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Article

Management of *Commelina benghalensis* with Saflufenacil in Shaded Environments

*Manejo de **Commelina benghalensis** com Saflufenacil em Ambientes Sombreados*

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ABSTRACT - The repetitive use of glyphosate in the control of weeds in eucalyptus plantations has selected tolerant species such as *Commelina benghalensis*. Therefore, the use of herbicides of other mechanisms of action, such as saflufenacil, in rotation or combination with glyphosate, is necessary to reduce damages caused by *C. benghalensis*, whose sensitivity to herbicides can be influenced by the shading caused by the eucalyptus crop. This study aimed to assess the efficiency of saflufenacil in the management of *C. benghalensis* at different shading levels. Three experiments were carried out regarding a certain shading level (cultivation environment with 0, 40, and 55% shade). The experimental design was a randomized block design with five herbicide doses (0, 24.5, 49, 73.5, and 98 g ha^{-1} of saflufenacil) and four replications. At 28 days after herbicide application, the percentage of control and shoot dry matter were assessed, as well as the biomass allocation to leaves, stems, and roots of *C. benghalensis*. Plants cultivated at 0% shade presented a higher dry matter accumulation and a better distribution of biomass in leaves, stem, and roots, contributing with the increased tolerance to saflufenacil and not being controlled with effectiveness under the assessed doses. As shading was increased, plants of *C. benghalensis* allocated most of their biomass to the shoot, especially leaves, reducing their reserve structures and increasing the contact area with the herbicide, making them more susceptible to saflufenacil.

Keywords: shading, chemical control, biomass allocation, weed, Benghal dayflower.

*RESUMO - O uso repetitivo de glyphosate no controle de plantas daninhas em plantios de eucalipto tem selecionado espécies tolerantes a esse herbicida, como a **Commelina benghalensis**. Diante disso, torna-se necessária a aplicação de herbicidas de outros mecanismos de ação, como o saflufenacil, em rotação ou em mistura com o glyphosate, para reduzir os danos causados por **C. benghalensis**, cuja sensibilidade aos herbicidas pode ser influenciada pelo sombreamento imposto pela cultura do eucalipto. Objetivou-se neste trabalho avaliar a eficiência do saflufenacil no manejo de **C. benghalensis** em diferentes níveis de sombreamento. Foram realizados três ensaios, sendo cada um referente a determinado nível de sombreamento (ambiente de cultivo com 0, 40 e 55% de sombra), seguindo o mesmo delineamento experimental em blocos casualizados com cinco doses de herbicida (0; 24,5; 49; 73,5; e 98 g ha^{-1} de saflufenacil) e quatro repetições. Aos 28 dias após a aplicação do herbicida, avaliou-se a porcentagem de controle e a massa da matéria seca da parte aérea, bem como a alocação de biomassa para folhas, caules e raízes das plantas de **C. benghalensis**. Plantas cultivadas a 0% de sombra obtiveram maior acúmulo de matéria seca e melhor distribuição de biomassa em folhas, caule e raízes, contribuindo com o aumento da tolerância ao saflufenacil,*

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*não sendo controladas com eficácia nas doses avaliadas. À medida que se aumentou o sombreamento, plantas de **C. benghalensis** alocaram a maior parte de sua biomassa para a parte aérea, em especial para as folhas, reduzindo suas estruturas de reserva e elevando a área de contato com o herbicida, tornando-as mais suscetíveis ao saflufenacil.*

Palavras-chave: sombreamento, controle químico, alocação de biomassa, planta daninha, trapoeraba.

INTRODUCTION

Light restriction occurs naturally as crop species grow, especially those of larger size, such as forest species, causing morphophysiological changes in the infesting flora. Among the adaptations found in plants developed under shade conditions, there is an increase in leaf blade area, less deposition of epicuticular waxes in the leaves, and reduction of the cuticle on the epidermis (Taiz and Zeiger, 2010). These characteristics, coupled with changes in the leaf angle and increase in the degree of stomatal opening (Taiz and Zeiger, 2010), provide favorable conditions for the interception and absorption of herbicide by leaves. Therefore, the shading exerted by crops on the weed community may be a viable alternative to reduce the applied dose of herbicides (Santos Júnior et al., 2013; Santos et al., 2015).

