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PERFORMANCE OF *Calendula officinalis* L. IN SUBSTRATES DEVELOPED WITH SOLARIZED SEWAGE SLUDGE AND AGRO-INDUSTRIAL WASTES

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KEYWORDS

alternative substrates, biosolids, ornamental plants, rice husk ash, sugarcane bagasse.

ABSTRACT

Efficient products can be developed for the ornamental plant sector using agro-industrial waste. This study evaluated the agronomic performance and ornamental quality of calendula plants (*Calendula officinalis*) cultivated in substrates formulated with solarized aerobic sewage sludge (SASS), rice husk ash (RHA), and sugarcane bagasse (SB). Five additive rates were used: S2: 33.33% SASS + 33.33% RHA + 33.33% SB; S3: 16.65% SASS + 41.67% RHA + 41.67% SB; S4: 12.48% SASS + 43.76% RHA + 43.76 % SB; S5: 8.32% SASS + 45.84% RHA + 45.84 % SB; S6: 4.16% SASS + 41.07% RHA + 54.76% SB; and S1: commercial substrate (reference). Raw materials and substrate formulations were characterized and agronomic and ornamental aspects were evaluated in calendula plants cropped in all substrates. The lowest agronomic performance was observed in S6 (lowest SASS rate), while the highest occurred in S3 compared to the other treatments. Regarding the ornamental potential, S3 and S4 and the commercial substrate (S1) were classified as excellent. This study highlights the successful use of organic raw materials (SASS and agro-industrial waste) to compose substrates for calendula production in pots, with the recommended proportions ranging from 12.48 to 16.65% of SASS combined with RHA and SB.

INTRODUCTION

Global flower and ornamental plant markets are expected to grow consistently over the next few years. There have been growing concerns regarding the correct management and disposal of urban solid waste, including agro-industrial wastes and sewage sludge that is mainly disposed of in landfills, which is a costly procedure (Zhou et al., 2020) that does not comply with modern principles of recycling residues and a circular economy. For countries with available agricultural lands and highly weathered soils, such as Brazil, the development of products based on waste reutilization is important for recycling and sustainability (Tessaro et al., 2016; Melo et al., 2018; Scaglia et al., 2018).

Due to the high levels of organic matter and essential elements for plant growth, sewage sludge has considerable advantages for agricultural use (Nobrega et al., 2017; Silva et al., 2020). Potential risks from pathogens may be overcome by inactivation by heating, lime stabilization, or composting. The Brazilian National Commission of Environment (CONAMA, 2020) has recently also included solarization as a way to reduce the pathogenic load through the generation of solarized aerobic sewage sludge (SASS), also known as biosolids (Monteiro et al., 2019; Pereira et al., 2020). Despite the growing concern about emerging contaminants, solar radiation inactivates pathogens while preserving nutrient content, thereby allowing for the creation of substrates for the cultivation of ornamental plants in a viable and environmentally sustainable manner for safe and efficient plant production.

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Under specific conditions, sugarcane bagasse (SB) and rice husk ash (RHA) can also provide benefits to industrial crops, especially for plant growth media that are widely used in protected environments. These compounds can aid in the regulation of processes such as water and nutrient availability, root aeration, and root anchorage, resulting in environmental benefits when compared to traditional disposal practices. Recent studies have demonstrated the ability of sewage sludge combined with locally available residues to provide efficient substrates for improved growth of sugarcane (Silva et al., 2020), acacia (Monteiro et al., 2021), eucalyptus (Manca et al., 2020), tomato (Cristina et al., 2020), and lettuce (Pereira et al., 2020; Monteiro et al., 2020a).

Calendula (*Calendula officinalis*) is cultivated worldwide for its medicinal properties and ornamental potential (Mishra et al., 2018). The flowers are used to produce tea and dermatological products with antitumor (Cruceriu et al., 2020), antimicrobial (Efstratiou et al., 2012), anti-inflammatory (Kiaei et al., 2018), and antioxidant (Escher et al., 2019) activities. The most important commercial use of calendula globally is ornamental, in the form of cut flowers (Chopde et al., 2015). Despite the well-established market, there are no specifications for substrates to this crop, and considering that SASS, RHA, and SB are widely available and represent considerable costs to companies for proper disposal, opportunities have arisen for new products derived from such wastes.

The present study aimed to evaluate the effects of increasing rates of solarized aerobic sewage sludge combined with rice husk ash and sugarcane bagasse on the physico-hydrical characteristics of substrates, and the agronomic performance and ornamental potential of calendula plants.

