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THE GERMINATION AND GROWTH OF BRASSICA OLERACEA L. VAR. CAPITATA F. RUBRA PLANTLETS UNDER THE INFLUENCE OF COLORED LIGHT OF DIFFERENT PROVENANCE

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ABSTRACT
In this study we followed comparatively the white and colored (blue, green, yellow and red) light effects emitted by superbright Light-Emitting Diodes (LEDs) and by fluorescent tubes, over the red cabbage seeds germination and the growth of the plantlets generated from theirs embryos. Luminous intensity corresponded at 1200 lx and the lighting regime was of 16 h/24 h. The control version was exposed to natural light, of northern orientation. The highest germination percentages were registered at the seeds illuminated with white light of various origins (97% - natural, 95% - LEDs and 93% fluorescent tubes). Instead, the lowest percentage of germination (81%) was recorded at the variant subjected to yellow fluorescent tubes. The biggest seedlings and the highest values of the dry weight were observed in the group illuminated with green LEDs light, the hypocotyl size being 75% higher and its dry mass 77% greater than those of the control samples, represented by seedlings grown in natural light. The highest dimension and dry weight of the plantlets grown under fluorescent colored lights were found at the red one, due to the increases with 48.8% of the hypocotyl length and with 41.5% of its dry mass. With the decrease of wavelength of light, the hypocotyls' color intensified, turned from pink to purple, an effect produced regardless of the nature of light.

Keywords: *Brassica oleracea* - plantlets - germination - growth - light-emitting diodes -fluorescent light

INTRODUCTION

Recently, there have been many discussions about the utility of the Light-Emitting Diodes (LEDs) in the growth of plants (*Bula* et. al., 1991; *Barta* et. al. 1992). Comparatively with other lighting source (*Berkovich* et. al., 1998; *Brinkman* et. al., 2005), LEDs are not only a much less expensive illumination alternative, but they also have a long lifespan, without decrement, being an ecological way to use the electricity with maximum of efficiency (*Erokhin* et. al., 2006).

Although it is known that, in general, *red* and *blue* light play an important role in the growth of plants (*Goins* et. al., 1997; *Yorio* et. al., 2001), each vegetal species reacts characteristically at the various spectral components of the luminous flux (*Avercheva* et. al., 2009), in the last decades important evidence was achieved regarding the role of the *green* light as a plant growth regulator (*Folta*, 2004; *Kim* et al. 2004).

The researches concerning the influence of LEDs on plants target either the analysis of the effects of LEDs light over *in vitro* vegetal cultures (*Vidican* and *Cachiţă*, 2010), over the processes of acclimatization of the exvitroplantlets at the life in a septic medium (*Hogewoning* et. al., 2007; *Brazaityte* et. al., 2009), or over the seeds germination and plantlets growth (*Sommer* and *Franke*, 2006).

Precedent experiments performed on the germination of the black pine (*Pinus nigra* Arn.) seeds and on the growth of the plantlets resulted from their embryos under light of different wavelengths produced by LEDs stayed at the base of the actual study (*Matioc* and *Cachiţă*, 2011).

This comparative study presents the effects of light of different colors, emitted by LEDs or by fluorescent tubes, over the germination of seeds and the growth of the plantlets of *Brassica oleracea* L. var. capitata f. rubra „Red Amager".

MATERIALS AND METHODS

The experiments were organized in the summer of 2011, in June-July. As vegetal material, we used red cabbage seeds (*Brassica oleracea* L. var. capitata f. rubra „Red Amager"), which were put to sprout in the laboratory, in uncolored plastic casseroles with cover lids, positioned in wood made boxes, having the size of 50 cm in length, 20 cm in width and 20 cm in height. The substrate for germination consisted of filter paper wetted with tap water. The germination and growth of seedlings was followed over 10 days,

period in which the cultures were either illuminated with LEDs or with fluorescent tubes, the photoperiod being of 16 hours of light / 24 hours, in both cases the light intensity was maintained at a constant value of 1200 lx. The control batch of reference, was represented by red cabbage seeds exposed to *natural* light (V_0), being located at a north oriented window.

In Fig. 1 there are presented the emission spectra of the *white* and *blue* light produced by LEDs, in comparison with that of the *white* light generated by fluorescent tubes.

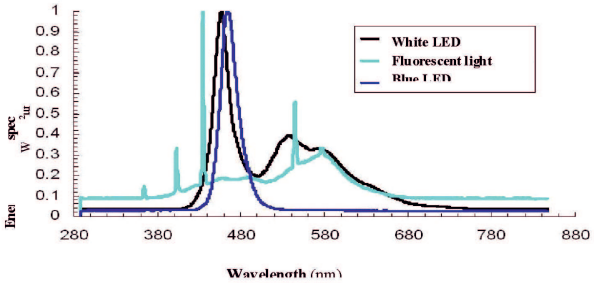

Fig. 1. Comparison between the emission spectra of the white and blue light produced by LEDs, respective, of the white light emitted by fluorescent tubes (modified after www.ruander.com).

