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# ALLELOPATHY OF *Ricinus communis* AND LIGHT SPECTRUM VARIATION DECREASE EMERGENCE AND GROWTH OF *Cyperus rotundus*

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## Abstract

Weeds negatively influence agricultural production. However, those losses depend on weed specie, its time of emergence, and period of interference on agricultural crops. Synthetic herbicides are commonly used to control these plants species; however, they may cause damage to the environment, human beings and animals health, and this problem justify the need to develop alternative bioherbicides. To evaluate the allelopathic potential of *Ricinus communis* (Castor bean) and light spectrum variation on the emergence and growth of *Cyperus rotundus* L., a trial was carried out in a protected environment with 15% of brightness reduction at the Center for Agricultural and Environmental Sciences at the Paraíba State University. Four aqueous extract concentrations of *R. communis* leaves were tested (0, 5, 10, and 15%) and four light spectrums variations (white, purple, blue, and red lights). Variables such as emergence, length, dry matter accumulation and growth rates of shoots and root of *C. rotundus* seedlings were assessed. Data were analyzed by normality test, analysis of variance, polynomial regression, and averages test. Soot and root emergence, length, and dry matter accumulation of *C. rotundus* seedlings were reduced due to the allelopathy caused by *R. communis* aqueous extract leaves (15% concentration) and under purple or red light spectrum radiation.

**Keywords:** Bioherbicide. Castor bean. Light quality. Sedge. Weed.

## 1. Introduction

Weeds are regarded as one of biotic elements that can adversely affect the production of various agricultural crops (Ximenez et al. 2019). Negative effects of these plants are related to competition for important natural resources (air, water, light, nutrients, and space), allelopathy or hosts for pests and diseases (Naeem et al. 2016). Average reductions of agricultural production due to weeds infestations vary from 20 to 58% (Morota et al. 2018). However, the intensities of these losses depend on weed species as well as their emergence time, density, and interference on crops (Hussain et al. 2015).

Among weed, *C. rotundus* has been associated to one of the most problematic species to crop production, because it is distributed nearly wordwide. In addition to its wide distribution, its ability to compete with crop plants, aggressiveness and resistance to very high temperatures, extreme water deficit, and even flooding, make *C. rotundus* control and eradication difficulties (Iqbal et al. 2018). Thus, this weed specie control has been done primarily by synthetic herbicides (Morota et al. 2018). That management has made it more resistant to herbicides, consequently, increased pollution in agricultural areas (Zimdahl 2018).

Considering this scenario, several alternatives to control *C. rotundus* infestation have been carried out (Fuentes-Gandara et al. 2019), with natural herbicides made of plant extracts (bioherbicides) and have been shown to be a feasible and promising alternative (Romdhane et al. 2019), specially to be used in agroecological crop systems.

Some plants species synthesize and release secondary metabolites substances (allelochemicals), which interfere with the growth and development of another specie (Carvalho et al. 2019). The advantage of using bioherbicides is their low solubility in water, absence of halogenated molecules, alternative ways of action, requirement for low concentrations for weed control, and less environmental damage (Fuentes-Gandara et al. 2019).

Among plants that have allelopathic action, Castor bean (*Ricinus communis* L.) has been extensively researched due to its various constituents in leaves, stem, and seeds that cause allelopathic effects (Islam and Kato-Noguchi 2013; Saadaoui et al. 2015). It is worth mentioning that environmental factors, such as light, may influence the allelopathic potential of plants, mainly due to their influence on plants biochemical composition.

Light availability is an important factor to be considered for the control of *C. rotundus* since plants grow mostly in blue and red lights range because chlorophyll absorb light in the wavelength of 450 nm (blue region) and 660 nm (red region) from visible range (Long et al. 2018). Indeed, plants are influenced by light intensity and quality and photoperiod (Fukuda 2019), however, the reviewed literature is incipient about how the mediation of luminosity occurs in *C. rotundus*, especially under allelopathic action of other species, for exemple *R. communis*.

There is a lack of studies regarding the combination of allelopathy plus light spectrum variation on *C. rotundus* seedlings growth, which highlight the need for more research on the combined action of these factors. Therefore, it is supposed that the combination of allelopathy and light spectrums variations control *C. rotundus* infestation in crops. On the base of above considerations, this research assessed rhizogenesis, emergence, growth, and dry matter accumulation of *C. rotundus* under the allelopathic effect of the aqueous extract of *R. communis* leaves and light spectrums variations.

## 2. Material and Methods

### Geographical localization, experimental design, and planting

This research was carried out during October 2018, in a greenhouse at the Center for Agricultural and Environmental Sciences of the Paraíba State University, located in the municipality of Lagoa Seca, Paraíba state, Brazil (7º09'S, 35º52'W and altitude 634 m). During the experimental period, weather variables were monitored (Figure 1) to be correlated to the results with the allelopathic effects of the aqueous extract of *R. communis* leaves (AER) and the light spectrum variations (LSV).

Experimental design was a completely randomized with 4x4 factorial scheme and four replications composed of six tubers of *C. rotundus* each one. The factors were four variations of light spectrums (LSV) symbolized by WL (white light), PL (purple light), BL (blue light), and RL (red light) and four concentrations (0, 5, 10, and 15%) of aqueous extract made up of *R. communis* leaves (AER).

Experimental unit was obtained by dividing a polyethylene tray into four equal parts. Trays (30 cm x 20 cm x 5 cm in length, width, and height, respectively) were filled with 2.0 $dm^3$ of autoclaved substrate composed of coarse sand and bovine manure in 3:1 proportion.

Medium-sized *C. rotundus* tubers, between 0.4 and 1.0 g weight (Silveira et al. 2010), were obtained from the experimental station at Paraíba State University and planted in trays approximately 3 cm in depth and density of 12 tubers per $dm^3$ of substrate. Substrate moisture content was kept between 70 and 100% at field capacity (FC) by weighing method, as described by Silva et al. (2020).