Among the weeds in eucalyptus plantations, the species *Commelina benghalensis* L. (Benghal dayflower) stands out for being tolerant to glyphosate, a herbicide currently used in eucalyptus, and shading, a condition commonly found in the understory, favoring the selection of this species (Costa et al., 2004; Lorenzi, 2008). In addition, *C. benghalensis* presents a high competitiveness with eucalyptus, which can cause significant losses in the dry matter of leaves, stems, and roots (Costa et al., 2004; Faustino, 2015).

The increase in shading level caused by crop development can significantly influence the tolerance of *C. benghalensis* to chemical control due to modifications of protective structures such as trichomes and epicuticular waxes, which confer tolerance to herbicide management (Monquero et al., 2005; Santos et al., 2015). On the other hand, due to the innate characteristic of the species *C. benghalensis* in tolerating glyphosate, it is necessary to use herbicides of other mechanisms of action, applied alone or in mixtures in order to reduce the selection pressure and hence the increase in the population of this weed species.

Thus, the use of saflufenacil, an herbicide inhibitor of the protoporphyrinogen oxidase (PROTOX) enzyme, has been an alternative for the management of *C. benghalensis* in eucalyptus cultivation. By inhibiting the Protox enzyme in the thylakoids, the protoporphyrin IX is accumulated in the cell cytoplasm, which, when associated with light and oxygen, leads to the formation of reactive oxygen species, causing peroxidation of membranes (Oliveira Jr., 2011).

In this context, the aim of this study was to assess the efficiency of saflufenacil in the management of *C. benghalensis* at different shading levels.

MATERIAL AND METHODS

The experiment was conducted between January and July 2015 in Viçosa, MG, Brazil (42º52'54" W and 20º45'10" S), under a daily average photoperiod of 6.3 hours.

Seedlings of *C. benghalensis* from plants at a full vegetative stage, i.e., before emitting inflorescences were used. To obtain the seedlings, the stem of plants was sectioned on cuttings approximately 5.0 cm long, containing two nodes and two expanded leaves cut in half. These stems were placed in trays containing coconut fiber substrate. At 30 days after planting the stems, the seedlings with approximately three expanded leaves were transplanted to 10 L pots filled with soil (Table 1) previously corrected with 0.30 g dm^{-3} of limestone and fertilized with 1.68 g dm^{-3} of triple superphosphate, 0.22 g dm^{-3} of potassium chloride, and 0.33 g dm^{-3} of ammonium sulfate. In addition, at 40 days after transplanting (DAT), seedlings had their shoot pruned to standardize the vegetative development and a topdressing fertilization was carried out with 0.33 g dm^{-3} of ammonium sulfate per pot.

Table 1 - Chemical and particle size analysis of the soil

pH	P	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	SB	t	T	V	m	OM
(H_2O)	(mg dm^{-3})		(cmol$_c$ dm^{-3})							(%)		(dag kg^{-1})
4.4	1.1	23	0.1	0.1	1.7	7.43	0.26	1.96	7.69	3.0	87.0	2.75

Clay	Silt	Sand	Textural classification	Soil type
(%)				
57	21	22	Clay	Clayey

pH in water; P and K^+ – Mehlich 1 extractor; Ca^{2+}, Mg^{2+}, and Al^{3+} – 1 mol L^{-1} KCl extractor; H+Al – 0.5 mol L^{-1} calcium acetate extractor pH 7.0; SB – sum of exchangeable bases; t – effective cation exchange capacity; T – cation exchange capacity pH 7.0; V – base saturation index; m – aluminum saturation index; OM – organic matter.