The Light-Emitting Diodes (LEDs) of high intensity, used for the realization of lighting installations, had a 5 mm in diameter (superbright Zextar). They were fixed on the ventral part of the mobile lids of some wooden made boxes in which were placed the casseroles with the seeds putted to sprout. LEDs light intensity was adjusted using a potentiometer. The density of LEDs was of 40/600 cm². They were located at a 20 cm distance from seeds, respective from plantlets. The used fluorescent tubes (Philips brand) had a power of 18w. Luminous intensity, in this case, was realized by modifying the distance from the tubes to the vegetal material.

The relative humidity of the air from the laboratory varied between 50-60%, the ambient temperature was of 25±1°C and was kept constant throughout the experiment, day and night.

Experimental variants were organized in order of increasing wavelength of light (Table 1).

During the experiments we monitored *the seeds germination percentage*, *the growth in length of the seedlings' organs* and their *fresh and dry weight* (*root*, *hypocotyl*, *cotyledons*) depending on the nature of the light which the plantlets were exposed to, as well as the type of light source used (LEDs or fluorescent tubes), and the wavelength (its color).

Data regarding the number of red cabbage seeds germinated normally, from 100 seeds put to sprout – in three repetitions, for each experimental variant, were reported to the data obtained from the control lot, consisting of seeds germinated in *natural* light, values considered as reference, of 100%.

The *growth* of the red cabbage seedlings, at each experimental variant, was estimated by biometrical measurements performed at three intervals of time, the **4th**, the **7th** and the **10th** day of germination, effectuated in three repetitions, each of 100 plantlets. Average values were used in calculations.

Fresh and *dry weight* determinations were performed in the **10th** day of germination, for each experimental variant and organ, individually (*root*, *hypocotyl*, *cotyledons*), on a total number of 30 red cabbage plantlets normally germinated, selected at random; the drying of the seedlings in the oven, at 105±2°C, was made for 72 hours, until the stabilization of their dry weight.

The average data obtained at the biometrical parameters, at each experimental variant, individually, were expressed in percentage values, reporting the results at the respective parameters determined at the control group, samples illuminated during the experiments with *natural* light, values considered as reference, of 100%.

Experimental values obtained were processed statistically with the aid of the Microsoft Office Excel software, calculating the *arithmetic mean*, the *standard deviation* from the mean and the *Student's* ***t*** *test* for independent samples groups, achieving the statistical probability of the experimental variants means

Table 1. The organization of experimental variants.

Variants depending on light sources		Light characteristics	
LEDs	*Fluorescent tubes*	*Wavelengths*	*Light color*
V_0		control variant	natural light
V_1^{LED}	V_1^{TUB}	380-760 nm	white
V_2^{LED}	V_2^{TUB}	450-465 nm	blue
V_3^{LED}	V_3^{TUB}	520-550 nm	green
V_4^{LED}	V_4^{TUB}	580-590 nm	yellow
V_5^{LED}	V_5^{TUB}	650-660 nm	red

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to be or not to be significantly different from the control version average. Statistically significant values, at a significance level p≤0.05, are found marked on the histograms shown in Fig. 3 and 4 with an asterisk (*), the standard deviation being represented graphically by error bars applied on histograms.

RESULTS AND DISCUSSIONS

Germination percentage of red cabbage seeds

The percentage of germination of the red cabbage seeds (*Brassica oleracea* L. var. capitata f. rubra „Red Amager"), lit with LEDs or with fluorescent tubes, at all experimental variants, had situated under that recorded at the control version (V_0), values which were considered of reference, of 100% (Table 2).

So, at the variants illuminated with LEDs, the reported shortcomings were of 2% - at the version lit with *white* LEDs (V_1^{LED}), of 5% – at the seeds germinated in the *blue* (V_2^{LED}) and *red* LEDs light (V_5^{LED}), of 14% – at those treated with bright LEDs issuing *green* (V_3^{LED}) or *yellow* (V_4^{LED}) light. These results are similar to those reported by us in a precedent study, made on black pine seeds germination, where the lowest germination percentage had been observed at the group illuminated with *yellow* LEDs light (*Matioc* and *Cachiță*, 2011).

of: 4% at the variant exposed to *white* light (V_1^{TUB}), of 8% in the case of the samples illuminated with *red* fluorescent tubes (V_5^{TUB}), of 9% at those exposed to the *blue* fluorescent tubes (V_2^{TUB}), of 11% at the seeds germinated in the *green* fluorescent light (V_3^{TUB}), and of 16% at the variant V_4^{TUB} subjected to illumination with *yellow* fluorescent tubes.

All of these differences, excepting those marked at the *white* light, proved to be statistically significant, in relation to the determinations made at the control batch (V_0) (p≤ 0.05) (Table 2).

B. Variations in growth of red cabbage seedlings depending on the stage of germination in which there were the seeds exposed to LEDs or fluorescent tubes, of various colors

1. The growth of the red cabbage plantlets organs in the 4th day of germination

a. In the light emitted by LEDs

The average increase in length of the embryonic *root* at the seeds exposed to the *white* LED light (V_1^{LED}), as opposed to the elongation of the similar organ measured at the control group (V_0), had registered an inhibition of 6.48% of this parameter, and an increase in average elongation of the *hypocotyl*, with 37.32%, statistically significant differences; also, an increase in growth, for this time insignificant from a statistical point of view, of 5.77% (Fig. 3A), had been observed in the case of *cotyledons* measurements.

