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Article

Substrate based on agro-industrial waste and color of cultivation benches influence the production of *Zinnia elegans*

Substrato à base de resíduos agroindustriais e coloração de bancadas de cultivo influenciam a produção de *Zinnia elegans*

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Abstract: Among the various technologies that can be used to modify the environmental conditions in protected cultivation, the use of agricultural waste and the use of cultivation benches of different colors can be beneficial to plants, providing adequate plant development and giving greater sustainability to the production system. The study aimed to identify the potential for using substrate based on agro-industrial waste and colored benches as alternatives for the production of *Zinnia elegans*. The experiment was conducted in the experimental area of the Mato Grosso do Sul State University (UEMS), in the Unit of Cassilândia, using a completely randomized design arranged in a 3 x 5 factorial scheme (three bench colors x five substrate doses), with three replications of four plants for each treatment. The treatments consisted of three colored benches (white, red, and control - metal bench) and five substrate mixtures with different concentrations of agro-industrial waste (SBRA) and Ecosolo® (0, 25%, 50%, 75%, and 100%) in which *Zinnia elegans* was grown. The variables analyzed were plant height, length of internodes, the number of leaves, relative chlorophyll content (SPAD), stem diameter, flower diameter, number of petals, time required for flowering and shoot dry mass. It was found that the composition of the substrate affected most of the characteristics evaluated, except for internode length and stem diameter. The benches resulted in significant differences in relative chlorophyll content and number of petals. Adding increasing proportions of SBRA, provides greater vegetative growth and flower development in *Zinnia elegans* plants.
Keywords: ornamental plants, protected cultivation, regenerative agriculture, sustainability.

Resumo: Dentre as diversas tecnologias que podem ser utilizadas para modificar as condições ambientais no cultivo protegido, o aproveitamento de resíduos agrícolas e a utilização de bancadas de cultivo de diversas cores podem ser benéficos às plantas, proporcionando um desenvolvimento adequado e conferindo maior sustentabilidade ao sistema de produção. O estudo teve como objetivo identificar o potencial de utilização de substrato à base de resíduos agroindustriais e bancadas coloridas como alternativas para a produção de *Zinnia elegans*. O experimento foi conduzido na Universidade Estadual de Mato Grosso do Sul (UEMS), Cassilândia-MS, utilizando delineamento inteiramente casualizado, disposto em esquema fatorial 3 x 5 (três cores de bancada x cinco doses de substrato), com três repetições. Os tratamentos consistiram de três bancadas coloridas (branca, vermelha e controle) e cinco misturas de substratos com diferentes concentrações de resíduo agroindustrial (SBRA) e Ecosolo® (0, 25%, 50%, 75% e 100%) em qual *Zinnia elegans* foi cultivada. As variáveis analisadas foram altura das plantas, comprimento dos entrenós, número de folhas, teor relativo de clorofila (SPAD), diâmetro do caule, diâmetro da flor, número de pétalas, tempo necessário para floração e massa seca da parte aérea. Verificou-se que a composição do substrato afetou a maioria das características avaliadas, exceto comprimento dos entrenós e diâmetro do caule. As bancadas resultaram em diferenças significativas no teor relativo de clorofila e no número de pétalas. A adição de proporções crescentes de SBRA proporciona maior crescimento vegetativo e desenvolvimento floral nas plantas de *Zinnia elegans*.
Palavras-chave: agricultura regenerativa, cultivo protegido, plantas ornamentais, sustentabilidade.

Introduction

The processes of industrializing agricultural products end up generating large amounts of organic waste. These, in turn, are often disposed of or stored in the wrong way, making them a risk to the environment and the surrounding population (Yaashikaa et al., 2022), making it necessary to create specific policies aimed at their correct disposal, giving sustainability to the production system. However, the use of this waste in agricultural production systems can be viable, provided that the toxicity characteristics are observed (Singh et al., 2021), in addition to other risks, which can be mitigated through physical, chemical, or biological processes of this waste.

