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Yield of chamomile capitula and essential oil in competition with weeds in different spacings and sowing dates

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Abstract

Chamomile is an important socioeconomic option for family farming. Its cultivation involves manual management practices and herbicide use restriction, and knowledge regarding weed interference on the yield of chamomile capitula and essential oil quality is still limited. In this perspective, this study aimed to assess the effect of sowing dates, plant spacings, and hoeing management on the yield of chamomile capitula, essential oil yield, and essential oil content under the environmental conditions of a region with a Humid Subtropical climate without defined seasons. The experiments were conducted on four dates (March 18, March 28, June 31, and August 30, 2017, with plants spaced 0.05, 0.10, 0.15, 0.20, 0.30, and 0.40 m within rows. On March 28 and May 14, 2018, the spacings between plants in the row were 0.05, 0.10, 0.15, and 0.20 m, including two hoeing managements (with and without weeds). The variables analyzed in the two years were the yield of dry capitula, the dry mass of chamomile plants and weeds (g m^{-2}), and the content and yield of essential oil in 2018. The sowing dates influenced the yield of floral capitula, the essential oil content, and the essential oil yield as a function of the duration of the cycle and weed occurrence. The autumn sowings resulted in a higher yield of floral capitula in both years. A linear reduction trend was also verified in the yield of floral capitula with the increase in plant spacing within the row from 0.05 to 0.20 m in the two crop years.

Keywords: *Chamomilla recutita*, Plant population, Meteorological conditions, Yield

Introduction

Chamomile [*Chamomilla recutita* (L.) Rauschert] is a medicinal, aromatic, and spice plant distributed along the subtropical and temperate areas of the globe. It has great socioeconomic importance in family farming, constituting an additional source of income for several rural properties (Corrêa Júnior & Schaeffer, 2014; Salimi et al., 2016). The species usually constitutes a second crop option, with a recent and growing production that still lacks more reliable technical information on its cultivation in order to supply the demand for flowers and essential oil (Upadhyay et al., 2016; Otto et al., 2015). In Brazil, the yield of chamomile capitula and essential oil is highly variable depending on the region of cultivation, sowing time, and management practices employed (Santos et al., 2015; Roza et al., 2016; Silva et al., 2020).

Chamomile has a slow early growth (Singh et al., 2011; Mohammad, 2011), leaving the soil uncovered for a period that favors weed growth. Thus, a low ability to compete against weeds is attributed to this crop (Silva Jr, 1997) in addition to the high demand for human resources, requiring several hoeing interventions throughout the crop cycle (Singh et al., 2011). Herbicide application is an improper management practice for medicinal, aromatic, and spice species since the main destination of final products is their consumption as phytotherapeutic products and teas. Herbicide use can directly affect essential oil quality by reducing the desirable compounds and leaving residues (Reichling, 1980).

The knowledge of the minimum plant population to be established based on the management of plant distribution and spacing can result in higher yields and reduce the negative effects of weed competition (Amaral et al., 2012), increasing the competitive ability of the crop in addition to potentially reducing the human resources required for hoeing. For chamomile,

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the recommended spacing between rows and plants varies from 0.20 to 0.60 m (Martins et al., 2000; Ramos et al., 2004). However, there are still no technical guidelines standardizing the ideal spacing between plants in order to achieve the maximum production potential and greater competitiveness against weeds. Furthermore, the spacing between rows should also allow an easier and, if possible, mechanized hoeing.

The sowing time is a management practice that interferes with the yield of floral capitula and the essential oil of aromatic plants, with the biosynthesis of essential oils being directly related to meteorological factors, which can determine the ideal place of cultivation and time of harvest (Mohammad et al., 2010; Silva et al., 2020). This factor is also directly related to weed occurrence since its favorability can potentialize the effect of other management practices for weed control.

The change in the spacing between plants and the establishment of a sowing time that favors the early growth of chamomile to the detriment of weeds should be considered when growing this crop. These factors can reduce weed incidence and the need for human resources for hoeing, minimizing adverse effects to the yield of capitula and essential oil of high commercial quality. Therefore, this study aimed to evaluate the yield of floral capitula, the essential oil yield, and the essential oil content of chamomile as a function of two hoeing treatments, plant spacing, and sowing dates.