Three experiments were carried out in a greenhouse with cultivation environments of 0, 40, and 55% shade. Each experiment was set up in a randomized block design with five doses of saflufenacil (0, 24.5, 49, 73.5, and 98 g ha^{-1}) and four replications. Shading levels were obtained through black polypropylene screens with 60 and 45% light transmission.

Saflufenacil application was performed at 70 days after seedling transplanting, in plants with approximately 20 cm of height and 50 cm of length of the branches. A CO_2-pressurized backpack sprayer equipped with nozzles TT110.02 spaced 0.5 m from each other was used in the application, which was carried out at a height of 0.5 m from the nozzles to the target, calibrated for an application of 140 L ha^{-1} of spraying solution at a pressure of 300 kPa.

At 7, 14, 21, and 28 days after herbicide application (DAA), visual control assessments were performed (ALAM, 1974), using a 0 to 100% scale, where 0% corresponds to the absence of phytotoxicity and 100% represents plant death. For the variable percentage of regrowth at 28 DAA, a scale ranging from 0 to 100% was adopted, where 0% represents the absence of regrowth, i.e., emission of new leaves, and 100% means that all the branches affected by the herbicide recovered from the intoxication, emitting sprouting.

The determination of the dry matter of leaves, stem, root, and total was performed at 28 DAA by collecting all the plant material remaining in the pots, which were packed in paper bags and taken to a forced air circulation oven at 65 °C until constant weight. In addition, the leaf (LMR), stem (SMR), and root mass ratio (RMR) were determined at 28 DAA (Hunt, 1990).

The extraction of the pigments chlorophyll *a*, *b*, and carotenoids was performed in leaf samples from the controls at 28 DAA by using 80% acetone v/v and estimated in a spectrophotometer (Lichtenthaler, 1987). Subsequently, the concentration of total chlorophyll (*Chl a+b*) (mg g^{-1} FM), total carotenoids (*Car*) (mg g^{-1} FM), chlorophyll *a* to chlorophyll *b* ratio (*Chl a/b*), and total chlorophyll to carotenoid ratio (*Chl/Car*) were determined.

The data from the three experiments were submitted to the analysis of joint variance. For the variables of biomass allocation, pigments, and percentage of regrowth, the Tukey's test was performed at 5% probability. For the variable percentage of intoxication, nonlinear equations were adjusted at 5% of probability, while for dry matter, regression equations were adjusted, with the means of treatments compared to each other using the standard deviation of the mean. All the statistical analyses were performed using the software Statistical Analysis System – SAS®.

RESULTS AND DISCUSSION

Plants of *C. benghalensis*, when developed under environments with light restrictions of 40 and 55% shade, was less tolerant to saflufenacil when compared to plants under 0% shade, regardless of the used dose (Figure 1). At 28 days after application (DAA), plants submitted to 55% of light interception were more susceptible to the herbicide when compared to levels of 0 and 40% shade, obtaining a superior response in the control (50.7 and 24.1%, respectively) at a dose of 24.5 g ha^{-1} of saflufenacil (Figure 1D).