Products obtained from organic materials from the agro-industry have been successfully applied to the production of species of commercial interest (Radziemska et al., 2019; Ribeiro et al., 2020; Ortega et al., 2022), including ornamental species (Vendruscolo et al., 2020). This is due to the beneficial characteristics observed in these compounds, such as increased moisture retention due to the increase in microporosity and density of the substrate to which they are added (Agarwal et al., 2021). The chemical composition is another characteristic to be observed since products generated from the composting of organic waste, depending on the source, can contain high levels of nutrients in their composition and have forms that are highly available to plants due to the changes resulting from the process of aerobic degradation of organic material through the action of microorganisms (Agarwal et al., 2021).

Optimizing all stages of the production process is necessary in highly technological production systems, such as the large-scale production of ornamental plants. Therefore, a range of techniques must be employed to increase the production and quality of these plants. In this sense, in addition to the availability of nutrients, there is the possibility of changing the environment, aiming to optimize the metabolic processes of developing plants (Costa et al., 2020a), through the use of benches of different colors, for example, that are capable of reflecting wavelengths influencing the photomorphogenesis of the plant, in addition to the photosynthetic process, providing adequate plant growth.

Species are known to be more responsive to the blue and red wavelengths of light in the visible spectrum. This makes it possible to modify the environment so plants can express their maximum genetic potential (Costa et al., 2020a). Some of these modifications can be made

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by introducing lamps that emit specific spectra, which result in an increase in chlorophyll levels (Vieira et al., 2015; Zheng and Van Labeke, 2017) or agricultural screens that filter sunlight and allow the transmission of the red spectrum (above 600 nm), culminating in an increase in plant structures with commercial value. These responses are related to the absorption of the red spectrum (around 660 nm) by chlorophylls, which stimulate an increase in the conversion of light energy into chemical energy, with an effect on growth, also affecting germination in positive photoblastic seeds, the absorption of the red spectrum by phytochrome, which is related to the induction of flowering, stem elongation, and leaf expansion. Light also influences the development of chloroplasts and the biosynthesis of photosynthetic pigments (Taiz et al., 2015).

The enhancement of plant ambiance by improving the distribution and availability of light in the protected environment, with the aid of silver reflective material on growing benches, has been developed for some species, such as jambolan *(Syzygium cumini* L.) (Salles et al., 2017), paricá (*Schizolobium amazonicum* Herb.) (Mortate et al., 2019), papaya (*Carica papaya* L.) (Cabral et al., 2020) and baru (*Dipteryx alata* Vog) (Costa et al., 2020b; Costa et al., 2020c). Despite this information, there have been no studies on different colors of cultivation benches with potential light reflecting material for the commercial production of ornamental plants. Among the ornamental species commonly used is *Zinnia elegans* Jacq, an ornamental flower widely used in gardens. *Zinnia elegans* (Fam. *Asteraceae*), commonly called "zinnia", is among the most important summer annual flowers. The species of bright and colorful flowers (red, pink, orange, yellow, and white) attract butterflies and are suitable for forming landscape borders, as they grow easily. They are temperature tolerant and used in cottage gardens, rock gardens, and pots (Saini et al., 2020). Its commercialization as a potted plant is also important, being an option among the species sold in Brazil (Martins et al., 2021).

Based on the results obtained in different studies and the hypothesis that substrates generated from the treatment of agro-industrial waste and the use of benches made from colored material can be applied with significant gains for the production of species of commercial interest, the study aimed to identify the potential for using substrate based on agro-industrial waste and colored benches as alternatives for the production of *Zinnia elegans*.

Material and methods

The experiment was conducted in the experimental area of the Universidade Estadual de Mato Grosso do Sul (UEMS), at the University Unit of Cassilândia, from February 21 to April 28, 2020, in a protected environment (greenhouse), with a galvanized steel structure, 8.00 m wide by 18.00 m long and 4.00 m high, with a zenith opening in the ridge, covered with 150 micron low-density polyethylene (LDPE) film, 42%-50% shading thermoreflective screen under the film and 30% shading black side screens.