MATERIAL AND METHODS

Product formulation

Different doses of solarized aerobic sewage sludge (SASS), rice husk ash (RHA), and sugarcane bagasse (SB) were evaluated for substrate formulation. The sewage sludge was collected at the Sewage Treatment Station of Santa Maria, RS, Brazil, belonging to the Companhia Riograndense de Saneamento Sanitation Company (CORSAN). Sludge was obtained from drying beds after sewage treatment in an aerobic reactor with a sludge blanket and forced and prolonged aeration.

The sewage sludge was subjected to solarization, whereby the material was distributed inside fiberglass boxes to form a layer of about 10 cm, in an agricultural greenhouse covered by translucent plastic (150 µm thick) with automated aeration and heating control. The sewage sludge remained in this condition for approximately 45 days until it reached a moisture content of less than 20%. Subsequently, the sludge was crushed and sieved until all particles passed through 8 mm (2 ½ mesh) opening size.

After solarization, a representative sample of SASS was subjected to analysis for the presence and concentration of pathogens, as well as chemical and potentially toxic elements (Table 1). All values were lower than the maximum limits allowed by Normative Resolution Nº 498/2020 (CONAMA, 2020) for the disposal of biosolids in agricultural areas and Brazilian Normative Instruction MAPA Nº 07/2016, which poses maximum limits of contaminants allowed for plant substrates. Thus, the solarization process was efficient in reducing the concentrations of contaminants to levels appropriate for agricultural use, either in pots or containers, or direct disposal in the soil.

TABLE 1. Chemical characteristics of solarized aerobic sewage sludge (SASS), rice husk ash (RHA) and sugarcane bagasse (SB) and maximum limits allowed for sewage sludge by current Brazilian legislations.

Parameters (Total contents)	SASS	RHA	SB [2]	Limits of CONAMA Nº 498/2020 [4]	Limits of MAPA Nº 07/2016 [5]
pH [1]	7.1	8.9	-		
Organic carbon content (%)	29	72.3	53.0		
Nitrogen (TKN) (%)	6.0	0.14	1.00		
Phosphorus (%)	3.0	1.50	0.29		
Potassium (%)	0.48	0.25	0.55		
Calcium (%)	1.8	0.91	0.23		
Magnesium (%)	0.83	1.00	0.15		
Sulphur (%)	0.95	0.41	-		
Copper (mg kg^{-1})	172	101	-		
Iron (%)	3.5	3.10	0.15		
Manganese (mg kg^{-1})	504	1,400	100		
Sodium (mg kg^{-1})	536	480	-		
Aluminum (%)	0.92	0.23	0.55		
Boron (mg kg^{-1})	42	14	-		
CEC (mmol kg^{-1})	573	528	248.4 [3]		
Arsenic (mg kg^{-1})	< 1.72	-	-	41	20
Barium (mg kg^{-1})	246.3	-	-	1300	
Cadmium (mg kg^{-1})	1.37	-	-	39	8
Lead (mg kg^{-1})	26.5	-	-	300	300
Copper (mg kg^{-1})	147.8	101	13	1500	
Chromium (mg kg^{-1})	85.9	-	-	1000	500
Chromium $^{6+}$ (mg kg^{-1})	< 0.172	-	-		
Mercury (mg kg^{-1})	< 0.115	-	-	17	2.5
Molybdenum (mg kg^{-1})	4.37	-	-	50	
Nickel (mg kg^{-1})	25.9	-	3.1	420	175
Selenium (mg kg^{-1})	< 1.72	-	-	100	80
Zinc (mg kg^{-1})	963.2	546	40	2800	

[1] Sample ratio substrate: water = 1: 5.
[2] Source: Figueredo et al. (2017).
[3] Source: Chacha et al. (2019).
[4] Limits for sewage sludge class B established by the Brazilian National Commission of Environment (CONAMA), Normative Instruction Nº 498 of 2020 - Maximum limits allowed in sewage sludge (biosolids) for use in agriculture.
[5] Limits for plant substrates established by the Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA), Normative Instruction Nº 7 of 2016 - Maximum limits of contaminants allowed in plant substrates.

RHA was obtained from a rice processing industry located in Pelotas, Rio Grande do Sul State, Brazil. This residue is the result of burning rice husks to generate thermoelectric power. The RHA was crushed and sieved so that the final size of all particles was standardized to < 4.0 mm and > 0.3 mm size. SB was obtained from mature stalks that were passed through a sugarcane press machine to extract the juice. The bagasse was dried and ground in a knife crusher designed for organic materials and then sieved until all particles passed through 8 mm (2 ½ mesh) opening size. Five substrates with different rates of SASS, RHA, and SB were then formulated (Table 2) to compare with a commercial formulation that consisted of a mixture of agro-industrial organic wastes: seeds, stalks and bagasse of grapes, ash, peat and carbonized rice husk (chemical composition: N: 2.05 g kg^{-1}; P: 1.99 g kg^{-1}; K: 2.61 g kg^{-1}; Ca: 6.32 g kg^{-1}; Mg: 1.90 g kg^{-1}; S: 2.72 g kg^{-1}; Cu: 34 mg kg^{-1}; Zn: 69 mg kg^{-1}; Fe: 5,210 mg kg^{-1}; and Mn: 171 mg kg^{-1}).