Material and Methods

Characterization of the experimental site

The experiments were conducted in a region with a Humid Subtropical climate, with hot summers and no defined dry season (Cfa) according to the Köppen classification, in Santa Maria - RS, Brazil (29°43'23"S; 53°43'15''W; 95 m a.s.l.), where the rainfall regime is well-distributed, with an annual mean of 1,712 mm (Buriol et al., 2006). The predominant soil class in the experimental area is the sandy Dystrophic Red Oxisol (Streck et al., 2008).

Treatments

In 2017, sowing was performed on March 18, April 28, June 30, and August 31 using the spacings of 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, and 0.40 m between plants in the row and 0.30 m between rows, corresponding to the densities of 66, 33, 22, 16, 13, 11, and 8 plants m^{-2}. The experiment was organized in a completely randomized design in a two-factor factorial arrangement with four replications, totaling 112 experimental units. A single initial hoeing intervention was performed along with the thinning of excess plants 40 days after plant emergence.

In 2018, sowing was performed on March 28 and May 14 by testing four spacings between plants in the row (0.05, 0.10, 0.15, and 0.20 m) and a 0.30 m spacing between plant rows, constituting the densities of 66, 33, 22, and 16 plants m^{-2} to test the four treatments that showed the best results in 2017. Two hoeing managements were included, with an initial weed hoeing being performed along with the thinning of excess plants. In addition to these two practices, two hoeing interventions were performed throughout the cycle, allowing the crop to grow on clean soil. The experiment was organized in a completely randomized design in a three-factor factorial arrangement with four replications and 64 experimental units.

All experimental units in the two years consisted of four plant rows with 1.2 m width and 4.0 m length, comprising a total area of 4.8 m² and a usable area of 2 m², not considering the edges.

Installation and conduction of the experiments

The chamomile cultivar Mandirituba was used, which was improved by selection conducted by farmers to adapt the crop to the conditions of the region of Mandirituba-PR (Corrêa Júnior, 1995). Conventional soil preparation was performed, with plowing and harrowing, aiming at leveling the soil surface. Sowing was performed manually and superficially in a straight line, along with fertilization calculated based on soil analysis and the requirement of the crop (CQFS-RS/SC, 2016). An irrigation system with drip tubes was installed along the sowing rows to provide supplementary irrigation whenever necessary in addition to rainfall, aiming at preventing the adverse effects of an eventual water deficit. No pest insects or disease incidence were observed in any of the experiments.

Meteorological variables

The daily data on maximum and minimum air temperature, rainfall, and solar radiation in 2017 and 2018 were obtained from the database of the Automatic Weather Station of Santa Maria, belonging to the 8th District of the National Meteorology Institute (INMET), located at 30 meters from the edge of the experimental area.

Variables analyzed

Observations were made throughout the following phenological stages: emergence – EM, beginning of flowering – IF (50% of plants with at least one open flower capitulum), full bloom – PF (75% of plants with open capitula), and physiological maturation - MAT (95% of plants with brown-colored inflorescences. After the beginning of flowering, floral capitula were harvested from 1.60 linear meters (0.48 m^2) every 20 days, with the number of harvests varying from two to five, depending on the sowing date. The floral capitula were manually collected when the flowers with ligule were open horizontally. Subsequently, the capitula were put in paper bags and dried in a forced-air oven at 60 °C until the samples reached constant weight. The floral capitula were then weighed in an analytical balance accurate to 0.001 g to determine the dry mass. The dry mass values were extrapolated to the dry mass yield of floral capitula in kg ha^{-1}.

The extraction of essential oil was performed for the two growing periods in 2018 by separating and weighing about 60 grams of fresh floral capitula in each treatment (depending on the availability of the harvested material), with four replications, totaling 64 samples from which the essential oil was extracted by hydrodistillation. For this extraction, a Clevenger apparatus was coupled to a round-bottom volumetric flask and heated by a heating mantle with a thermostat for approximately 2 hours and 30 minutes at 100 °C. The essential oil samples extracted were weighed to determine the yield and production of essential oil. The yield of each plot was determined by the dry mass of floral capitula summed to the fresh mass used to extract the essential oil multiplied by the ratio between the dry and fresh mass. Thus, the fresh mass used to extract the oil was transformed into dry mass after determining the moisture of each sample that went to drying. The essential oil content was obtained based on the relationship between the mass of the essential oil extracted and the mass of the sample from which the oil was extracted already transformed into dry mass. The yield of the floral capitula was multiplied by the essential oil content to calculate the essential oil yield.