In the *blue* LEDs light (V_2^{LED}) (Fig. 3A), the average size of the plantlets *roots* was stimulated with 3.93%, and that of the *hypocotyl* with 35.74%, but an inhibition with 10.12% of the *cotyledons* length was remarked, comparative with the respective parameter determined to the blanks (V_0), differences statistically significant.

Table 2. The germination percentage of the red cabbage seeds (*Brassica oleracea* L. var. capitata f. rubra „Red Amager") under the influence of the colored light of different provenance – LEDs or fluorescent tubes, where V_0 – *natural* light, V_1 – *white* light, V_2 – *blue* light, V_3 – *green* light, V_4 – *yellow* light and V_5 – *red* light.

Nature of light / Experimental variant	LEDs			Fluorescent tubes		
	% of germination	[1]S (%)	[2]p	% of germination	[1]S (%)	[2]p
V_0	97±2.00	-	-	97±2.00	-	-
V_1	95±1.50	76.19	ns	93±2.51	90.30	ns
V_2	92±2.00	96.24	*	88±3.00	98.76	*
V_3	83±4.54	99.19	**	86±2.30	99.67	**
V_4	83± 3.60	99.58	**	81±3.21	99.82	**
V_5	92±1.64	97.14	*	89±1.73	99.37	**

Note:

[1]S(%) – the statistical probability for the experimental media variants to be significantly different from the control, expressed in %;

[2]p represents the *statistical significance* compared to the control (V_0): [**] statistically very significant differences from the control; [*] statistically significant differences from the control; [ns] statistically insignificant differences from the control (p ≤ 0.05).

In the lots of red cabbage seedlings illuminated with fluorescent tubes, the notified decreases were

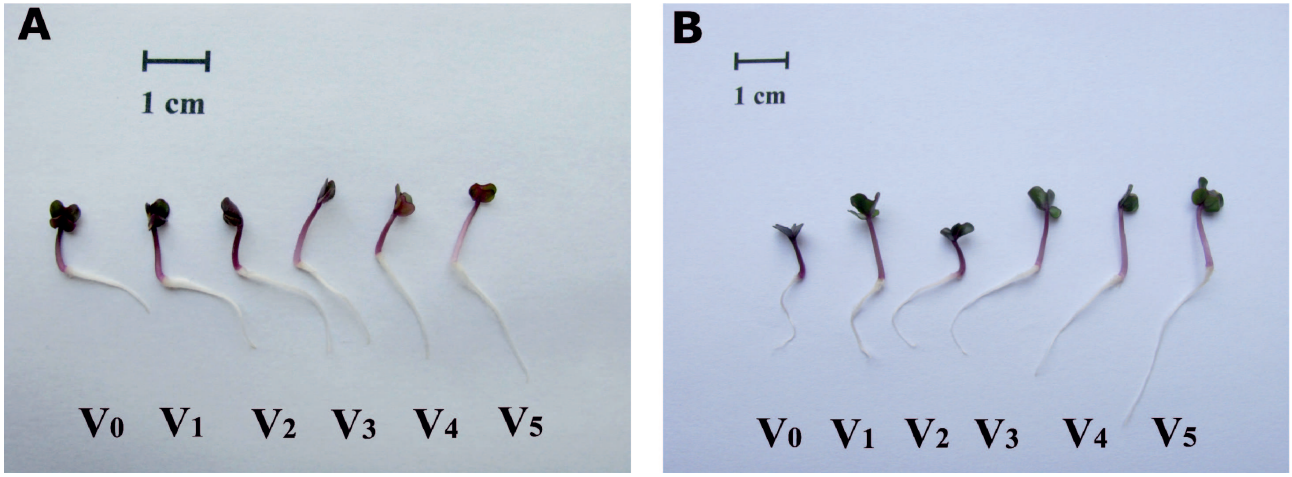

Fig. 2. The appearance of the red cabbage plantlets (Brassica oleracea L. var. capitata f. rubra „Red Amager"), in the 4th day of germination, which were illuminated as follows: V0 – natural light; V1 – white light; V2 – blue light; V3 – green light; V4 – yellow light and V5 – red light: A. illumination with LEDs; B. illumination with fluorescent tubes.