TABLE 2. Composition of proposed substrates (mass: mass) based on solarized sewage sludge collected in Santa Maria, RS State, Brazil.

Substrate	Solarized aerobic sewage sludge	Rice husk ash	Sugarcane bagasse
S1	Control: Commercial Substrate		
S2	33.3%	33.3%	33.3%
S3	16.65%	41.67%	41.67%
S4	12.48%	43.76%	43.76%
S5	8.32%	45.84%	45.84%
S6	4.16%	41.07%	54.76%

Physical and hydraulic characterization of the formulated substrates

The following variables were determined at the Soil Physics Laboratory from Embrapa Clima Temperado: wet density (WD), total porosity (TP), aeration space (AS), easily available water (EAW), buffering water (BW), available water (AW) remained water (RW), water retention capacity (WRC) and dry density (DD). The pH was determined with a pH meter in a solution of 1 (substrate): 5 (water); WD and DD were determined by the self-compaction method described by Brazil (2007). The variables TP, AS, WRC, and all other water fractions were considered from the volume of pores from substrate samples occupied by water in equilibrium in the tension table, after being subjected to the following conditions: saturation (TP), 1 kPa (WRC), between the saturation condition and 1 kPa (AS), between 1 and 5 kPa (EAW), 5 and 10 kPa (BW), 1 and 10 kPa (AW), and in equilibrium at 10 kPa (RW) of suction, all determined according to the methods described in De Boodt and Verdonck (1972) and Fermino (2014).

Agronomic performance of calendula plants under controlled conditions

The experiment for agronomic performance of the formulations was conducted in a greenhouse with a controlled environment using calendula ('Bonina Sortida' cultivar). A set of homogeneous seedlings were produced and transplanted 33 days after emergence (DAE) into 2 L pots filled with substrate. The experiment was conducted in a randomized block design with six treatments and five replications, each repetition consisting of the mean of two plants, totaling 30 experimental units. The response variables evaluated for agronomic performance were shoot height (cm), neck diameter (mm), fresh mass of aerial parts (FMAP, g), dry mass of aerial parts (DMAP, g), and number of flower buds.

Visual assessment of ornamental potential

After 60 days of transplantation, or 93 DAE, when the plants were ready for the market, a visual evaluation of the ornamental potential of all the experimental plants was performed by four independent evaluators (potential consumers), who answered an eight question questionnaire regarding the quality and beauty of the plants grown on different substrates with regard to height, stem stiffness, flower shape, number of flowers, flower aroma, composition aroma (pot + plant), general plant visual perception, and commercial potential. For each criterion, scores from 1 to 4 were assigned, corresponding to increasing levels of ornamental quality based on the individual view of each evaluator. The ornamental potential evaluation was performed without identification of plants or substrates and was randomly distributed.

Statistical analysis

The raw data of the physical and hydraulic characteristics of the substrates and the response variables obtained in the evaluation of agronomic performance and ornamental potential were verified for adjustment to the normal probability distribution and the presence of discrepant values. They were then subjected to analysis of variance (ANOVA). When significant differences were observed, the means were compared using the Duncan test ($p<0.05$) with Winstat 2.0 software (Machado & Conceição, 2003).