The dry mass of chamomile plants and weeds was determined by collecting the plants in full bloom - PF (75% of open capitula). The area of the harvested samples was delimited with the aid of a 0.30 m x 0.60 m rectangle (area = 0.18 m²) placed randomly on the usable area of the plot, cutting the plants close to the soil to obtain the shoot dry mass. The collected material, both chamomile and weeds, was put in paper bags and dried in a forced-air oven at 60 °C until reaching constant weight. Subsequently, the samples were weighed in a precision balance accurate to 0.001 g and the values were extrapolated to g m^{-2}.

Results analysis

The data on the dry mass of floral capitula, essential oil yield, and essential oil content were subjected to the test for error normality by applying the Shapiro Wilk test and homogeneity of variances by the Bartlett test, both using the software Action® 2.5. When necessary, the Box-Cox methodology was used for appropriate data transformation to meet the assumptions of the mathematical model. The means of the transformed variables were shown in the results with the original values. The data were subjected to analysis of variance by the F-test at 5% probability with the aid of the software Sisvar® (Ferreira, 2011). When significant, the qualitative variables were compared by the Scott-Knott test, while the quantitative variables were subjected to regression analysis.

Results and Discussion

The different sowing dates exposed the crop to different meteorological conditions, especially maximum and minimum air temperature, solar radiation, and rainfall in the two crop years (Figure 1A and 1B). In 2017, the maximum air temperatures were higher than those recorded in 2018. In 2017, maximum temperatures above 30°C were recorded throughout the cycle of the plants for all sowing dates, which may have negatively influenced chamomile development, especially in the flowering period (Timothy & Mwang, 2015).

The year 2017 had, overall, more continuous rainfall events along with greater oscillations of maximum and minimum daily air temperatures, resulting in greater interference on chamomile development and better environmental conditions for the occurrence of weed species.

Although the experiment obtained a high CV (Table 1) due to the high plant heterogeneity, the dry mass yield of floral capitula in 2017 showed a difference between the different plant spacings and sowing dates, allowing us to verify that the yield is highly correlated with environmental conditions. In the coexistence with weeds, the April sowing resulted in a mean yield of 611.61 kg ha^{-1}, not differing from the sowing performed in March, with a similar yield of 581.96 kg ha^{-1} (Table 1). The two yields obtained were superior to the national mean of 500 kg ha^{-1} (Corrêa Júnior & Taniguchi, 1992).

The mean yield value obtained on the four sowing dates is similar to the mean yields of dry floral capitula obtained by Amaral et al. (2014) and Nalepa and Carvalho (2007) by maintaining hoeing throughout the cycle and with sowing performed in July in Piraquara (499.6 kg ha^{-1}) and Campo Magro (471.8 kg ha^{-1}), Paraná.

Likewise, this value is similar to the yields of dry chamomile capitula of 451 kg ha^{-1} and 615 kg ha^{-1} obtained by Roza et al. (2016) and Santos et al. (2015) in São José dos Pinhais-PR with sowing performed in May.