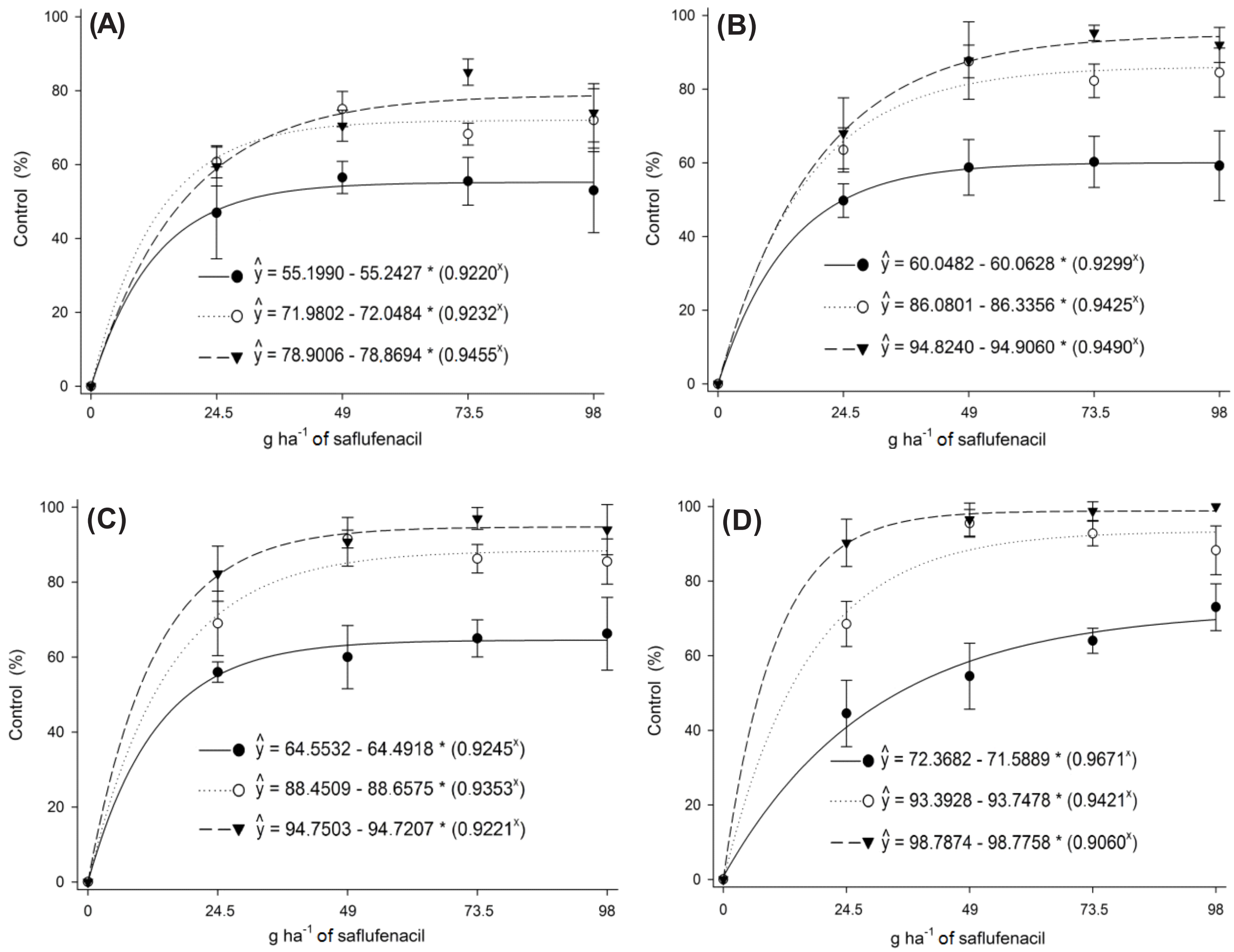

Figure 1 - Percentage of control of *Commelina benghalensis* grown under 0% shade (—●), 40% shade (····○), and 55% shade (– –▼) at 7 (A), 14 (B), 21 (C), and 28 (D) days after saflufenacil application. Bars indicate the standard deviation of the mean.

The response of *C. benghalensis* to saflufenacil is fast, especially under environments with a higher luminosity (0% shade) due to its mechanism of action, leading to an accumulation of protoporphyrin IX in the cell cytoplasm, which, when interacting with light and oxygen, provides the formation of reactive oxygen species (ROS), causing peroxidation of cell membranes and leaf necrosis (Grossmann et al., 2010; Oliveira Jr., 2011). Osipe et al. (2010), in a study with *Conyza canadensis*, observed a control over 90% at 7 DAA when this weed was managed with saflufenacil, evidencing its rapid effect. On the other hand, when developed under shaded environments, *C. benghalensis* presents a higher leaf area and a lower epicuticular wax deposition, which favors the penetration and subsequent control with glyphosate (Santos Júnior et al., 2013; Santos et al., 2015). It may also have contributed to the faster and more intense effect of saflufenacil on plants maintained under environments with lower luminosity (40 and 55% shade), even though they were maintained at the respective luminosity intensities after application. However, plants that developed without luminosity restriction and maintained in this environment after application are subject to a lower absorption of the herbicide and to its faster action, with an effect more superficial and at a lower depth, justifying the low efficiency under this condition at 28 DAA (Figure 1D).