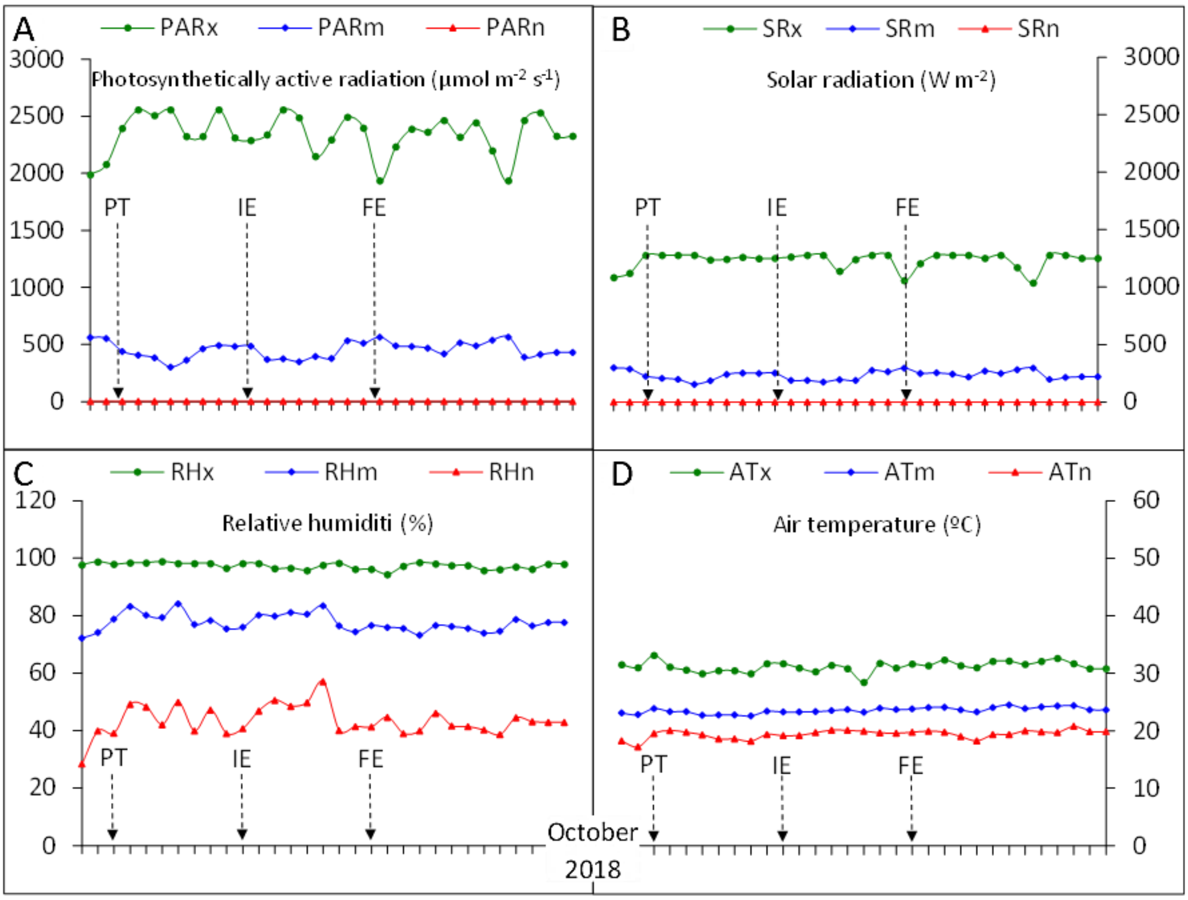


**Figure 1.** Meteorological variables recorded during the experimental period in Lagoa Seca, PB, Brazil. A – maximum photosynthetically active radiation (PARx), mean photosynthetically active radiation (PARm), minimum photosynthetically active radiation (PARn); B – maximum solar radiation (SRx), mean solar radiation (SRm), minimum solar radiation (SRn); C – maximum air relative humidity (RHx), mean air relative humidity (RHm), minimum air relative humidity (RHn); D – maximum air temperature (ATx), mean air temperature (ATm), minimum air temperature (ATn). PT - planting tubers; IE - initial evaluation; FE - final evaluation.

**Obtaining spectrums variations**

In order to obtain variations of light spectrum (LSV), trays were covered with light filter with two layers of cellophane sheets, namely, transparent paper for WL, purple paper for PL (320 to 400 nm), blue paper for BL (400 to 485 nm), and red for RL (600 to 680 nm), according to Yamashita et al. (2011). Trays were placed inside an environment with 15% of shade reduction.

**Obtaining aqueous extract from R. communis leaves**

To prepare the AER, leaves of *R. communis* plants, in vegetative stage, were collected, kept in paper bags and arranged in a protected environment for pre-drying and then placed in a forced air circulation oven at 65 ºC until constant weight, for 72 h, and later, grinded in a Willey mill. AER concentrations were obtained from 5, 10, and 15 g of leaves dry weight plus 100 mL of distilled water; the control treatment (0% concentration) consisted of just distilled water (Rigon et al. 2014).

### Seedling emergence assessment

Assessment of *C. rotundus* seedlings behavior, variables such as emerged seedlings percentage (ESP, %), emergence speed index (ESI, dimensionless), and average emergence time (AET, in days) were analyzed. Emerging seedlings counting procedure was carried out at 24 hours intervals and considered emerged those seedlings with epicotyl emergence ≥ 2.0 mm on the substrate surface. Emerged seedlings percentage was calculated 20 days after the beginning of the experiment by Eq. (1).

$$\text{ESP} = \left(\frac{N_2}{N_1}\right) \text{ x } 100 \qquad (1)$$

Where, ESP = emerged seedlings percentage. $N_1$ = number of tubers placed to sprout, and $N_2$ = number of emerged seedlings.

Emergence speed index (ESI) estimates the average of seedlings emerged per day and, therefore, the higher the value obtained from ESI, the greater the emergence speed and, consequently, the greater seedling vigor. ESI was calculated as shown in equation Eq. (2).

$$\text{ESI} = \left(\frac{100}{N}\right) \text{x} \sum \left(\frac{n}{j}\right) \qquad (2)$$

Where: N = number of tubers planted, n = number of seedlings emerged on day j (j = number of days after planting).

Average emergency time (AET) means weighted average time required for seedlings emergency, that is, the shorter the time, the greater the emergency speed (Edmond and Drapala 1958). AET was calculated according to the Eq. (3).

$$\text{AET} = \left(\frac{\sum_t^n}{\sum n}\right) \qquad (3)$$

Where: AET = average emergency time, n = number of emerged seedlings, and t = number of days after planting (Labouriau and Valadares 1976).

### Seedling growth estimation

Growth variables, initial shoot average length (ISL, in cm) at eight days after planting (DAP), final shoot average length (FSL, in cm) at 16 DAP, and relative shoot growth rate (RSGR, in cm $cm^{-1}$ $day^{-1}$) were evaluated. In each experimental unit, the two largest seedlings were collected to be measured with a graduated ruler in mm. RSGR was obtained by Eq. (4).

$$\text{RSGR} = \frac{\ln W2 - \ln W1}{t2 - t1} \qquad (4)$$

Where: RSGR = relative shoot growth rate; ln = neperian logarithm; $W_1$ = initial length, at eight DAP; $W_2$ = final length, at 16 DAP; $t_1$ = initial time (8 days); and $t_2$ = final time (16 days) (Ferraz et al. 2017).

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Initial root average length (IRL, in cm) at eight DAP, final root average length (FRL, in cm) at 16 DAB, and root relative growth rate (RRGR, in cm $cm^{-1}$ $day^{-1}$) were assessed. After eight and 16 DAP, respectively, in each experimental unit, the biggest two seedlings were harvested and sectioned close to the tuber to separate the shoot and the root portions and measured with a ruler graduated in mm. RRGR was obtained using the equation Eq. (5).

$$RRGR=\frac{\ln W2-\ln W1}{t2-t1} \qquad (5)$$

Where: RRGR = root relative growth rate; ln = neperian logarithm; $W_1$ = inicial lenght, at eight DAP; $W_2$ = final lenght, at 16 DAP; $t_1$ = Initial time (8 days); and $t_2$ = final time (16 days) (Ferraz et al. 2017).