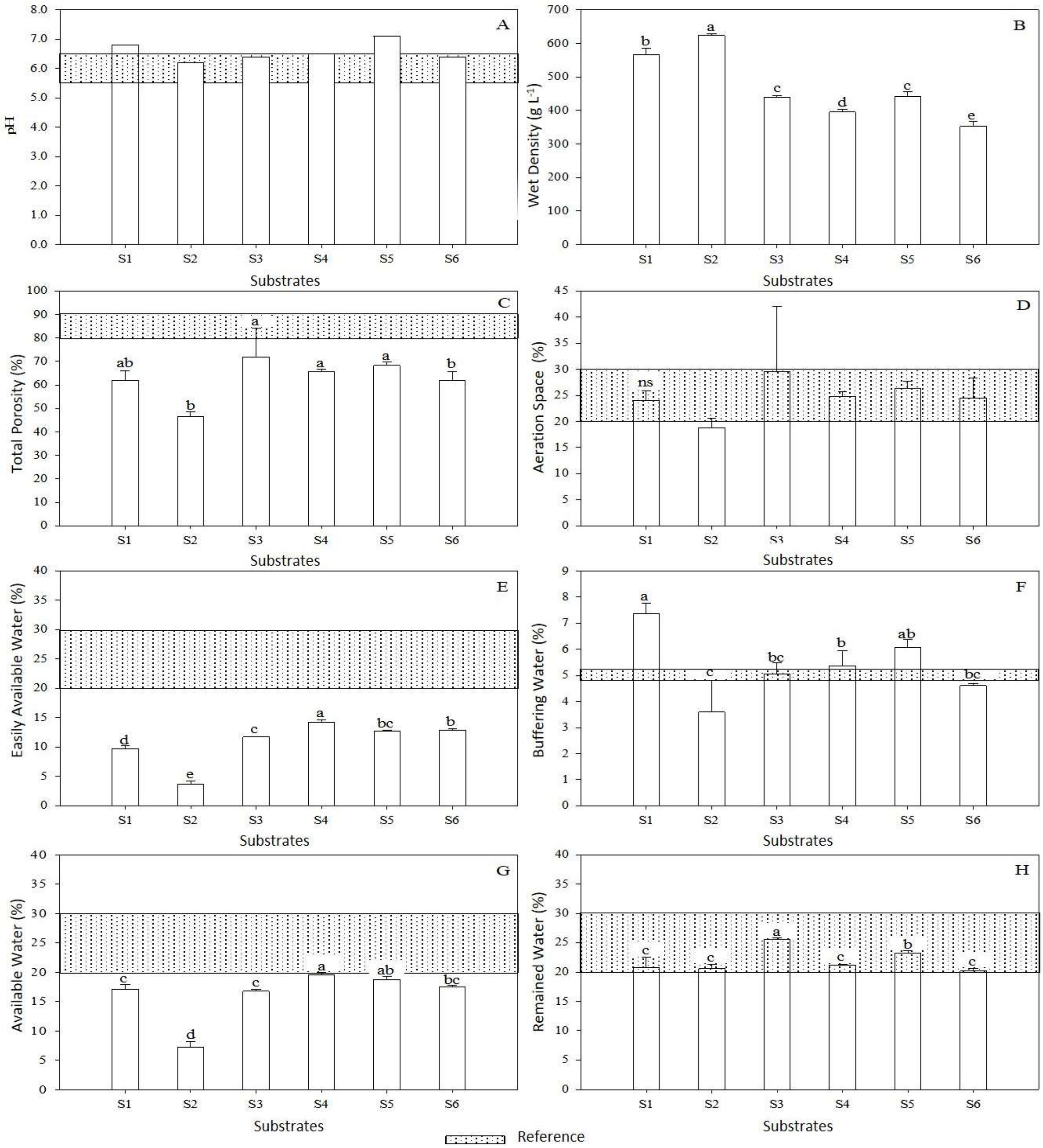
RESULTS AND DISCUSSION

Physical and hydraulic characteristics of substrates

The raw materials used in the formulations significantly influenced the physical composition and water attributes (WD, PT, AS, EAW, BW, AW, and RW) of the substrates (Figure 1). In contrast, the pH (1:5 substrate: water ratio) was not significantly influenced by increasing SASS proportions (Figure 1A).

The ideal pH range for substrates varies according to the species to be cultivated, but the range of 5.5 to 6.5 is considered ideal for most crops to achieve optimal availability of nutrients. This was not the case for substrates S1 (control) and S5, which presented values above 6.5. The pH value of S5 could relate to this substrate having the highest proportion of RHA, which is an alkaline material and an intrinsic characteristic of this raw material (Islabão et al., 2014).

The wet density (WD) decreased as the SASS proportion reduced (Figure 1B). Substrate S2 presented the highest WD, differing statistically from the other formulations, followed by substrate S1 (control). The lowest WD was observed in the substrate with the lowest proportion of SASS (S6: 4.16% SASS + 41.07% RHA + 54.76% SB). The other substrates showed intermediate WD values (Figure 1B).



Means followed by equal letters do not differ statistically from each other by the Duncan test at 5% of probability error. Shaded areas represent the range recommended for substrates, as proposed by De Boodt & Verdonck (1972).
S1: commercial substrate; S2: 33.33% SASS + 33.33% RHA + 33.33% SB; S3: 16.65% SASS + 41.67% RHA + 41.67% SB; S4: 12.48% SASS + 43.76% RHA + 43.76% SB; S5: 8.32% SASS + 45.84% RHA + 45.84% SB; S6: 4.16% SASS + 41.07% RHA + 54.76% SB.

FIGURE 1. Values of pH and physico-chemical characterization of substrates based on solarized aerobic sewage sludge (SASS), rice husk ash (RHA) and sugarcane bagasse (SB).