Table 2 shows a higher partition of biomass for the leaf area and stem of plants of *C. benghalensis* when developed under conditions of light restriction. Biomass allocation to leaves was higher in 55.3, 64.7, and 82.7% when compared to that accumulated in the root system at shading levels of 0, 40, and 55%, respectively. For these same shading levels, the accumulation of dry matter in the stem was higher in 32.3, 41.9, and 76.9% in relation to the roots, respectively (Table 2).

Table 2 - Leaf (LMR), stem (SMR), and root mass ratio (RMR) of *Commelina benghalensis* developed under different cultivation environments at 28 days after application (DAA)

Environment	LMR	SMR	RMR
	$(kg\ kg^{-1})$		
0% shade	0.47 ± 0.02b	0.31 ± 0.02b	0.21 ± 0.03a
40% shade	0.51 ± 0.02ab	0.31 ± 0.03b	0.18 ± 0.0a
55% shade	0.52 ± 0.01a	0.39 ± 0.02a	0.09 ± 0.03b

Mean ± standard deviation. Means followed by the same letter in the column do not differ from each other by the Tukey's test at 5% probability.

The more uniform partition of photoassimilates between the leaves (0.47), stem (0.31), and roots (0.21) provided a higher tolerance of *C. benghalensis* to saflufenacil when developed under the 0% shade environment (Table 2 and Figure 1). On the other hand, an increase of the shading level results in an increase in leaf surface, reduction of epicuticular waxes, and lower reserve accumulation (Dias-Filho, 1999, 2000; Gondim et al., 2008), making the plants more susceptible (Santos Júnior et al., 2013; Santos et al., 2015).

The growth of *C. benghalensis* plants was influenced by the environment in which they were developed, resulting in a higher dry matter accumulation in leaves, stem, root system, and total in plants without luminosity restriction when compared to the shading levels of 40 and 55% (Figure 2). Figure 2D shows that in treatments without herbicide application, the total dry matter of *C. benghalensis* grown at 0% shade was 35.3 and 38.5% higher when compared to those grown at 40 and 55% shade, respectively, which reflects in a higher efficiency in the use of resources available in the environment. Similar responses were obtained by Santos Júnior et al. (2013), who observed that plants of *C. benghalensis* and *Cyperus rotundus*, developed under shading environments (30 and 50% shade), obtained a lower shoot dry matter accumulation when compared to those developed at full sun. According to Gobbi et al. (2009), plants of *Urochloa decumbens* grown under environments with light restriction reduced dry matter accumulation by 15% in relation to the control at full sun, which is in accordance with the results found in our study.

The recovery of *C. benghalensis* was observed in all plants submitted to the dose of 24.50 $g\ ha^{-1}$ of saflufenacil, reaching 6.7, 4.0, and 2.5% of regrowth at 28 DAA under environments with 0, 40, and 55% shade, respectively (Table 3). However, under the other doses, only plants developed at 0% shade presented regrowth, a fact related to a higher reserve accumulation in the stem and root (Table 2).

Plants developed at 0% shade tend to partition a lower biomass for leaf formation since there are no light restrictions, being necessary a more robust root system for water and nutrient absorption (Table 2), as observed by Dias-Filho (1999, 2000). In addition, these plants allocate most of their photoassimilates to the protection system against water loss to the environment, with an increased cuticle thickening, higher wax deposition, lower leaf area, and leaf blade size (Godim et al., 2008). These characteristics also provide additive effects on the tolerance to saflufenacil, causing a reduction in the control and a consequent increase in the regrowth index under environments without light restriction (Figure 1 and Table 3).