**Assessment of seedlings dry matter accumulation**

At the end of trial period, initial (AIDM, in g) and final (AFDM, in g) dry matter accumulations, initial (RIDM, in g) and final root dry matter (RFDM, in g), and relative shoot (ADMRG, in g $g^{-1}$ $day^{-1}$) and root dry matter gain (RDMRG in g $g^{-1}$ $day^{-1}$). After eight and 16 DAP, respectively, in each experimental unit, the biggest two seedlings were harvested and sectioned close to the tuber to separate shoot and root portions, placed in paper bags, dried in forced air circulation oven, and weighed in an analytical scale. Dry matter relative gain by shoot and roots were obtained by Eq. (6).

$$DMRG=\frac{\ln IDM-\ln FDM}{t_2-t_1} \qquad (6)$$

Where, DMRG = relative dry matter gain by shoot and root; ln = neperian logarithm; IDM = initial dry matter obtained at eight DAP; FDM = final dry matter obtained at 16 DAP; $t_1$ = initial time (8 days) and $t_2$ = final time (16 days) (Ferraz et al. 2017).

**Statistical analysis**

Data were submitted to Shapiro-Wilk's normality test. Analysis of principal components (PCA) and variance was performed by F test (with 95% of confidence) when the assumptions of normality were met. For unfolding LSV degrees of freedom, multiple comparisons of means test (Tukey) was applied at the level of 5% of error probability, whereas, for AER concentrations, a polynomial regression analysis was performed (Barbosa and Maldonado Júnior 2015) with Statistica v.7 and Sisvar v. 5.6 softwares.

**Systematic literature review for identification of allelochemicals**

A systematic literature review was carried out to identify allelochemicals in the AER as described by Ferraz et al. (2019). References search was conducted between 28 and 29 February 2020, without restrictions on date, place or filters use. The search took place in databases (DB), in which $DB_1$: Science Direct, $DB_2$: Scielo, $DB_3$: Wiley Online Library, $DB_4$: Scholar Google, $DB_5$: CAPES Thesis and Dissertation Bank, $DB_6$: Web of Science, $DB_7$: Scopus, and $DB_8$: Springer Link. In these databases the search string was "allelopathy" AND "*Ricinus communis*". The references found were analyzed for the AER allelopathic potential.

## 3. Results

Two principal components (PC) were identified with values greater than the unit ($\lambda > 1$) and with more than 10% of explanation of experimental explained variance ($S^2$). These values explain 74.1% of $S^2$ of interaction between light spectral variations (LSV) and the concentrations of aqueous extract of *R.*

*communis* leaves (AER). $PC_1$ represents 54.7% of $S^2$ and was composed by seedlings emergence, growth, and dry matter accumulation variables, while $PC_2$ accounts for 19.4% of $S^2$ and was formed by the shoot and roots relative growth rates and the shoot and roots relative dry matter accumulation rate (Figure 2A, B).

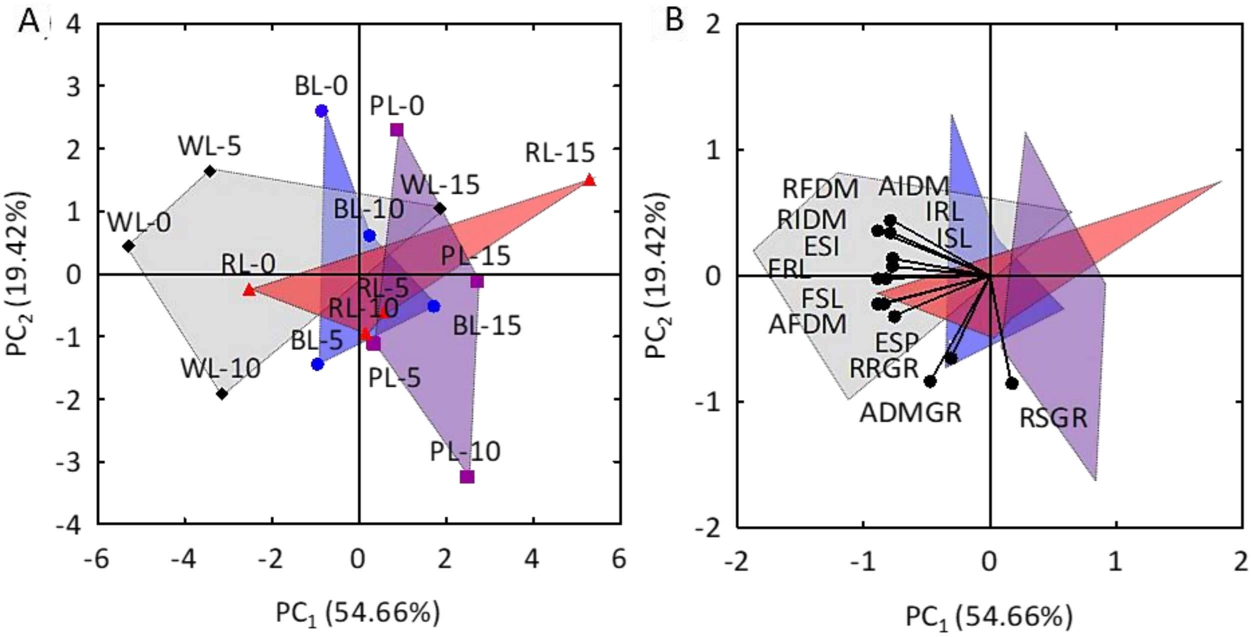


**Figure 2.** A – Two-dimensional projection of factorial scores coordinates; B – factorial loads of interactions between light spectrum variations (white —■—WL, purple ---▲---PL, blue ····●····BL, and red – – ◆ – –RL lights) and the aqueous extracts of *R. communis* (0, 5, 10, and 15%) in the principal components ($PC_1$ and $PC_2$).

Light spectrums variations (LSV) promoted a significant effect ($p<0.01$) on emergency speed index (ESI) and on mean emergence time (AET), while the percentage of emerged seedlings was not influenced by light ($p>0.05$). All seedling emergence variables were significantly influenced ($p<0.01$) by the concentrations of the aqueous extract of *C. rotundus* (AER) leaves. There was a significant interaction between the factors LSV and AER at ESI and AET (Table 1).

There was a 32.9% reduction in the *C. rotundus* ESP due to the application of 15% of AER, in which 52.7% emergence was observed, differing from the 78.6% recorded in the plots that were not submitted to the extract (Figure 3A).