The experiment was conducted using a completely randomized design arranged in a 3 x 5 factorial scheme (three bench colors x five substrate doses), with three replications of four plants for each treatment. The treatments consisted of three colored benches (white, red, and control - metal bench) and five substrate mixtures with different concentrations of agro-industrial waste (SBRA) and Ecosolo® (0, 25%, 50%, 75%, and 100%) in which *Zinnia elegans* (California Giant cultivar, pink colored) was grown.

The treatments consisted of substrates established by mixing SBRA (Ecosolo) and the commercial peat substrate (Carolina Soil®). The SBRA was subjected to laboratory analysis, and the results are shown in Table 1.

Table 1. Physical-chemical characterization of the substrate based on agro-industrial waste.

Parameter	Value	Unit
Density	0.45	g dm^{-3}
Organic matter	39.40	g dm^{-3}
P (Mehlich)	8.80	mg dm^{-3}
K	1.12	$cmol_c$ dm^{-3}
Ca	14.20	$cmol_c$ dm^{-3}
Mg	7.30	$cmol_c$ dm^{-3}
H+Al	0.80	$cmol_c$ dm^{-3}
Al	0.00	$cmol_c$ dm^{-3}
CEC	23.40	$cmol_c$ dm^{-3}
Base saturation	96.60	%
Total porosity	43.26	%
pH ($CaCl_2$)	6.10	-

The mixture of substrates was used for both the formation of the seedlings and the cultivation of the plants. The seedlings were grown in a greenhouse (42%-50% shading) in expanded polystyrene trays with 200 cells. After 18 days, the seedlings were transplanted into high-density polyethylene pots with 10 cm height, 12 cm diameter, and a volume of 1 m³, filled with the substrates of the respective treatments.

The pots with the different treatments were placed on the different colored cultivation benches (Fig. 1). Formica was used over the 80 cm high metal bench for white and red cultivation benches, while the control treatment consisted of the metal bench. The pots were distributed 20 cm apart to avoid shading the plants.

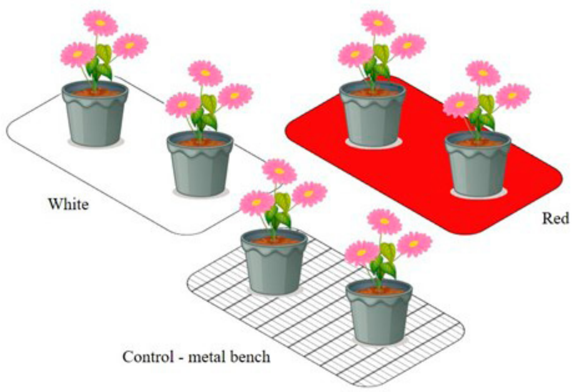

Fig. 1. Representative scheme of *Zinnia elegans* plants on the cultivation benches with different colors.

The irrigation system used was a semi-automated sprinkler system consisting of a 1,000 m³ reservoir, a 2 hp motor pump, a control head with a disc filter, a pressure gauge and a drawer damper, 32 mm PVC pipes in the main irrigation line and 24 mm PVC pipes in the lateral lines. The micro sprinklers were installed in the lateral lines with a spacing of 2 meters between sprinklers and 2 meters between lateral lines, located at the top of the structure of the protected environment in a longitudinal direction and fixed to galvanized wires.

After consolidating the uniformity and application intensity tests, a Christiansen's Uniformity Coefficient (UC) of 89% was obtained, which is considered good, according to the classification proposed by Frizzone et al. (2012). Due to the characteristics of the irrigation system, the application intensity was equal to 13 mm h^{-1}, equivalent to 0.21 mm min^{-1}. Therefore, the ratio between ETc (obtained by the weather station installed inside the protected environment) and the application intensity established the daily irrigation times required for the crop. In addition, no pests or diseases occurred during the experiment.