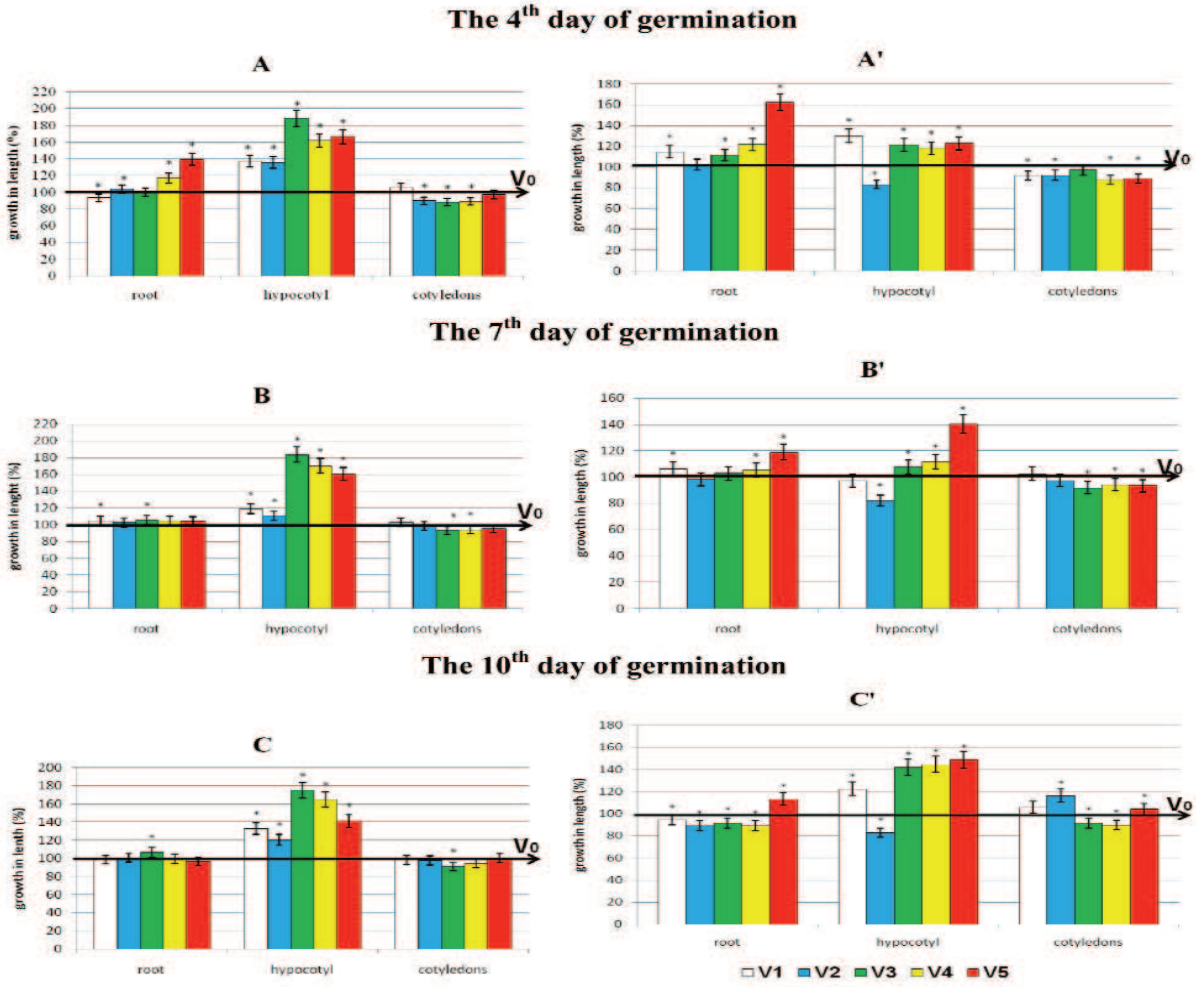

Fig. 3. The growth of red cabbage seedlings organs (Brassica oleracea L. var. capitata f. rubra „Red Amager") under varied lighting regime, as follows: V0 – natural light; V1 – white light; V2 – blue light; V3 – green light; V4 – yellow light; V5 – red light, where: A-C – light emitted by LEDs; A'-C' – light emitted by fluorescent tubes.

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The average waist of the *root* of plantlets germinated in the *green* light of LEDs (V_3^{LED}) was like the one measured at the control lot seedlings (V_0); contrarily, at this type of light, an increase with 88.09% of the *hypocotyl* medium length, the highest values from all data obtained at other experimental variants, had been registered at this version (Fig. 3A). The plantlets *cotyledons* illuminated with LEDs issuing *green* light (V_3^{LED}) presented smaller dimensions, with 11.91%, in relation to those marked at the benchmark, data which were not statistically significant at $p \leq 0.05$.

Compared to the parameters marked at the seedlings grown in *natural* light (V_0), whose values were considered 100%, the plantlets exposed to the *yellow* light emitted by LEDs (V_4^{LED}) presented larger *roots* with 17.42% than the average length of the control group, and the *hypocotyl* size was increased by 61.78% as opposed to that recorded at the red cabbage plantlets maintained in day light (V_0); however, as in the case of the *green* light, the medium size of the *cotyledons* was more reduced with 10.92% (Fig. 3A), statistically significant differences.

In the **4th day** of germination, in comparison with the control lot (V_0), the most intense growth of the embryonic *root* was marked at the red cabbage plantlets germinated and grown in the *red* LEDs light (V_5^{LED}) (Fig. 3A), the noticed increase of 39.63% being significant from a statistical point of view; the average increase in length of the *hypocotyl* registered a rise - highly statistically significant - of 66.53%, meanwhile the *cotyledons* had a similar size as the reference samples.