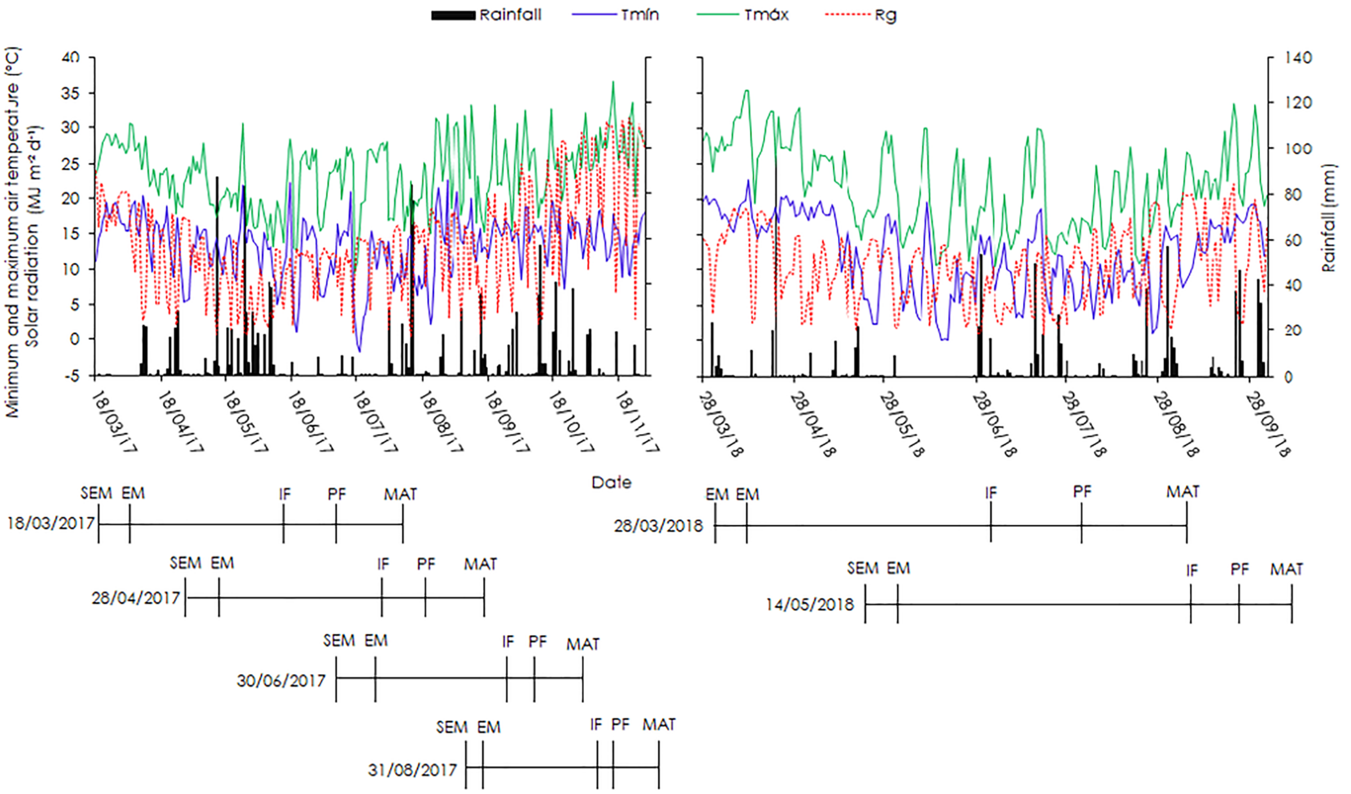

Figure 1. Minimum (Tmin; °C) and maximum daily air temperatures (Tmax; °C), solar radiation (Rg; MJ m^{-2} day^{-1}), and rainfall (rain; mm) from March 18 to November 30, 2017 (A), and from March 28 to October 3, 2018 (B), and ontogeny of chamomile plants sowed on different dates in Santa Maria - RS. (SEM = sowing; EME= emergence; IF= beginning of flowering; PF= full bloom; MAT= physiological maturation).

Table 1. Mean yield of chamomile capitula (kg ha^{-1}) on different sowing dates in autumn/winter 2017, in a Humid Subtropical climate in Santa Maria, RS.

Sowing date	Capitula yield
18/03/2017	581.96 a*
28/04/2017	611.61 a
30/06/2017	357.40 b
1/08/2017	106.17 c
Mean	418.09
CV (%)	39.52

*Means followed by the same letter in the column do not differ statistically by the Scott-Knott test at 5% error probability.

The yield of the floral capitula decreased significantly as sowing was delayed, with a reduction of more than 41% from the April sowing to the June sowing and 83% from April to August. According to Mohammad et al. (2010), the sowing date strongly influences the growth and yield of chamomile plants, and sowing anticipation in order to make the plant cycle coincide with lower air temperatures results in better growth and higher crop yield. Therefore, this response trend is mainly related to the extension of the crop growth period in environments with lower air temperatures, such as in Belgium, which has a temperate climate (Mohammad et al., 2010). The highest yields of floral capitula obtained from March to April may be related to the lower air temperature oscillation verified during the cycle of the plants sowed on these dates, especially in the flowering subperiod, which comprised the months when the maximum and minimum temperatures were lower compared to the remaining sowing dates (Figures 1A and 1B). In turn, the reduction in the yield of the floral capitula with the delay in sowing is linked to the higher occurrence of high air temperatures in the reproductive period, leading to the shortening of the cycle and favoring weed growth.