Photosynthetically active radiation (µmol m^{-2} s^{-1}) was obtained in the cultivation benches with different colors using a portable digital pyranometer (MP-200, Apogee, Santa Monica, USA) in the morning, under cloudless skies, between 9 and 10 am. The sensor was positioned facing downwards at 20 cm from the cultivation benches and facing upwards in the center of the protected environment to obtain the reflected and incident photosynthetically active radiation, respectively.

The biometric characteristics of the plants were assessed at the moment when anthesis, defined by the total expansion of the flowers, was observed for each plant. The variables analyzed were plant height (cm), measured with a graduated ruler from the base of the plant to the beginning of the calyx. The length of internodes (cm) by measuring each internode and calculating the average of these afterward; the number of leaves (one) by counting the true leaves; relative chlorophyll content (SPAD), obtained with a digital chlorophyll meter on a leaf from the middle portion of the plant; stem diameter (cm), at the height of the neck; flower diameter, measured with a digital caliper; number of petals (one), by counting the fully expanded petals; time required for flowering (days), by counting the time between transplanting and the flowers opening; shoot dry mass (%), obtained by drying the plants in a forced air circulation oven at 65 °C for 72 hours.

The data was subjected to analysis of variance (ANOVA), and the means of the cultivation benches with different colors were compared using the Tukey test at a probability of 5%. The means for the treatments with different substrates were fitted to polynomial regression analysis.

Results and discussion

It was found that the white and red cultivation benches reflected higher percentages of the photosynthetically active radiation incident inside the protected environment, with the white bench standing out (Fig. 2). Compared to the control treatment, there was an increase of 7.58% and 2.47% in the radiation reflected by the white and red cultivation benches, representing a total of 55.33 and 18.00 µmol m^{-2} s^{-1}, respectively.

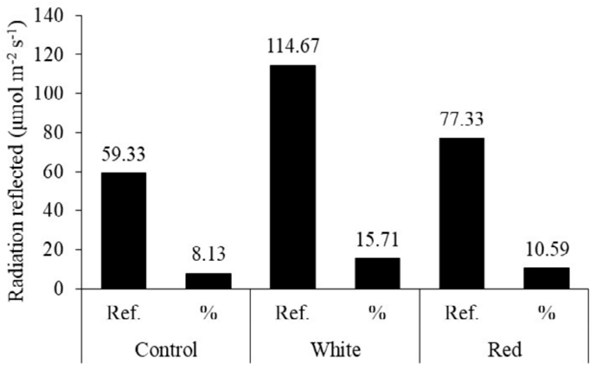

Fig. 2. Average values of radiation reflected by the cultivation benches with different colors and their respective percentage concerning incident radiation (730 µmol m^{-2} s^{-1}) during the experiment.

No interaction was observed between using benches with different colors and proportions of SBRA. However, it was found that the benches resulted in significant differences in relative chlorophyll content and number of petals. It was also found that the composition of the substrate affected most of the characteristics evaluated, except for internode length and stem diameter (Table 2).

Table 2. Mean values and significance of regression analysis for the characteristics of *Zinnia elegans* plants grown on benches with different colors and proportions of agro-industrial waste substrate.

Bench	HEI	NL	ILE	RCC	SD	FD	NP	SDM	DAF
	(cm)	(-)	(cm)	(CCI)	(mm)	(mm)	(-)	(g)	(days)
Control	33.37a	8.53a	3.96a	8.04b	2.99a	53.55a	12.35ab	0.94a	27.00a
White	29.67a	8.27a	3.66a	8.49ab	2.76a	52.83a	10.93b	0.84a	24.87a
Red	29.37a	8.07a	3.60a	9.27a	2.92a	51.11a	13.00a	0.85a	25.53a
Substrate									
LR	*	**	ns	**	ns	*	**	**	**
QR	ns	ns	ns	ns	ns	*	ns	ns	*
CV%	23.19	16.97	19.72	13.79	17.26	16.75	17.09	30.78	15.25

HEI - plant height; NL - number of leaves; ILE - internode length; RCC - relative chlorophyll content; SD - stem diameter; FD - flower diameter; NP - number of petals; SDM - shoot dry mass; DAF - days to flowering; LR - linear regression; QR - quadratic regression; CV - coefficient of variation; * and ** - significant at 5 and 1% of variation, respectively.