About the morphology of the red cabbage plantlets (Fig. 2A), it had been remarked that their exposure to the *green* (V_3^{LED}), *yellow* (V_4^{LED}) and *red* (V_5^{LED}) light of LEDs, led to a discoloration of the *hypocotyl* (the color transfer from purple to bright pink), that can be attributed to the variation of the anthocyanins concentration from the epidermal cells, being known the fact that the red cabbage is a plant that contains this type of pigments (*Wu* et. al., 2006; *Horbowicz* et al., 2008).

b. In the fluorescent light

The *white* fluorescent light (V_1^{TUB}) (Fig. 3A') stimulated with 14.54% the growth of the embryonic *root* and with 29.82% the *hypocotyl* elongation; the *cotyledons* were, on the other hand, smaller with 8.35% than the respective parameter values determined at the control group plantlets (V_0), all differences being validated by statistical calculations, at a significance level $p \leq 0.05$.

The embryonic *root* of the red cabbage plantlets, exposed to the *blue* light produced by fluorescent tubes (V_2^{TUB}), had presented a medium dimension close to the similar organ measured at the control group (V_0) (Fig. 3A'). On the other hand, the average growth of the *hypocotyl* marked a diminution with 17.09% of its length; meanwhile the *cotyledons*' growth registered a reduction with 8.02% of their dimension, in relation to the size of the reference plantlets organs (V_0), these data being significant from a statistical point of view.

The red cabbage seedlings grown in the *green* fluorescent light (V_3^{TUB}) had marked an average increase of the embryonic *root* size of 11.42%, while the noticed increase regarding the medium length of the *hypocotyl* situated at 21.19%. As in other cases, compared to the similar parameters measured at the seedlings grown in *natural* light (V_0), the *cotyledons* registered a size reduction of 3.11%, compared to the control batch (Fig. 3A'). As a result, excluding data related to the *cotyledons*' growth, the remaining differences proved to be highly statistically significant.

At the *yellow* light of the fluorescent tubes (V_4^{TUB}), the red cabbage plantlets *roots* had an average length greater with 21.73% than the one marked at the control lot, and that of the *hypocotyls* which were subject to the *yellow* fluorescent lighting increased 18.45%; instead, this time, the *cotyledons*' size was inhibited with 12.43% (Fig. 3A'), as compared to the values recorded at the reference samples, considered100%, of the benchmark (V_0), the noticed differences being supported by statistical calculations.

The medium size of the embryonic *root* of the plantlets subjected to fluorescent illumination emitting *red* light (V_5^{TUB}) (Fig. 3A'), was increased with 62.34%, and that of the *hypocotyl* with 22.72% in relation to that marked at the control group seedlings (V_0); on the other hand, the growth in length of the *cotyledons* was inhibited in a proportion of 11.33%. All indicated differences were statistically validated.

From a morphological point of view, the red cabbage plantlets exposed to the colored light of the fluorescent tubes differ, especially in the coloration of the *hypocotyl* and size of the embryonic organs (Fig. 2B). Regarding the *hypocotyl* stain, it is caused by the presence of the anthocyanins in the epidermal cells, pigments with a protective role against the luminous stress (Gould, 2004). The highest concentration of anthocyanins seems to be in the *hypocotyl* epidermis of the red cabbage plantlets grown in the *blue* fluorescent light (V_2), decreasing to the other regions of the luminous spectrum: *green* (V_3) → *yellow* (V_4) → *red* (V_5), observations maintained throughout the experiments (Fig. 2B).

2. The growth of the red cabbage plantlets organs in the 7th day of germination

a. In the light emitted by LEDs

After **7 days** of illumination of the red cabbage cultures with *white* LEDs (V_1^{LED}) (Fig. 3B), in relation with the determination made at the seedlings exposed to *natural* light (V_0), the average size of the embryonic *root* marked an increase in growth of 5.1%, and that of the *hypocotyl* recorded a stimulation of 18.70% (data statistically significant at $p \leq 0.05$), while the difference in growth of the *cotyledons* was insignificant, of only 2.59%.

At the red cabbage seedlings exposed to the *blue* LED light (V_2^{LED}), the medium size of the *root* and of the *cotyledons* were closed to those of the similar organs from the control group (V_0) (Fig. 3B), while that of the *hypocotyl* registered an increase in growth statistically significant, of 10.41%.

The *green* light of LEDs (V_3^{LED}) (Fig. 3B) induced a stimulation of the *root* size growth of only 5.90%, comparative with the similar parameter determined at the control lot (V_0); on the other hand, this type of light stimulated the elongation with 83.70% of the *hypocotyl* length and inhibited – in a proportion of 7.13% – the *cotyledons* growth, significant values validated by statistical calculations.

LEDs emitting *yellow* light (V_4^{LED}) (Fig. 3B) led to a slight increase in the length of the embryonic *root* with just 4.75% but, regarding the medium increase in growth of the *hypocotyls*, a percent of 70.29% - contrary to the control - had been marked; the *cotyledons* elongation was slightly inhibited, with 5.90%, the mentioned differences being statistically significant.

The *red* light of LEDs (V_5^{LED}) stimulated with only 4% the growth of the embryonic *root* of the red cabbage seedlings, while the growth percentage registered a statistically significant increase of 60.34% compared to the size of the similar organ from the blanks; on the other hand, as usually the *cotyledons*' growth was inhibited, with 4.65%, contrary to that of the similar organs measured at the experimental batch illuminated with *natural* light (V_0) (Fig. 3B).

b. <u>In the fluorescent light</u>

On the **7th day** of germination, at the *white* fluorescent light (V_1^{TUB}), the average length of the embryonic *root* was increased with 6.18%, in relation to the similar organ analyzed at the benchmark (Fig. 3B'), while the *hypocotyl* and *cotyledons'* sizes were like those marked at the plantlets grown at *natural* light (V_0), whose values were considered of reference, of 100%. However, the marked differences were not statistically significant.