Martins et al. (2012), in a study with *C. benghalensis* management, observed a fast initial control at 7 DAA with 48 $g\ ha^{-1}$ of saflufenacil, reaching 46.7% of intoxication. However, at 45 DAA, these authors observed an inefficient control with a complete regrowth. Osipe et al. (2010) obtained similar results in a study with *Conyza canadensis*, with regrowth observed at 28 days after saflufenacil application, as observed in our study (Table 3).

Plants of *C. benghalensis* developed under shaded environments presented a higher increment in the contents of *Chl a* and *Chl b* and, consequently, of the total chlorophyll content (*Chl a+b*), in order to increase light absorption (Table 4). On the other hand, under shading conditions, a low ratio was observed between *Chl a* and *Chl b*, which is an indicator between the proportion of light-collecting complexes associated with the photosystem II (PSII) and other complexes containing chlorophyll. Leaves of plants maintained at 0% shade presented a lower concentration

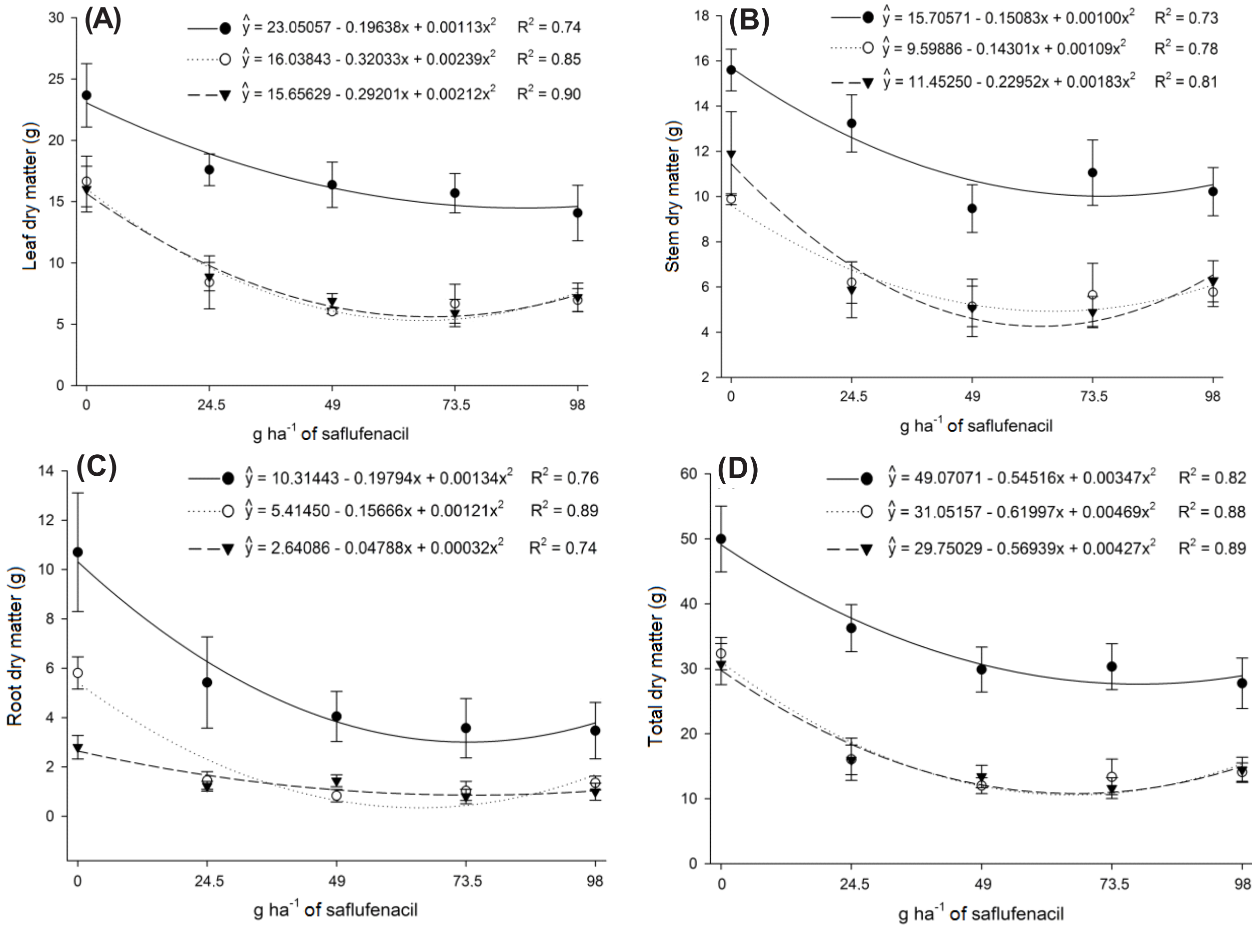

Figure 2 - Leaf (A), stem (B), root (C), and total dry matter (D) of *Commelina benghalensis* grown under 0% shade (—●), 40% shade (······○), and 55% (– –▼) submitted to the application of increasing saflufenacil doses at 28 days after application. Bars indicate the standard deviation of the mean.

Table 3 - Percentage of regrowth of *Commelina benghalensis* grown at different shading levels at 28 days after saflufenacil application (DAA)

g ha^{-1} of saflufenacil	0% shade	40% shade	55% shade
24.50	6.75 ± 2.87ab	4.00 ± 1.15	2.50 ± 3.11
49.00	8.50 ± 1.73a	0.00	0.00
73.50	6.00 ± 2.00ab	0.00	0.00
98.00	4.00 ± 1.15b	0.00	0.00

Mean ± standard deviation. Means followed by the same letter in the column do not differ from each other by the Tukey's test at 5% probability.