The highest emergence speed index (ESI) of *C. rotundus* seedlings was obtained with the white light (WL), while, under purple (PL) and red (RL) lights, ESI of 8 and 13 were recorded, respectively, with differentials of 63.6% and 40.9% in relation to the ESI obtained under WL (Figure 3B). 15 % of AER concentration reduced the ESI to 7.7 and 10.8 under brightness with WL and BL, respectively, with differentials of 62.0% and 36.5% in relation to ESI of 20.4 and 17.0, achieved under WL and BL in *C. rotundus* seedlings not submitted to the aqueous extract (Figure 3C).

Cultivation without AER application the average emergency time (AET) was reduced by RL to 0.15 days, which represented a 31.8% reduction in relation to 0.22 days obtained under WL. On 10% of aqueous extract application, a lower AET (0.11 days) was recorded under PL (Figure 3D). Without AER application and under cultivation on WL, PL, and BL, the AET of 0.21, 0.19, and 0.18 days were verified, respectively. However, by applying 15% of the extract, the AET was reduced to 0.14, 0.12, and 0.16 days in those respective lights (Figure 3E).

There was a significant difference ($p<0.05$) among LSV in relation to the initial shoot average length (ISL), while the final shoot average length (FSL) and relative shoot growth rate (RSGR) were not influenced by light ($p>0.05$). AER concentrations had a significant difference ($p<0.05$) for ISL and FSL but did not influence RSGR ($p>0.05$) (Table 1).

For *C. rotundus* rhizogenesis, there was a significant difference ($p<0.01$) between LSV and among AER concentrations for initial (IRL) and final (FRL) root length variables.

**Table 1.** Summary of the analysis of variance of sprouting and emergence, growth and rhizogenesis, and dry matter accumulation under of C. rotundus under R. communis allelopathy and light spectrums variations.

| Source of variation | DF | Square of the mean | | | | |
|---|---|---|---|---|---|---|
| | | ESP | ESI | AET | ISL | FSL |
| Light spectral variation (LSV) | 3 | 652.41$^{ns}$ | 85.02$^{**}$ | 37e-3$^{**}$ | 7.04$^{*}$ | 8.06$^{ns}$ |
| *R. communis* stract (AER) | (3) | 3418.72$^{**}$ | 166.64$^{**}$ | 54e-3$^{**}$ | 29.10$^{**}$ | 76.35$^{**}$ |
| Linear regressionr | 1 | 5980.26$^{**}$ | 435.78$^{**}$ | 15e-2$^{**}$ | 78.83$^{**}$ | 158.35$^{**}$ |
| Quadratic regression | 1 | 4170.89$^{**}$ | 55.48$^{ns}$ | 40e-4$^{ns}$ | 1.04$^{ns}$ | 8.24$^{ns}$ |
| Regression deviation | 1 | 105.01$^{ns}$ | 8.68$^{ns}$ | 24e-4$^{ns}$ | 7.44$^{ns}$ | 62.45$^{**}$ |
| Interaction LSV x ERA | 9 | 752.80$^{ns}$ | 39.21$^{*}$ | 19e-3$^{*}$ | 3.70$^{ns}$ | 19.45$^{**}$ |
| Residue | 48 | 470.19 | 15.45 | 84e-4 | 2.14 | 6.06 |
| CV (%) | | 29.42 | 32.71 | 18.14 | 26.91 | 19.81 |
| | | RSGR | IRL | FRL | RRGR | AIDM |
| Light spectral variation (LSV) | 3 | 41e-3$^{ns}$ | 2.41$^{**}$ | 7.64$^{**}$ | 19e-4$^{ns}$ | 231.35$^{**}$ |
| *R. communis* stract (AER) | (3) | 33e-3$^{ns}$ | 9.02$^{**}$ | 18.50$^{**}$ | 16e-3$^{ns}$ | 207.37$^{**}$ |
| Linear regressionr | 1 | 41e-3$^{ns}$ | 26.19$^{**}$ | 54.98$^{**}$ | 1e-7$^{ns}$ | 593.83$^{**}$ |
| Quadratic regression | 1 | 47e-3$^{ns}$ | 0.84$^{ns}$ | 0.51$^{ns}$ | 47e-3$^{ns}$ | 16.93$^{ns}$ |
| Regression deviation | 1 | 13e-3$^{ns}$ | 0.05$^{ns}$ | 63e-4$^{ns}$ | 9e-5$^{ns}$ | 11.34$^{ns}$ |
| Interaction LSV x ERA | 9 | 33e-3$^{ns}$ | 0.58$^{ns}$ | 2.40$^{*}$ | 22e-3$^{ns}$ | 20.20$^{ns}$ |
| Residue | 48 | 18e-3 | 0.41 | 0.97 | 19e-3 | 30.47 |
| CV (%) | | 40.20 | 25.45 | 24.45 | 76.17 | 46.88 |
| | | AFDM | ADMRG | RIDM | RFDM | RDMRG |
| Light spectral variation (LSV) | 3 | 6740.73$^{**}$ | 29e-3$^{ns}$ | 227.10$^{**}$ | 2196.95$^{**}$ | 87e-3$^{ns}$ |
| *R. communis* stract (AER) | (3) | 3056.55$^{**}$ | 25e-2$^{**}$ | 33.72$^{ns}$ | 309.71$^{ns}$ | 51e-4$^{ns}$ |
| Linear regressionr | 1 | 5794.45$^{**}$ | 12e-3$^{ns}$ | 66.61$^{*}$ | 685.44$^{*}$ | 57e-4$^{ns}$ |
| Quadratic regression | 1 | 2914.65$^{*}$ | 66e-2$^{**}$ | 22.56$^{ns}$ | 236.39$^{ns}$ | 97e-4$^{ns}$ |
| Regression deviation | 1 | 460.56$^{ns}$ | 84e-3$^{ns}$ | 12.01$^{ns}$ | 7.29$^{ns}$ | 1e-7$^{ns}$ |
| Interaction LSV x ERA | 9 | 1366.99$^{*}$ | 78e-3$^{ns}$ | 32.65$^{*}$ | 214.68$^{ns}$ | 13e-2$^{ns}$ |
| Residue | 48 | 645.73 | 57e-3 | 14.38 | 142.08 | 98e-3 |
| CV (%) | | 57.63 | 49.95 | 82.56 | 85.94 | 75.10 |

$^{**}$ - significant to 1%, $^{*}$ - significant to 5% and $^{ns}$ - non-significant, values by F test; DF - degree of freedom; CV - coefficient of variation; ESP - percentage of emerged seedlings; ESI - emergence speed index; AET - average emergency time; ISL - initial shoot length; FSL - final shoot length; RSGR - relative shoot growth rate; AIDM - shoot initial dry matter; AFDM - final shoot dry matter; ADMRG - shoot dry matter relative gain; RIDM - initial root dry matter; RFDM - final root dry matter; RDMRG - root dry matter relative gain.

The smallest ISL was 4.6 cm obtained under light condition with PL with a difference of 24.6% in relation to the ISL of seedlings conducted under WL, in which a 6.1 cm length was recorded (Figure 3F). *C. rotundus* seedlings grown without application of AER showed an ISL of 6.9 cm with a reduction of 43.5% under application of 15% of the extract, in which was recorded an ISL of 3.9 cm (Figure 3G).