The *blue* fluorescent light (V_2^{TUB}) inhibited the red cabbage seedlings growth due to the reduction (statistically significant) with 18.10% of the *hypocotyl* medium dimension, the lengths of the embryonic *roots* and of the *cotyledons* being close to those of the similar organs from the control sample (V_0) (Fig. 3B'). This effect over the *hypocotyl* was similar to that recorded by us in a previous study (Matioc and Cachiță, 2011) made on black pine seedlings which were illuminated with ***blue*** LEDs.

The average dimension of the *root* at the experimental variant illuminated with *green* fluorescent tubes (V_3^{TUB}) (Fig. 3B') was just with 2.72% greater than that of the benchmark, difference statistically insignificant, and that of the *hypocotyl* marked an increase of 7.47%; simultaneously, the length of the *cotyledons* was reduced with 8.10%, compared to the similar parameters determined at the reference samples (V_0), considered 100%.

At the *yellow* fluorescent light (V_4^{TUB}), the length of the red cabbage seedlings *root* was increased by 5.22%, that of the *hypocotyl* by 11.60%; instead, the *cotyledons* size suffered a decrease of 5,73% (Fig. 3B'), data less significant from a statistical point of view.

The red cabbage plantlets exposed to the *red* light emitted by fluorescent tubes (V_5^{TUB}), in relation to the similar parameters marked at the control group plantlets organs (V_0), illuminated with *natural* light, whose values were considered 100%, presented a medium size of the embryonic *root* increased by 19.01%, that of the *hypocotyl* was stimulated with 40.40%, and the *cotyledons* length 6.67% more reduced (Fig. 3B'), differences that were statistically validated.

3. The growth of the red cabbage plantlets organs on the 10th day of germination

3.1. The variation of the growth in length of the plantlets organs on the **10th day** of germination

a. <u>In the light emitted by LEDs</u>

The medium size of the embryonic *root* of the red cabbage seedlings exposed to the *white* light of LEDs (V_1^{LED}) was close to that of the similar organ measured at the control lot plantlets (V_0), and the average length of the *hypocotyl* registered an increase compared to the homologous control organ with 32.78%; also, the *cotyledons* dimension situated at minus 1.90% under that of reference of the plantlets *naturally* lighted (V_0), differences that were not statistically significant (Fig. 3C).

In comparison with the reference values of the samples exposed to *natural* light (V_0), measurements realized at the red cabbage seedling group illuminated with *blue* LEDs (V_2^{LED}) (Fig. 3C), revealed the following: the average length of the embryonic *root* was similar to the control plantlet, the *hypocotyl* presented a medium dimension, significantly increased with 20.24% in contrast to the blank samples, and the *cotyledons* had their size smaller with 2.51% compared to the reference data.

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The increase of the medium size of the red cabbage embryonic *roots* which were exposed to the *green* light of LEDs (V_3^{LED}) was only of 6.63%, while the average length of the *hypocotyl* grew with 74.96% compared to that recorded at the similar organ of the control lot plantlets (V_0), and that of the *cotyledons* diminished with 9.03% (Fig. 3C), data which were statistically significant.

The fact that the *green* light of LEDs, characterized by a narrow emission band, can have a stimulating effect on plant growth was also reported by other researchers (*Talbot* et. al., 2002; *Golovatskaya*, 2005). Some authors consider that exposure of the seeds, not necessarily of the seedlings, even for a short time, at high *green* LEDs light, in biostimulatory doses, would lead to a considerable increase in weight of plant organs (*Sommer* and *Franke*, 2006). However, there are contradictory studies claiming that *green* light acts as a signal for plants to stop growing (*Folta* and *Maruhnich*, 2007).

At the samples exposed to the *yellow* light of LEDs (V_4^{LED}) (Fig. 3C), the embryonic *root* of the red cabbage plantlets presented a dimension equal to that of the reference samples (V_0). The medium length of the *hypocotyl* grew with a significant 64.67% compared to that marked at this organ at the control lot but that of the *cotyledons* situated at minus 5.55% reported to the control values, considered 100%.

Illumination of the red cabbage seedlings with LEDs issuing *red* light (V_5^{LED}) (Fig. 3C) inhibited with 3.66% the average size of the *root* and increased, statistically significant, with 41.26%, that of the *hypocotyl*, *cotyledons* marking a medium length equal to that of the control plantlets (V_0).

b. In the fluorescent light

In relation to the dimension of the similar organs from the control lot (V_0), the *white* fluorescent light (V_1^{TUB}) (Fig. 3C') diminished with 5.5% the average size of the embryonic *root* of the red cabbage plantlets, increasing, in the same time, the medium length of the *hypocotyl*, with 22.39%, and of *cotyledons* with 5.94%. Only the differences marked in the case of the *hypocotyl* were statistically significant.