Plants grown on red colored benches showed a 15% higher relative chlorophyll content compared to the control treatment and a 19% higher number of petals compared to the white bench (Table 2). This result is related to the quality and intensity of the light reflected by the cultivation benches, acting as a supplementary light source, since the reflected radiation has values close to those provided by some LED (Light Emitter Diode) lamps (Nanya et al., 2012).

The reflective photosynthetically active radiation reaches the adaxial epidermis of the leaf, and the photons reach the leaf mesophyll captured by the photosynthetic pigments (especially chlorophylls) in photosynthesis I and II, located in the chloroplasts (Taiz et al., 2015). This increase in the availability of photosynthetically active radiation led to greater production of photosystems for greater conversion of light energy into chemical energy due to the supplementation of photosynthetically active radiation provided by the red bench, leading to a greater accumulation of chlorophylls. Even though the red bench provided less photosynthetically active radiation (intensity) than the white bench (Table 1), the red bench provided better radiation supplementation with the red wavelength, directly influencing the plant photosynthetic process and photomorphogenesis (Campos et al., 2023).

Supplementation with white and red light positively affects chlorophyll levels in micropropagated banana seedlings (*Musa* spp.) compared to light emitted by fluorescent lamps (Vieira et al., 2015). In addition, Poudel et al.

(2008), studying the effect of red LED light emitting lamps on grapevines (*Vitis vinifera* L.), found that they optimized photosynthesis, directly influencing shoot height, internode length, and rooting frequency. A positive effect of red-light supplementation, with increased photosynthetic pigments, was also found for *Ficus benjamina* (Zheng and Van Labeke, 2017), another full sun species, and *Zinnia elegans*.

Similarly, to this study, Ovadia et al. (2009) found that under conditions in which the red spectrum (above 600 nm) was transmitted to lisianthus (*Eustoma grandiflorum*) and sunflower (*Helianthus annuus*) plants (grown under full sun conditions), there was a positive effect on the size of the inflorescences. The authors relate the results to the quality of light incident on the plants, which directly influences quality and can be used as an alternative to applying products such as phytohormones. This response is due to the intense absorption of the red spectrum (around 660 nm) by chlorophylls, which stimulates growth through phytochrome and affects flowering induction (Taiz et al., 2015).

For plant height, number of leaves, relative chlorophyll content, and shoot dry mass, it was found that an increase in the participation of SBRA implied a linear increase in these characteristics of 24.76%, 26.06%, 76.34%, and 56.33%, respectively, when comparing the substrate composed of 100% SBRA to the commercial substrate (0% SBRA) (Fig. 3).

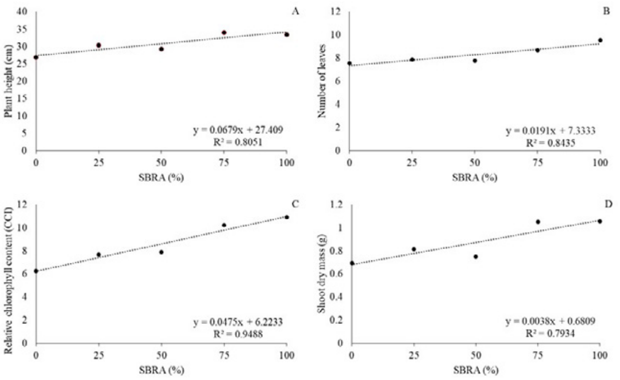

Fig. 3. Plant height (A), number of leaves (B), relative chlorophyll content (C), and shoot dry mass (D) of *Zinnia elegans* plants grown in different proportions of the agro-industrial waste-based substrate.