After 16 DAP, the final shoot length of *C. rotundus* (FSL) was delayed under brightness with RL (5.8 cm) and stimulated under PL and BL, with recorded lengths of 11.2 and 11.6 cm, respectively (Figure 3H). Under WL and RL, *C. rotundus* seedlings grown without application of AER had a greater FSL of 16.3 cm and 16.7 cm, respectively, decreasing by 10.6 cm and 8.0 cm after application of 15% of the extract in these respective luminosities (Figure 3I).

As seen in Figure 3J, under PL, BL, and RL light conditions, the *C. rotundus* had the initial average root lengths (IRL) of 2.4, 2.4, and 2.3 cm, so that these values were 22.6, 22.6, and 43.5% lower than those recorded in plants grown under WL (3.1 cm). Under application of 15% AER, the IRL was 1.7 cm, with reduction of 50% compared to the 3.4 cm recorded in plants that were not treated with *R. communis* leaf extract (Figure 3K).

Unfolding the effect of LSV within AER concentrations, it was found that plants not treated with the aqueous extract have a shorter final root length (FRL), about 4.0 cm under BL. It was found that plants not treated with AER have shorter final root length (FRL), about 4.0 cm under BL, differing from the 6.0 cm recorded with WL and RL. With 10% of the AER, WL promoted an FRL of 5.5 cm, while under PL, BL, and RL the length was reduced to 3.0, 3.1, and 3.3 cm, respectively. When applying 15% of the AER, the RL reduced the FRL to 1.2 cm, as well as, it differed from the 3.7 cm recorded in the WL (Figure 4A).

15% of AER application promoted an FRL of 4.1 cm in WL, 2.7 cm in PL, 3.0 cm in BL, and 1.4 cm in RL. These values correspond to the reductions of 31.7, 46.0, 48.3, and 67.4% in relation to the lengths of 6.0, 5.0, 5.8, and 4.3 cm observed in the light spectrums applied to the plants that were not submitted to the aqueous extract (Figure 4B).

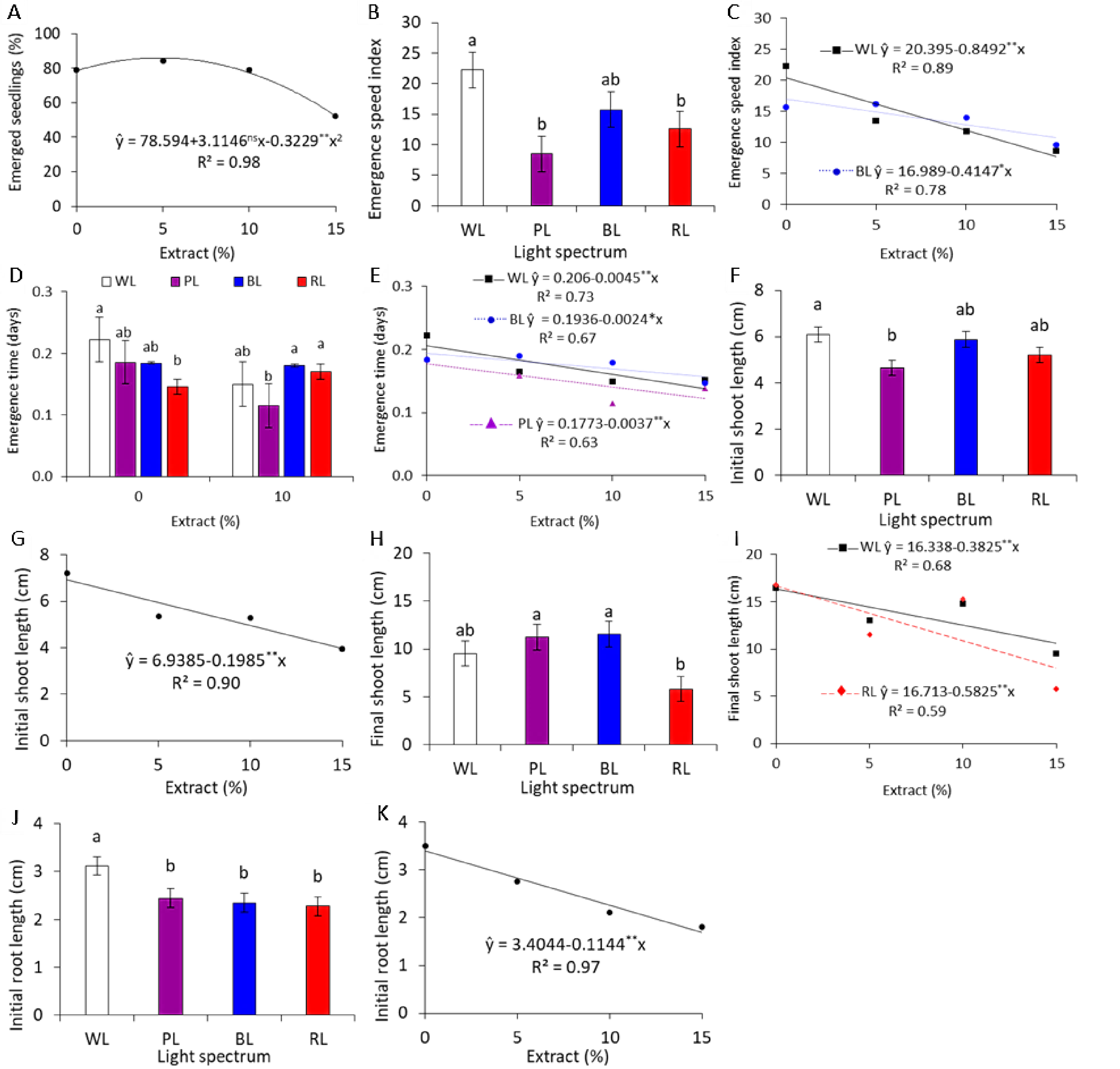


**Figure 3.** A – percentage of *C. rotundus* emerged seedlings; B and C – emergence speed index; D and E – average emergence time; F and G – initial average shoot length; H and I – final shoot length; J and K – initial average root length, under light espectral variations (white —■—WL, purple ---▲--- PL, blue ···●···BL, and red -- ◆ --RL lights) and concentrations of aqueous extracts of *R. communis* (0, 5, 10, and 15%).

There was a significant difference (p <0.01) among shoot initial (AIDM) and final (AFDM) dry matter and root initial (RIDM and final (RFDM) dry matter, while shoot (ADMRG) and root (RDMRG) relative dry matter increases were not influenced by LSV. AER concentrations promoted significant differences (p <0.01) in AIDM, AFDM, and ADMRG. There was a significant interaction (p <0.05) between LSV and AER for AFDM and RIDM accumulations (Table 1).