At the red cabbage plantlets illuminated with *blue* fluorescent tubes (V_2^{TUB}) (Fig. 3C'), compared to the similar parameters marked at the reference samples (V_0), the medium dimension of the embryonic *root* was lowered with 10.88%, and that of the *hypocotyl* with 17.15%; remarkable is the fact that, on the other hand, the *cotyledons'* length recorded an increase in growth of 16.34%, data validated through statistical calculations.

Green fluorescent light (V_3^{TUB}) provoked a decrease of 8.36% of the embryonic *root* size of the red cabbage plantlets and of 8.27% of that of *cotyledons*; contrarily, this light significantly stimulated with 42.15% the *hypocotyl* elongation (Fig. 3C').

Red cabbage illumination with *yellow* fluorescent tubes (V_4^{TUB}) (Fig. 3C') inhibited with 10.93% the embryonic *root* growth and with 10.15% that of the *cotyledons*; also, at this type of light the average size of the *hypocotyl* was increased by 44.59%, differences that were statistically significant, compared to the values determined at the similar organs of seedlings grown in daylight (V_0).

In comparison with the reference values registered at the cultures exposed to *natural* light (V_0), the medium dimension of the embryonic *root* of the red cabbage plantlets illuminated with *red* fluorescent light (V_5^{TUB}) increased with 13.28%, that of the *hypocotyl* with 48.80%, and of the *cotyledons* with

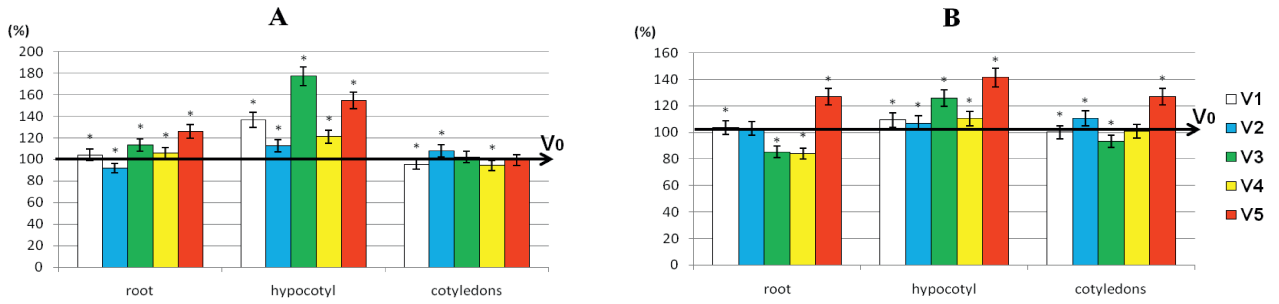

Fig. 4. Dry weight of red cabbage plantlets organs (Brassica oleracea L. var. capitata f. rubra „Red Amager"), expressed as percentage, reported to the control group values, illuminated with natural light (V0) (reference values, considered 100%), on the 10th day of germination, in the illumination conditions of the seeds and seedlings with different light colors, emitted by LEDs and fluorescent tubes [V1 – white light, V2 – blue light, V3 – green light, V4 – yellow light, V5 – red light]: A. dry weight of plantlets illuminated with LEDs; B. dry weight of the plantlets illuminated with fluorescent tubes.

4.20%, (Fig. 3C'), all noted differences being very significant from a statistical point of view.

3.2. The variation of the dry weight of the plantlets organs on the **10th day** of germination

a. In the light emitted by LEDs

Compared with the reference values of the control lot (V_0), values which were considered 100%, at the variant illuminated with *white* LEDs (V_1^{LED}), average dry weight of the *root* mass showed an increase of only 4.18%, whereas that of the *hypocotyls* marked a significant increase of 36.50%; in contrast, in the case of the *cotyledons* a decrease of 4.60% of their dry weight had been remarked (Fig. 4A).

Plantlets exposed to the *blue* light produced by LEDs (V_2^{LED}) presented a medium dry weight of the *roots* smaller with 8.07% than that recorded at the control lot (V_0) (Fig. 4A); nevertheless, both the *hypocotyls* and *cotyledons* marked statistically significant raises ($p \leq 0.05$) of their dry weight, with 12.7%, and with 7.94%, in relation to the similar parameters determined at the control seedlings, which were grown in *natural* light (V_0).

Dry weight of organs of the plantlets subjected to a lighting with LEDs issuing *green* light (V_3^{LED}) was greater than that of the control samples, exposed to *natural* light (V_0), namely with 13.45% that of the *roots*, with 77% that of the *hypocotyls* and with just 2.23% that of the *cotyledons* (Fig. 4A). Excluding amounts reported for *cotyledons*, the remaining data proved to be statistically significant.

At the lot of plantlets grown under the incidence of the *yellow* light emitted by LEDs (V_4^{LED}), there were marked increases in dry weights only in the *roots* (+5.71%) and *hypocotyls* (+21.06%), *cotyledons* registering a minus of 5.57% (Fig. 4A); all signaled differences were statistically validated, in relation to the control group values (V_0).

Average increased values of the dry weight of *root* and *hypocotyl* mass (Fig. 4A), statistically significant, were noticed and to the seedlings exposed to the *red* light of LEDs (V_5^{LED}), the numbers being of plus 25.88% and of plus 54.50%, in relation to the reference values, of 100%, of the control lot (V_0); the *cotyledons* of the plantlets exposed to the *red* LEDs (V_5^{LED}) had a dry weight similar to that of the control samples (V_0).