Table 4 - Concentration of total chlorophyll (*Chl a+b*) (mg g^{-1} FM), total carotenoids (*Car*) (mg g^{-1} FM), chlorophyll *a* to chlorophyll *b* ratio (*Chl a/b*), and total chlorophyll to carotenoid ratio (*Chl/Car*) of *Commelina benghalensis* grown at different shading levels

Variable	0% shade	40% shade	*55% shade*
Chl a+b	0.86 ± 0.15b	1.14 ± 0.04a	*1.12 ± 0.09a*
Chl a	0.59 ± 0.11b	0.79 ± 0.03a	*0.77 ± 0.06a*
Chl b	0.27 ± 0.05b	0.35 ± 0.02a	*0.35 ± 0.02a*
Chl a/b	2.27 ± 0.02a	2.26 ± 0.03ab	*2.22 ± 0.01b*
Car	0.63 ± 0.07b	0.75 ± 0.02a	*0.76 ± 0.05a*
Chl/Car	1.35 ± 0.09b	*1.51 ± 0.06a*	*1.48 ± 0.03a*

Mean ± standard deviation. Means followed by the same letter in the column do not differ from each other by the Tukey's test at 5% probability.

of carotenoids (0.63 mg g^{-1} FM) and chlorophyll to total carotenoid ratio (*Chl/Car*) (1.35) when compared to *C. benghalensis* under shading conditions (Table 4).

Plants developed under environments saturated by solar radiation tend to invest less in the light-collecting pigments chlorophyll *a* and *b* when compared to shaded environments since this resource is not restricted to full sun and the high concentration of energy collecting centers may contribute with an increased ROS, overloading the plant photoprotection system (Dias, 2006).

Plants of *C. benghalensis*, when developed under shaded environments, invested more in the efficiency of their photosynthetic apparatus, as well as in the shoot growth, while plants grown without light restriction allocated more photoassimilates in reserve organs, such as stem and roots, making possible the regrowth after saflufenacil application. Therefore, plants of *C. benghalensis*, when developed under shading environments, are more susceptible to saflufenacil.

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