The highest WD presented by substrate S2 was strongly related to a greater proportion of SASS (33.33%). Trigueiro & Guerrini (2014) reported that a high proportion of sewage sludge in the mixture increases the density of substrates and reduces drainage and aeration, creating an environment that is not conducive to root system development. Density affects the choice of an appropriate substrate, as it prevails over other attributes, such as porosity, available water, and aeration space. By increasing the density, the total porosity is reduced, and over a certain limit, the relationship between the substrate and the plant is modified to restrict root growth.

None of the substrates presented TP values that were considered ideal (from 80 to 90%) when compared to those proposed by De Boodt & Verdonck (1972). The highest TP was observed in substrates S3, S4, and S5, and these substrates did not differ statistically from each other but differed from those of S2 and S6. Substrate S1 (control) presented intermediate TP values but was not statistically different from any of the evaluated formulations (Figure

1C). Similar to the WD, low TP values can negatively affect gas exchange, drainage, and water movement. Therefore, high porosity facilitates aeration of the root system but may result in low water retention capacity (Zorzeto et al., 2014), which produces formulations with poor resilience to water stress.

The AS ranged from 18.77% to 29.63% among the evaluated substrates, which was within the suitable range of 20 - 30% (De Boodt & Verdonck, 1972) for seedling production. With the exception of S2, the other formulations were satisfactory for this physical water variable (Figure 1D). Therefore, the results presented by S3, S4, S5, and S6 may be related to the presence of higher concentrations of RHA and SB, which resulted in formulations with a particle-size distribution that favored larger aeration pore spaces.

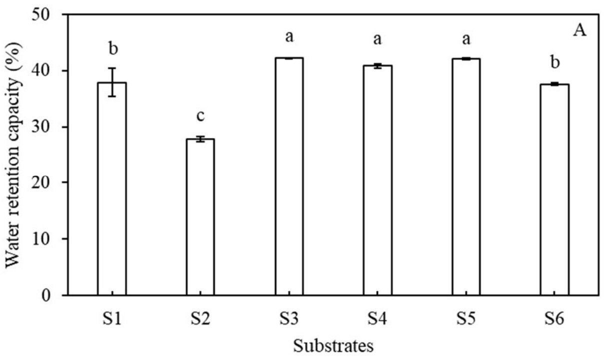
For EAW, none of the substrates achieved the optimal result of 20 - 30% (De Boodt & Verdonck, 1972). The highest EAW was observed for S4 (14.17%), which differed significantly from the other substrates (Figure 1E). However, the EAW represents a narrow interval of water potentials and, therefore, does not constitute a significant reservoir of water for plants. Thus, when the percentage of EAW in the substrate is too high, it is necessary to prolong the interval between irrigations. Therefore, this type of substrate may not be viable for many plant species or for plant nursery managers (Costa et al., 2017).

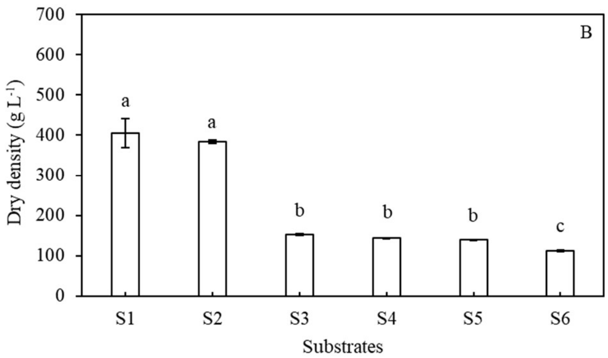
For BW, the literature shows an ideal value of approximately 5% (De Boodt & Verdonck, 1972), which provides an adequate water supply for plants (Figure 1F). Among the analyzed substrates, S3 presented values closer to the ideal and did not differ statistically from those of S4, S5, S6, and S2. The highest BW was observed for substrate S1, which differed significantly from the other substrates. Substrates with a BW close to the recommended level provide an adequate water supply for plants; however, in protected commercial crops, water retained at this pore-size fraction is generally not used, since the plants would be under water stress in this cultivation condition (Zorzeto et al., 2014).

The highest percentage of AW (19.53%) found in substrate S4 (Figure 1G) was close to the lower limit of the range of 20 - 30%, taken as a reference by De Boodt & Verdonck (1972). The smallest fraction of AW was observed in S2 (AW = 7.24%), which was well below the range recommended by those authors. The lower AW value presented by substrate S2 is related to the higher percentage of SASS present in this substrate.