Although there are expert studies that demonstrate that supplementation of *red* light emitted by LEDs with *blue* fluorescent light would have positive effects on both the growth and especially on organic matter accumulation in plants organs exposed to this combined light (*Urbonaviciute* et. al., 2007; *Avercheva* et. al., 2009), in our case, the separate illumination of red cabbage seedlings, with *red* light produced by LEDs and *blue* fluorescent light, produced contradictory effects. So, if the *red* light had a positive influence on growth and dry weight of plantlets of red cabbage, the *blue* one inhibited their growth, reducing the length of the *hypocotyl* with 17.15%, determining, in turn, 10.70% higher values of the dry weight of the *cotyledons*, compared to the reference values of the control samples, *naturally* illuminated.

b. In the fluorescent light

Reporting the dry weight of red cabbage plantlets grown in *white* fluorescent light (V_1^{TUB}) to that of seedlings exposed to *natural* light (V_0), the control variant – values which were taken as 100% (Fig. 4B), we can conclude the following: the increase in dry mass marked by the *roots* was just 3.36%, whereas that of the *hypocotyls* situated at 9.49%, and that of the *cotyledons* from this experimental version (V_1^{TUB}) did not record any gain in dry weight compared to the control samples (V_0).

The exposure of the red cabbage seedlings to the *blue* fluorescent light (V_2^{TUB}) determined an increase in dry weight of the *roots* of 3.19%, data that were not statistically significant in comparison with the similar ones registered at the control samples (V_0). However, the increase in dry weight of the *hypocotyls* was of 7.07%, and that of *cotyledons* was 10.72% (Fig. 4B).

At the variant subjected to an illumination with *green* fluorescent light (V_3^{TUB}), in relation to the data collected from the lot of seedlings grown in *natural* light (V_0), the *roots* presented a significant diminution, with 14.63%, of their dry weight, and *cotyledons* with 6.55% (Fig. 4B); contrarily, the *hypocotyls* had their dry weight raised with 26.05% compared to the similar organs from the control group, difference statistically valid.

The light produced by *yellow* fluorescent tubes (V_4^{TUB}) caused a 15.80% decrease in the dry weight of the *roots*, but also a slight increase of the values of this parameter, with 10.45%, at the *hypocotyls* level, data statistically significant ($p \leq 0.05$); the *cotyledons* presented values of their dry weight very close to the seedlings from the control group (V_0) (Fig. 4B).

The highest values of the dry weight were notified at the seedlings illuminated with *red* fluorescent light (V_5^{TUB}), when they were compared with those of the control lot (V_0), the recorded gains being of 27.06% at *roots*, of 41.48% at *hypocotyls* and of 27.09% at *cotyledons* (Fig. 4B), all these differences being strongly significant from a statistical point of view.

CONCLUSIONS

The highest percentages of germination, on the **4th day** from the moment when red cabbage seeds were

released to sprout were met at the variants illuminated with *white* light: 97% - natural, 95% – LEDs and 93% fluorescent light, which indicate us the fact that, in order to germinate optimally, the seeds of red cabbage require energy quanta derived from the entire spectrum light. The lowest percentage of seeds germination was recorded under the illumination with *yellow* fluorescent tubes (81%).

After monitoring within **10 days** of germination the embryonic organs growth of the red cabbage seedlings exposed to colored light, emitted either by LEDs, or by fluorescent tubes, the most striking differences of the medium size had been remarked especially at the *hypocotyl* level, the embryonic *root* and *cotyledons* presenting values more or less close to the control group, represented by seedlings grown in daylight.

On the **4th day** of germination, the most spectacular growth of the plantlets exposed to the LEDs light was notified in the case of *hypocotyls* illuminated with *green* light (+88.09%), being confirmed at the ulterior measurements, performed on the **7th day** (+83.70%) and on the **10th day** of germination (+74.96%).

Determinations made on lots of red cabbage seedlings illuminated with fluorescent tubes have revealed that, this time, the *red* light had the strongest stimulating effect on their growth. On the **4th** germination **day**, the *red* fluorescent light promoted the increase of the average length of the embryonic *root* with 62.34% and of the *hypocotyl* with 22.72%, following that on the **7th day** and on the **10th day** from the putting of seeds to sprout, its influence the growth of the *hypocotyl* to reinforce, leading to increases of 40.40% and of 48.80%.

Regarding the dry medium weight of organs of the red cabbage plantlets, the largest increases were also observed at the *hypocotyls* of the seedlings subjected to an illumination with *green* LEDs light (+77%).

Referring to the data obtained from measurements performed at the experimental variants lit by fluorescent light, compared with the reference values of the control, the highest increase in dry weight was registered at the *hypocotyls* of the red cabbage plantlets exposed to the *red* light (+41.48%).

Thus, if from the experimental variants subjected to the colored light of LEDs, the largest seedlings were observed at the variant illuminated with *green* light, from the lots of plantlets grown under the incidence of the light produced by fluorescent tubes, the greatest size of them was seen in *red* light.

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