In this study, the lowest *C. rotundus* AIDM accumulation was obtained under PL (8 mg) and RL (10 mg) with reductions of 52.9% and 41.1% in relation to WL (Figure 4C). 15% of AER concentration promoted 7.6 mg of AIDM accumulation, which represented a reduction of 52% in relation to 15.9 mg of AIDM for seedlings not submitted to the extract (Figure 4D).

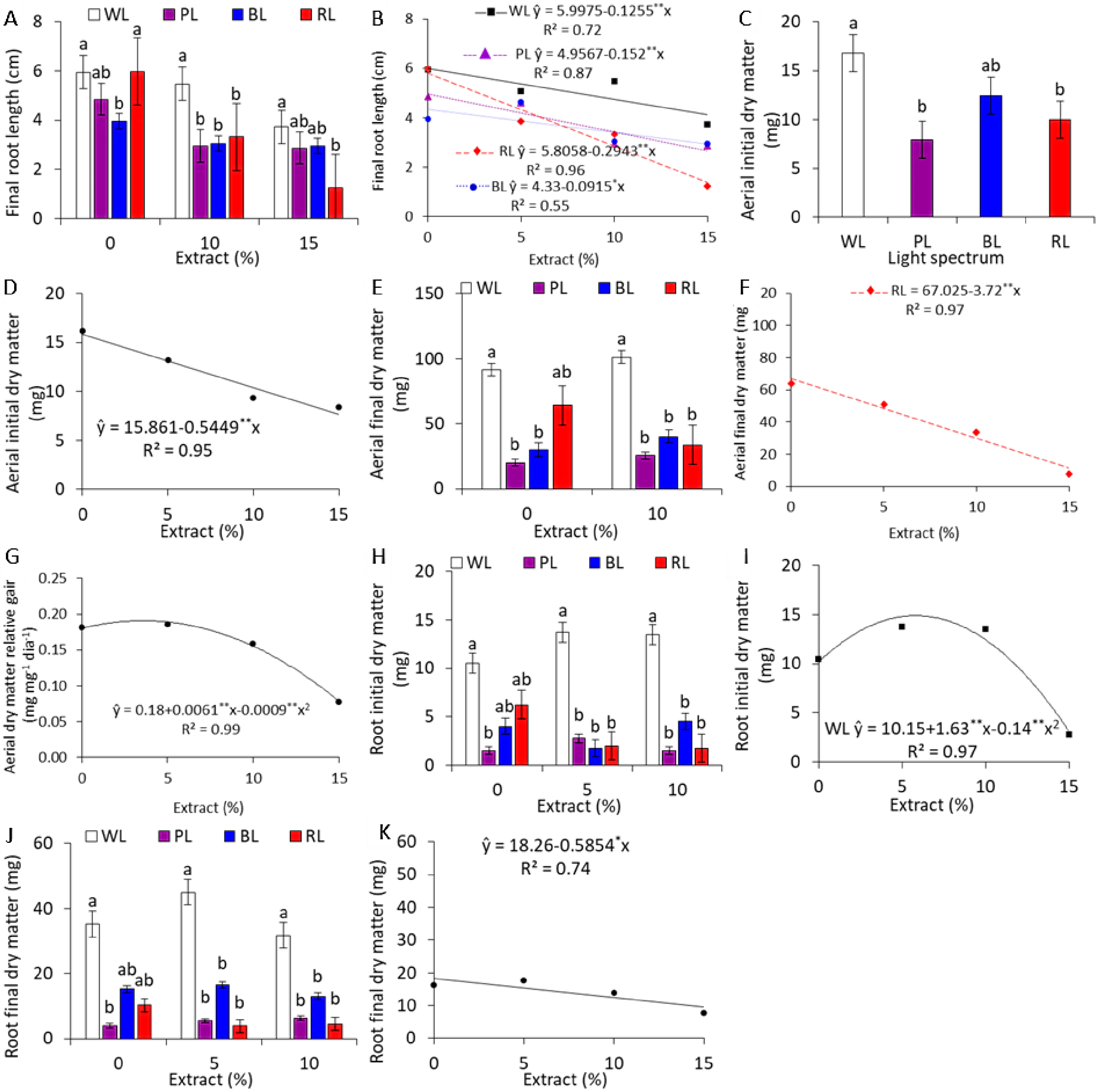

**Figure 4.** A and B – final root average length; C and D – initial shoot dry matter; E and F – final shoot dry matter; G – relative shoot dry matter gain; H and I – initial root dry matter; J and K – final root dry matter, under light espectral variations (white —■—WL, purple ---▲--- PL, blue ···●···BL, and red -- ◆ --RL lights) and concentrations of aqueous extracts of *R. communis* (0, 5, 10, and 15%).

Without aqueous extract application (control), the lowest AFDM was obtained under PL (20 mg) and BL (30 mg) with 78.2% and 67.3% differences, respectively, in relation to the 92 mg observed under WL. In 10% concentration of the AER, the PL, BL, and RL promoted the accumulation of AFDM of 26, 40, and 34 mg, differing from the WL in 101 mg (Figure 4E). Under RL 15% application of the aqueous extract reduced the AFDM to 11 mg and it differed from the 67 mg obtained from plants not submitted to the aqueous extract (Figure 4F).

For regression model, an ADMRG of 0.07 mg $mg^{-1}$ $day^{-1}$ was estimated with 15% AER application, which represents a 61% reduction in relation to the relative gain of 0.18 mg $mg^{-1}$ $day^{-1}$ obtained in seedlings that were not submitted to aqueous extract (Figure 4G).

Without application of aqueous extract, the PL induced a significant reduction in RIDM, reaching 2.0 mg, while, under 5 and 10% of AER application, the PL, BL, and RL promoted a greater reduction in RIDM (Figure 4H). In the environment under WL, a RIDM of 14.9 mg was estimated at 5.8% of the AER concentration, followed by a significant reduction to 3.10 mg with 15% of the extract concentration (Figure 4I).

Light conditions with PL, BL, and RL reduced RFDM accumulation by 80.6%, 58.1%, and 80.5% compared to WL (Figure 4J). Under 15% AER application, RFDM accumulation was 9.5 mg, which represents a reduction of 48.1% in relation to the 18.3 mg obtained in plants not submitted to the extract (Figure 4K).

The number of references related to allelopathy and *Ricinus communis*, in each database, is shown in Figure 5. Analyzing these references, it was found that *R. communis* has an 4.5% allelopathic potential (Hong et al. 2003), possibly due to: I) the toxicity of lectins such as ricin in seeds and ricinin in leaves (Hong et al. 2003); and II) the presence of casbene diterpenoid (Guo et al. 2018), 1-methylnicotinonitrile, 4- and 6-pyridones (Cordell 2013); *Ricinus communis* agglutinin. Dayan et al. (2009) mentioned that the essential oils of *R. communis* eliminated the target plant between 3 and 4 days after application.