Regarding RW, all evaluated substrates presented values within the range of 20 - 30% (Figure 1H), as recommended by De Boodt & Verdonck (1972). RW is related to water retained at high water tension (above 10 kPa) and is associated with water stored in micropores, thus occupying a large part of the pore space that is desirable for root development. Substrates should be designed to provide sufficient available water to plants, retained under low energy, thus avoiding drought stress or energy losses that would be detrimental for plant growth.

The WRC was higher for intermediate rates of SASS (8.32 to 16.65%). The highest and lowest SASS rates (S2 and S6) had reduced WRCs compared to the other rates (Figure 2). These results probably did not affect calendula development during the experiment, but would benefit S3, S4, and S5 for commercial users by offering better moisture conditions for plant development and avoiding or attenuating drought stress. Nevertheless, all formulations remained between 20% and 80%, which is the recommended range of the WRC for vegetables (De Boodt & Verdonck, 1972).





Means followed by equal letters do not differ statistically from each other by the Duncan test at 5% of probability error. S1: commercial substrate; S2: 33.33% SASS + 33.33% RHA + 33.33% SB; S3: 16.65% SASS + 41.67% RHA + 41.67% SB; S4: 12.48% SASS + 43.76% RHA + 43.76% SB; S5: 8.32% SASS + 45.84% RHA + 45.84% SB; S6: 4.16% SASS + 41.07% RHA + 54.76% SB.

FIGURE 2. Values of water retention capacity (WRC) and dry density (DD) of substrates based on solarized aerobic sewage sludge (SASS), rice husk ash (RHA) and sugarcane bagasse (SB).

The highest rate of SASS resulted in a DD value similar to that of the commercial formulation. Thus, intermediate and lower SASS rates resulted in soft substrates, as observed with formulations S3 to S6. Soft substrates benefit the development of early roots; therefore, calendula can take advantage of formulations with low DD values.

Agronomic Performance

The performance of calendula plants was significantly influenced by the SASS, RHA, and SB substrates. Most of the morphological characteristics, including plant height, neck diameter, and number of flower buds (Table 3) as well as shoot fresh matter and shoot dry matter (Figure 3), showed that intermediate rates of SASS (8.32%, 16.65%, and 33.33%) resulted in the best agronomic performance of calendula plants.

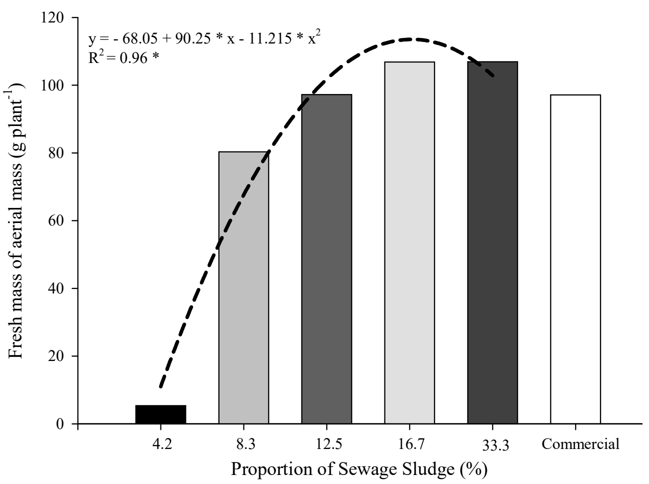
For plant height, neck diameter, and number of buds, the lowest mean values were presented by S6 (4.16% SASS + 41.07% RHA + 54.76% SB), and differed statistically from the other substrates (Table 3). This is possibly related to the low amount of SASS in the S6 substrate, causing low loads of macronutrients, mainly nitrogen and phosphorus (Table 1), which are essential for the development and growth of commercial plants.

TABLE 3. Mean values of plant height, neck diameter and number of flower buds of calendula plants grown on different substrates based on solarized aerobic sewage sludge (SASS), rice husk ash (RHA) and sugarcane bagasse (SB).

Substrate	Plant height (cm)	Neck diameter (mm)	Number of flower buds
S1	35.05 a	9.38 a	9.20 a
S2	35.55 a	8.45 a	5.80 a
S3	38.05 a	9.67 a	9.20 a
S4	37.15 a	9.40 a	9.40 a
S5	30.90 a	8.56 a	4.40 ab
S6	16.15 b	3.38 b	0.00 b

Means followed by equal letters do not differ statistically from each other by the Duncan test at 5% probability of error. S1: commercial substrate; S2: 33.33% SASS + 33.33% RHA + 33.33% SB; S3: 16.65% SASS + 41.67% RHA + 41.67% SB; S4: 12.48% SASS + 43.76% RHA + 43.76% SB; S5: 8.32% SASS + 45.84% RHA + 45.84% SB; S6: 4.16% SASS + 41.07% RHA + 54.76% SB.