Silva et al. (2020) obtained, in the central region of Rio Grande do Sul, yield values above 800 kg ha^{-1} of dry floral capitula with sowing dates from March to April, keeping the crop on clean soil through hoeing. For the sowings performed in the winter period, the yield reduction was only 16% for the sowing performed in June, while no yield difference was confirmed for the sowing performed in August. Thus, the yield of floral capitula varied according to the date of cultivation, being associated with variations in the meteorological conditions as well as with weed occurrence, depending on the weed species present, the time of cultivation, soil management, and the integration between all factors (Manalled et al., 2001).

Even with the reduction in the yield of the floral capitula, it is possible that chamomile cultivation, for sowing dates from March to April in the central region of Rio Grande do Sul, can be implemented as an additional income alternative in the property. In these months, the yields of dry floral capitula of 666.9 and 509.5 kg ha^{-1}, obtained in the spacings of 0.50 and 0.10 m, respectively (Figure 2A and 2B), are sufficient to generate economic return since there is no need for a great number of hoeing interventions with plant densification in the row.

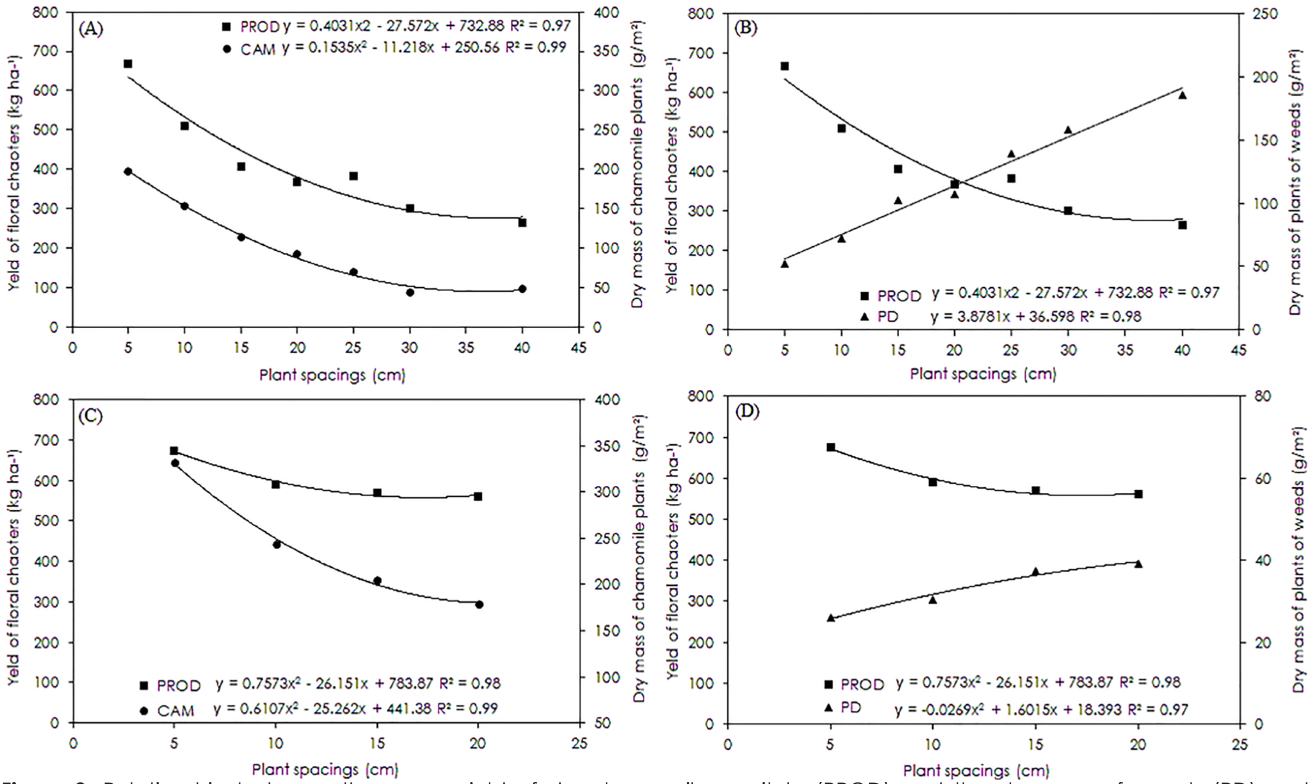

Figure 2. Relationship between the mean yield of dry chamomile capitula (PROD) and the dry mass of weeds (PD) and chamomile plants (CAM) in the flowering subperiod, in different spacings between plants in the crop years of 2017 (A and B) and 2018 (C and D) in Santa Maria – RS.

The yield decrease observed in the wider plant spacings compared to the smaller ones is possibly due to the greater weed competition when performing only one initial hoeing associated with the lower plant density, implying fewer capitula per area. Thus, there was a positive linear relationship between the mean yield and the dry mass of chamomile plants in the PF-MAT subperiod; in other words, the higher yield of floral capitula was directly related to the higher number of plants per area as well as the lower competition of weed species since, in the smaller spacings, the dry mass of weeds was lower (Figure 2). Kwiatkowski et al. (2020), with organic chamomile cultivation in Poland, studying the cultivars “Złoty Łan” and “Mastar” and the between-row spacings of 0.30 and 0.40 cm, verified a lower incidence of total weeds in the smaller plant spacing tested. The relationship between the mean yield of the floral capitula and the dry mass of weeds was inverse or conditioned by the lower competition ability of chamomile. The increase in plant spacing resulted in a higher dry mass of weeds. The association between the highest number of weeds and the lowest dry mass of chamomile plants per area resulted in a lower yield of floral capitula (Figure 2A and 2B).

