nature, where: V_0 – ***natural*** light, V_{00} – ***white*** fluorescent light, V_1 – ***white*** LEDs light, determined in the **21st day** after the seeds were putted to germinate, in the condition of lighting of seedlings 16 hours of light / 24 hours.

CONCLUSIONS

By comparison with the data obtained after the determinations performed on the batches of seedlings originated from black pine seeds germinated in ***natural*** light, the control variant, reference values, considered 100%, the ***white*** light of LEDs increased with 55.6% the germination percentage of the seeds, determined in the **7th day** from the moment when seeds were put to germinate. The black pine seeds germination was inhibited by the ***yellow***, ***green***, ***red*** and ***blue*** LEDs light, the lowest germination percentage, of 24%, being observed in seeds germinated at the ***yellow*** light.

The most effective light, regarding the black pine plantlets size and the dry weight increases, after **21 days** of exposure of the samples to such treatments, in relation to the values marked at the plantlets maintained in ***natural*** light (control lot, as reference) proved to be the ***white*** light emitted by fluorescent tubes, which stimulated the *growth* in *length* of the *plantlets* with 45.3% and their dry weight with 50.7%. At the group of seedlings exposed to the ***white*** LEDs light, the stimulation of the growth in length of the plantlets and their dry mass accumulation exceed, also, the control lot, but with less than 25%.

As against to the plantlets grown in ***natural*** light, those exposed to the ***red*** LEDs light, for **21 days**, presented a size increase of 39.8% and a gain of their dry weight of 47.1%.

At the plantlets illuminated with LEDs emitting ***yellow*** or ***green***, time for **21 days**, the growth in length and the accumulation in dry mass was situated to the similar values levels recorded at the control variant, the exceptions being the measurements performed in the **7th day** of germination, when the growth of the *roots* and *hypocotyls* was inhibited, especially by the ***blue*** LEDs light and by the ***green*** LEDs light, this negative effect being maintained even in the case of the measurements realized in the **14th day** of germination.

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