In general, there was an increase in FMAP and DMAP production with increasing SASS dose (Figure 3). Both variables followed a quadratic model (R^2 = 0.96, $p<0.05$, and R^2 = 0.99, $p<0.01$), adjusted as a function of increasing SASS in the formulation. This result is related to the greater capacity of SASS to supply N, P, Ca, Mg, S, and micronutrients (Table 1), while the physical-hydraulic characteristics were maintained at the optimal interval. Monteiro et al. (2019) and Monteiro et al. (2021), when evaluating the chemical characteristics of substrates with different doses of sewage sludge and carbonized rice husks, found that the amount of nutrients increased with an increase in the percentage of sewage sludge in the substrate. Many studies addressing the use of sewage sludge in agriculture state that it is a source of nutrients in substrates, particularly P, N, and Ca (Guerrini & Trigueiro, 2004; Santos et al., 2014; Monteiro et al., 2020b).



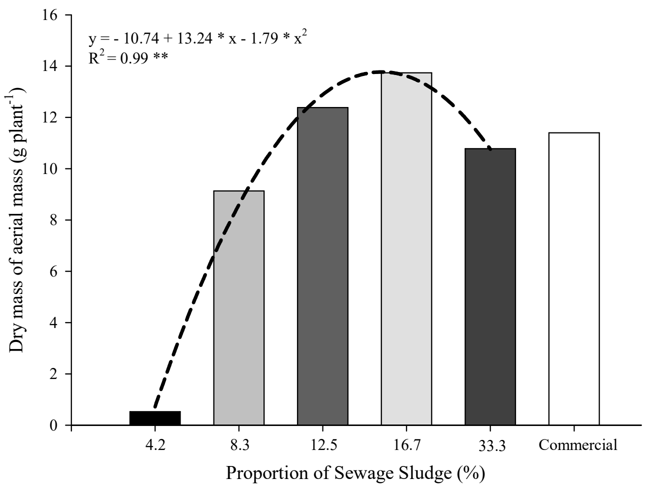


FIGURE 3. Fresh and dry mass of aerial parts (FMAP and DMAP) of calendula plants grown on substrates formulated with solarized aerobic sewage sludge (SASS), rice husk ash (RHA) and sugarcane bagasse (SB).

No significant differences were observed between S1 and S5 in terms of plant performance (plant height and neck diameter). A low performance was shown by S6, at a lower rate of SASS. This reinforces the role of SASS as a nutrient source for calendula as observed with S3 and S4, which presented a number of flower buds that was similar to that of the commercial plant. The number of flower buds is of great commercial importance for the architecture and beauty of plants. In summary, plants grown on commercial substrates and formulations with SASS doses ranging from 8.32% to 33.3% obtained satisfactory results, particularly those with 16.65% (S3).

There is a diversity of results in the literature regarding the effects of sewage sludge rates on the productivity of different types of plants, which can be related to the chemical and physical characteristics of each sludge type, as well as the nutritional requirements of each species. The sewage treatment, sludge disinfection, and drying processes are also crucial aspects that affect the composition and behavior when mixed with other raw materials to compose substrates.

Faria et al. (2013) evaluated the use of organic residues in the growth of *Mimosa setosa* seedlings, where substrates formulated with sewage sludge, carbonized rice husk, and fresh coffee straw in a ratio of 8: 1: 1 provided the best results for the morphological characteristics of plants. Silva et al. (2020) evaluated the development of sugarcane seedlings (*Saccharum officinarum*) and found that media formulated with equal proportions of solarized sewage sludge, rice husk ash, and vermiculite showed the best agronomic performance, while high doses of solarized sewage sludge (87.5%) caused damage to the initial development of seedlings.

In contrast to the results obtained in the present study, Siqueira et al. (2019), when evaluating the use of treated sewage sludge in the substrate composition of

Plathymenia reticulata seedlings, found that the lowest proportion of sewage sludge (20%) in then two mixtures tested was the most suitable for the evaluated crop, with growth patterns similar to those produced with commercial substrates. Similar results were found by Monteiro et al. (2019), who evaluated the effect of increasing proportions of SASS on the water retention of substrates and the agronomic performance of black wattle (*Acacia mearnsii*) seedlings. The substrate with 20% SASS, 40% vermiculite, and 40% rice husk ash presented the best physical-hydraulic conditions for the development of black wattle seedlings in the period from germination to transplantation.

Based on the data obtained in this study, particularly the results of FMAP and DMAP, it can be suggested that proportions of 12.48% (S2) to 16.65% (S3) of SASS in the substrate result in the best agronomic performance for calendula production.