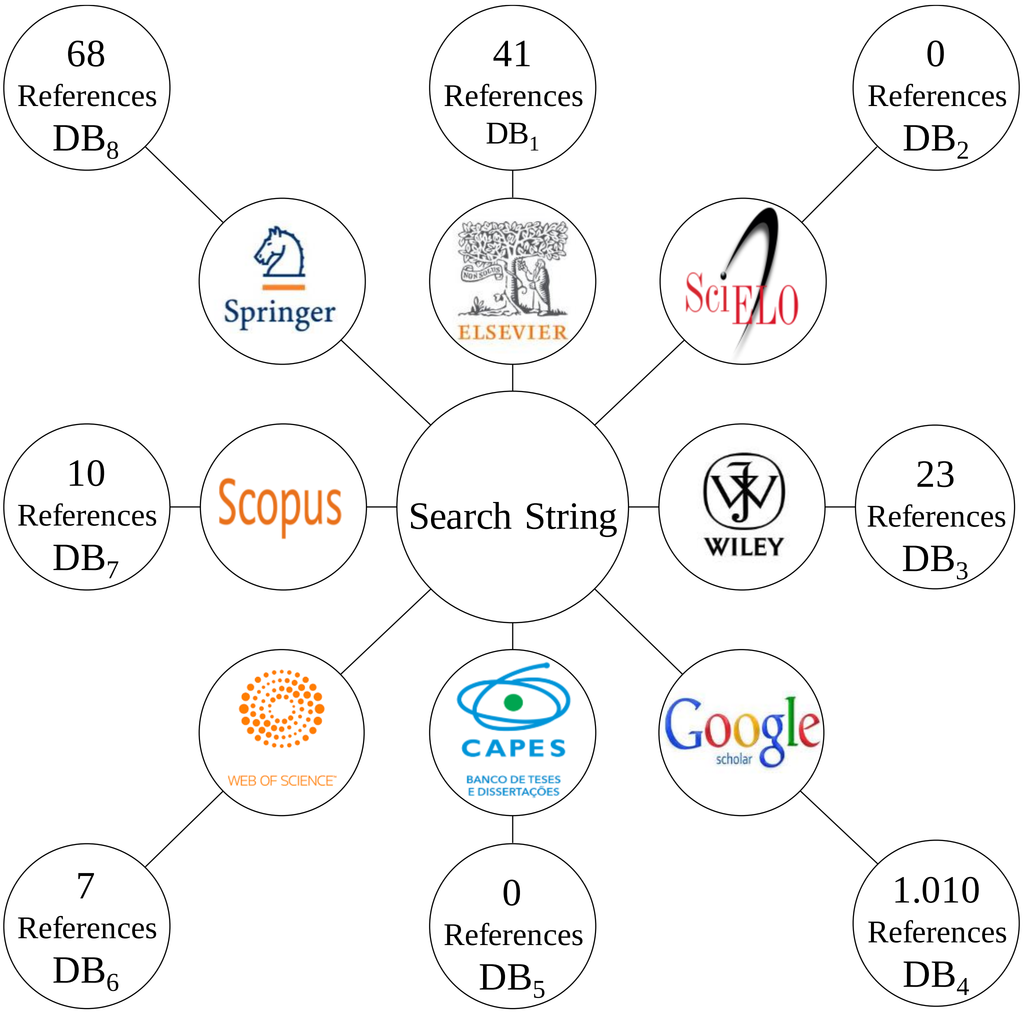


**Figure 5.** References related to the search string "allelopathy" AND "*Ricinus communis*" in the main databases.

**4. Discussion**

A summary of the interaction between AER and LSV is shown in Figure 6. WL without application of AER was considered the control and was compared with all treatments. Negative sign (-) indicates reduced in length and dry matter of seedling. Equality sign (=) indicates no differences.

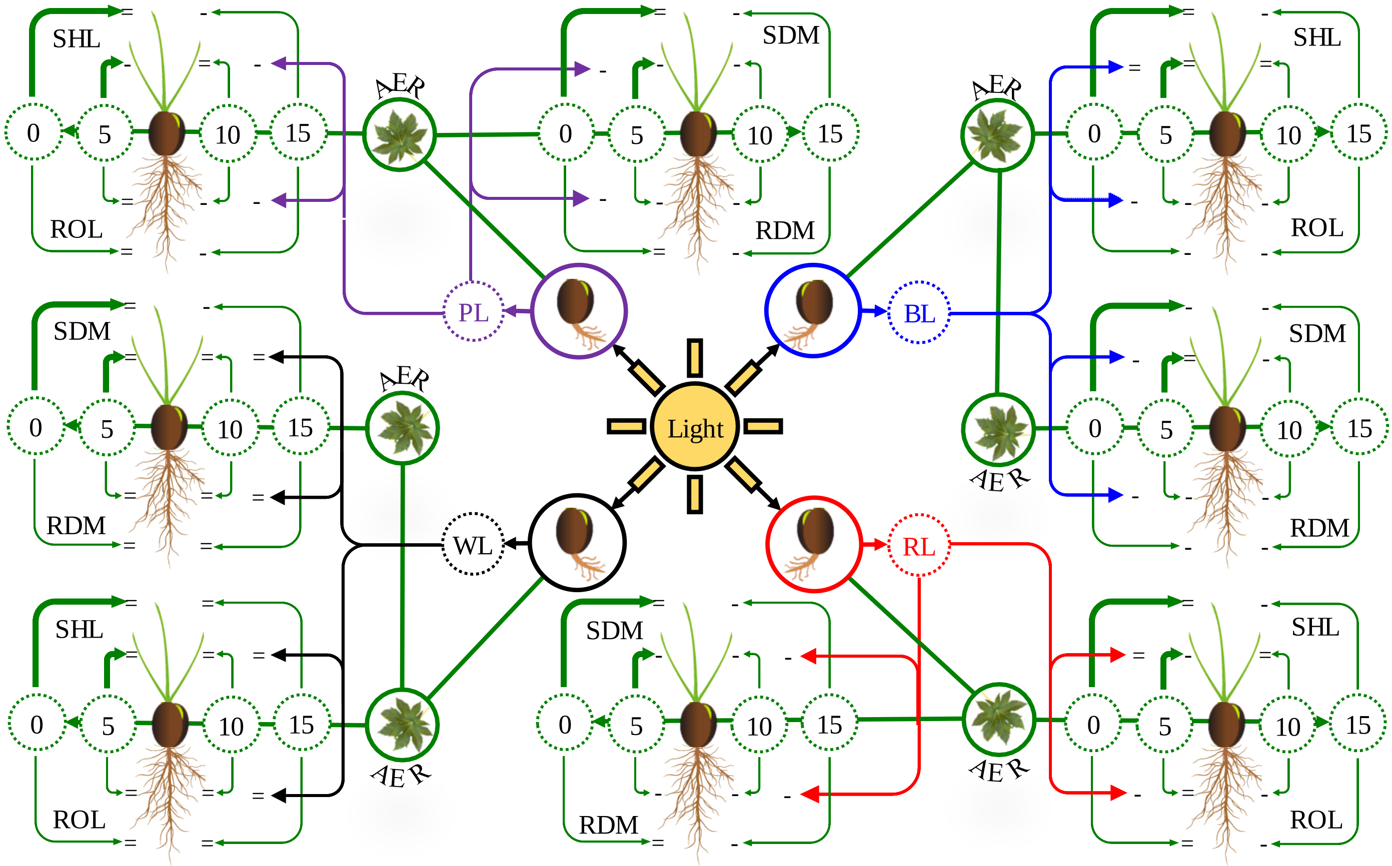


**Figure 6.** Interaction between AER and LSV for reduced in length and dry matter of seedling. SHL - soot length; ROL - root length; SDM - shoot dry matter; RDM - root dry matter.