Similarly, to the results obtained for the vegetative growth characteristics, the increase in SBRA participation positively affected reproductive structures (Fig. 4 A and B). In this sense, flower diameter was increased up to the estimated maximum point of 73.86% SBRA, which resulted in a gain of 35.11% over the commercial substrate, while for the number of petals and the time required for flowering, the increase provided by the substrate composed only of SBRA was 24.96% and 34.78%, respectively.

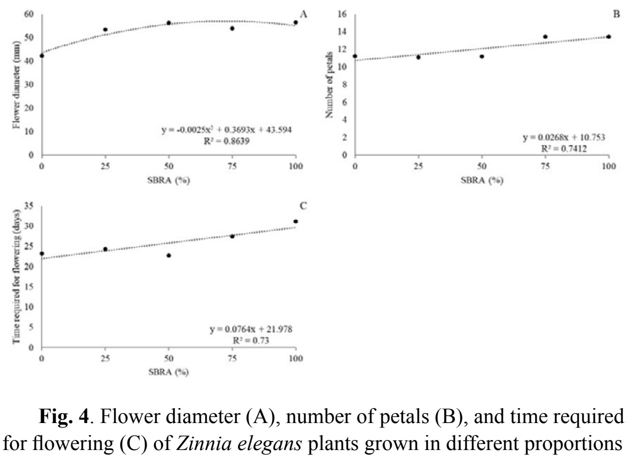

Fig. 4. Flower diameter (A), number of petals (B), and time required for flowering (C) of *Zinnia elegans* plants grown in different proportions of the agro-industrial waste-based substrate.

Similar results were obtained by Vendruscolo et al. (2020), who verified an increase in the biometric characteristics of the vegetative and reproductive organs when there was an increase in the participation of SBRA in the composition of the substrate used for the production of *Zinnia elegans* mini plants. These authors relate the positive responses to the increased participation of SBRA to its chemical and nutritional composition.

Other studies have also pointed to the importance of adequate nutrition for *Zinnia elegans* plants during their development, with the application of nutrients, regardless of the source, being beneficial to obtaining high quality plants (Damaceno et al., 2022; Souza et al., 2022). This fact is related to the participation of nutrients in the most varied activities conducted by plant organs, such as protein synthesis, gas exchange, photosynthesis, and enzyme activation, among others (Taiz et al., 2015).

Also, the physical characteristics of SBRA may have improved the conditions for water retention and nutrient retention (Agarwal et al., 2021) since its density is higher than that observed for the commercial substrate used, around 0.381 g dm^{-3} (Menegaes et al., 2017). In excess, the substitution of macroporosity for microporosity can have consequences for root development, given the accumulation of moisture and the generation of an anaerobic environment (Costa et al., 2017), but when controlled, it can be useful for maintaining the stability of the root structure during seedling transplanting, preventing the roots from being damaged during the process (Pêgo et al., 2019).

Substrates based on agro-industrial waste and colored cultivation benches are promising techniques for application in the cultivation of ornamental plants, given the benefits in terms of the growth and development of the species. However, the characteristics of each one must be observed, adjusting the proportion to be used in the formulation of the substrates.

Conclusions

Adding increasing proportions of SBRA, up to 100% of the composition, provides greater vegetative growth and flower development in *Zinnia elegans* plants, constituting an option for use in production systems for this ornamental species. Also, adding a red reflective surface on the growing bench can potentially improve the quality of the plants to be marketed, by increasing the number of petals.

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Author contribution

DFC: conceptualization, validation, investigation, data curation, writing. **EPV**: investigation, data curation, writing, supervision. **FEAB**: investigation, data curation, writing. **FPAPB**: investigation, data curation, writing. **EC**: data curation, writing. **FFSB**: data curation, writing. **BLQR**: data curation, writing.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

The research data is contained in the manuscript.

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