Evaluation of ornamental potential

The mean scores attributed to the ornamental quality characteristics by the evaluators are presented in Table 4. Regarding the height and stiffness variables, treatments S1 - S5 presented high potential, in which treatments S1, S3, and S4 were highlighted. Regarding leaf shape (related to their visual effect on the composition of the plant), the S2 treatment presented low ornamental potential; that is, the plants cultivated in S2 presented superior shoot development to the others. Despite the significant load of nutrients present in mixture S2, this formulation resulted in plants with large amounts of leaves and branches, causing disharmony and impairing their visual effect. The lower values attributed by the judges to S6 are probably due to the fact that plants grown in this substrate have incomplete development caused by a lack of nutrients.

TABLE 4. Ornamental quality characteristics of calendula plants grown on commercial substrate, on different sewage sludge-based substrates, and a commercial plant taken as reference.

Substrate	Height	Rod stiffness	Leaf shape	Flowers	Flowers Aroma	Aroma pot + plant	General perception	Commercial potential
S1	3.30	3.50	3.05	3.05	2.50	2.35	3.20	3.10
S2	2.55	2.75	2.05	1.90	2.00	1.95	2.15	1.70
S3	3.05	3.35	2.80	3.00	2.35	2.25	3.05	3.00
S4	3.30	3.40	2.65	2.85	2.35	2.25	3.00	3.00
S5	2.65	3.25	2.65	2.35	2.00	2.00	2.55	2.40
S6	1.05	1.95	1.15	1.00	2.00	2.00	1.05	1.00

Scores: for values above 3.25 points - *high* ornamental potential (excellent); from 2.51 to 3.25 points - *medium* ornamental potential; from 1.76 to 2.50 points - *low* ornamental potential; and less than 1.75 points - *minimum* ornamental potential.
S1: commercial substrate; S2: 33.33% SASS + 33.33% RHA + 33.33% SB; S3: 16.65% SASS + 41.67% RHA + 41.67% SB; S4: 12.48% SASS + 43.76% RHA + 43.76% SB; S5: 8.32% SASS + 45.84% RHA + 45.84% SB; S6: 4.16% SASS + 41.07% RHA + 54.76% SB.

For the variables "flowers" (which evaluates the beauty and number of buds), "general perception" (height, size, flowers, and stiffness) and "commercial potential" of the plants, treatments S1, S3, and S4 presented the most satisfactory results. These variables are extremely important for the commercial evaluation of the product. Improved results in the ornamental characteristics of calendula plants should be directly related to the balance of the physical-water characteristics and chemical composition, and their maintenance within the recommended ranges, considering a narrow range and balancing of the components of the formulations.

For the variables of inflorescences and pot plus plant composition aroma, all treatments yielded unsatisfactory results. However, the aroma present in plant flowers is an intrinsic characteristic of each culture; therefore, it was not directly related to the plant growth media evaluated in the present study. The characteristic aroma of calendula flowers is associated with the presence of sesquiterpenes in the volatile fraction (Reznicek & Zitterl-Eglseer, 2003), which are hydrocarbons found in plants and insects as defense agents or pheromones.

Overall, the ornamental potential of the treatments based on intermediate rates of SASS (S3 and S4) surpassed that of the commercial substrate used as a control (S1), thus demonstrating the potential use of innovative substrates based on SASS and agro-industrial residues for ornamental species. Among the raw materials and substrate formulations that were characterized, developed, and evaluated, those with intermediate proportions of SASS (S3: 16.65% SASS + 41.67% RHA + 41.67% SB; and S4: 12.48% SASS + 43.76% RHA + 43.76% SB) presented the best results for agronomic performance and ornamental quality of potted calendula.

CONCLUSIONS

The combination of solarized sewage sludge with agro-industrial wastes (sugarcane bagasse and rice husk ash) evaluated in this study was efficient for formulating substrates for calendula plants under controlled conditions.

For the successful use of organic raw materials (SASS and agro-industrial wastes) as substrates for calendula production in pots, a set of physical and chemical characteristics should be observed, selecting formulations that fall under the recommended ranges.

Adjustment of substrate composition and maintenance of physical and hydraulic characteristics of substrates under optimal ranges were determinants of agronomic performance and ornamental potential of calendula plants.

For the efficient production of calendula in pots, S3 (16.65% solarized aerobic sewage sludge + 41.67% rice hush ash + 41.67% sugarcane bagasse) and S4 (12.48% solarized aerobic sewage sludge + 43.76% rice hush ash + 43.76% sugarcane bagasse) presented the best physical and hydraulic conditions, resulting in higher ornamental potential, and are therefore recommended. Proportions of solarized aerobic sewage sludge larger than 16.65% or smaller than 12.48% provided lower or insufficient plant development and ornamental quality of calendula plants.

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