Percentage of emerged seedlings (ESP) reduction (Figure 3A) is probably associated to the presence of phytochemicals in the aqueous extract which were released into the environment after application and they caused an allelopathic effect on the *C. rotundus* (Silva et al. 2018). Indeed, secondary metabolites of *R. communis* leaves act against other plants, which makes its aqueous extract a promising alternative to be used in agroecological crops, especially because it is a natural product from plant metabolism (Saadaoui et al. 2015).

These results from ESI (Figure 3B, C) confirm those found by Rigon et al. (2014) when they observed that 32% concentrations of aqueous extract of *R. communis* leaves completely inhibited the *Bidens pilosa* L. germination under 12 and 24 h photoperiods. The authors report that these effects occur due to the *R. communis* allelopathic action.

Interaction between LSV and AER occurs because light is essential for synthesis and degradation of defense substances in plants (Kapoor et al. 2018), so, synergistic effect of these factors negatively influenced *C. rotundus* ESI and AET (Figure 3D, E) and this behavior may has been attributed to the allelopathic effect of the substances presents in *R. communis* leaves as well as their biosynthesis and photodegradation (Islam and Kato-Noguchi 2013).

Probably, seedlings cultivated under PL (Figure 3F) expressed smaller size due to the activation of specific photoreceptors for production of substances related to the defense and reduction of the perception of photosynthetically active radiation (Demotes-Mainard et al. 2016).

According to Silveira et al. (2012) the action of allelochemicals affects numerous physiological processes such as inhibition of germination percentage and emergence speed, which leads to a reduction on weed seedlings initial growth (Figure 3G), markedly due to the exposure delay of leaves to the sun and, consequently, the reduction of photosynthetic activity.

Seedlings length increase on PL and BL and the reduction on RL (Figure 3H) may be due to plants gene transcription, biochemical activity, and gas exchange, as reported by Wang et al. (2009) who registered an intensification in transcriptional levels of 10 genes that encode key enzymes in Calvin cycle, increase in sucrose and starch contents, stomatal conductance, and RuBisCO activity under PL and BL, while RL reduced $CO_2$ assimilation rate, quantum efficiency, and PSII electron transport rate.

Allelochemical compounds from *R. communis* extract can affect germination and emergence processes, seedling growth, and nutrient assimilation, consequently, it affects the growth of weeds (Borella and Pastorini 2009). This proposition justifies the linear reductions observed while the extract concentrations were increased (Figure 3I).

Reduction in *C. rotundus* growth in response to PL at 8 DAP and RL after 16 DAP, indicates the possibility of cultivating this specie under changing light quality conditions, especially due to the distinguished action of photoreceptors in plant growth and development processes (Fukuda 2019). In addition, the presence of allelochemical substances in the AER may have caused interference in shoot growth of *C. rotundus* seedlings, since these biomolecules interact with other substances produced by this species, which can act negatively in the cell division and elongation processes (Ricci et al. 2006).

These informations are importants to improve strategic food production plans and ensure food security, particularly in relation to the agroecological production systems, because using these bioherbicides can generate a significant reduction of synthetic phytosanitary products volume and resulting on mitigation of damage to the environment (Zimdahl 2018).

Reduction in *C. rotundus* root growth (Figure 3J, 4A), as a result of light spectrum variation, indicates that this spontaneous plant has photoreceptors sensitive to environment light changes (Eprintsev et al. 2018), suggesting the possibility of handling this species with light filters. In fact, light is an important aspect for plants growth and development (Long et al. 2018), therefore these results can be promising for making decisions about the *C. rotundus* control in agricultural crops.

Root growth reductions due to AER concentrations (Figure 3K, 4B), occur because of allelopathic effects of bioactive substances extracts, such as ricin A, B and C, and ricinin, in addition to alkaloids, glycosides, and toxins (Saadaoui et al. 2015). It is important to emphasize that the application of these extracts must be carried out with caution and it needs further studies to evaluate its spectrum of action so as not to bring risks to the dynamic agroecosystems balance.

Dry matter values, mainly for spectrums variations with PL and RL (Figure 4C, D), may be related to emergence delay and the shorter exposure time of photosynthetic apparatus to solar radiation, this can have limited photosynthesis and carbon accumulation, which reflected in lower seedling growth, as also reported by Rigon et al. (2014).

The reduction in AFDM of *C. rotundus* seedlings, under combined action of AER and LSV (Figure 4E, F), possibly occurred due to the shorter root and shoot lengths that induced less water and nutrient absorption and which triggered a reduction light capture area, as well as nutrients translocation, a feature that can be ratified by decreasing in ADMRG (Hoffmann et al. 2007).

These results from RIDM (Figure 4H, I) and RFDM (Figure 4J, K) are agree with those reported by Rigon et al. (2014) who found the lowest values for total dry matter of *Bidens pilosa* L. seedlings when they were submitted to 24 h of photoperiod in different concentrations of the aqueous extract of *R. communis*.

Roots are known to be sensitive to light radiation as observed in this research because, probably, the tubers were planted at low depth (3 cm), so that spectrum radiation from light may have caused photodegradation of important substances present in the roots, for example biflorin, which is a photosensitive compound (Santana et al. 2015). Roots system impairment may have reduced water absorption and translocation to seedlings shoot and may have caused less photosynthetic activity, which decreased the flow of photoassimilates for root nutrition.

Shoot and root of *C. rotundus* seedlings behavior to spectrum variation of light suggests that this weed may be controlled by light quality manipulation, since the RL may have influenced phyA, phyB, phyC, phyD, and phyE, because these photoreceptors are responsible for perception, light modulation, and gene expression through signal transduction systems (Oka and Yamamoto 2019) and this may have been transcribed and induced growth reduction.

Growth reductions are responses to PL, BL, and RL light spectrums and may have occurred due to changes in plant hormones balances, because phytochromes (phy) and cryptochromes (cry) are associated to light signal perception and phytohormone biosynthetic signaling, which induces growth adaptations depending on the quantity and quality of light (Kong et al. 2018). This interaction becomes more evident since the nutsedge tubers have high amounts of phytohormones, such as auxin (Cavalcante et al. 2018).

## 5. Conclusions

Shoot and root emergence, length, and dry matter accumulation, in *C. rotundus* seedlings, were reduced due to allelopathy with 15% of aqueous extract of *R. communis* leaves, associated with cultivation under purple or red light spectrum radiation.

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