The higher yield of floral capitula obtained in the smaller plant spacings can be explained by the faster closure of the chamomile canopy, which decreased the flow of solar radiation within the canopy and on the soil surface, disfavoring weed growth and development. Ramos et al. (2004) found different responses when testing five different spacings between chamomile plants, cv. Mandirituba, obtaining the highest yield of floral capitula in the smallest plant spacing (0.11 m between plants in the row and 0.27 m between plant rows), with a total yield of 1,080 kg ha^{-1} in Dourados – MT. Silva et al. (2020), testing different plant spacings, obtained the highest yield of floral capitula in the 0.10 m spacing, which was above 600 kg ha^{-1} in the period from March to April 2017, keeping the crop free of weeds. The fact that the highest yield of the floral capitula was obtained in the smaller spacings indicates that the competition between chamomile plants occurred within an acceptable level, with no negative effects on plant growth and development as to affect the yield significantly. However, the reduction in the yield is related to weed occurrence throughout the crop cycle since a single initial hoeing was performed.

The yield of the floral capitula, the essential oil content, and the essential oil yield of chamomile showed no interaction between the factors of sowing date, plant spacing, and weed management in 2018. However, the capitula yield and the essential oil content and yield showed differences in relation to the sowing date. For the spacing between plants, only the yield showed a significant difference. For the management factor (with and without weeds), no significant statistical difference was observed for any of the variables analyzed. The mean yield of the floral capitula was 602.9 kg ha^{-1} in the hoed management (without weeds) and 595 kg ha^{-1} when hoeing only once (with weeds), indicating that one initial hoeing is sufficient to prevent significant weed competition.

The maximum yield of floral capitula in 2018 was obtained when sowing was performed on March 28 (968.00 kg ha^{-1}), differing from the sowing performed on May 14, with a mean of 230.5 kg ha^{-1} (Table 2). The air temperature means in the two subperiods (IF-PF and PF-MAT), which were lower in 2018 (Figure 1), can explain the highest capitula yield obtained with the sowing performed on March 28. The lower air temperatures from IF to PF kept weed development under unfavorable conditions. On the other hand, it favored chamomile, which showed faster initial growth and a higher production potential than that obtained in the previous year. These values were also higher than that reported by Silva et al. (2020), who verified more than 800 kg ha^{-1} for the same region. Matsushita et al. (2018), sowing the cultivar Mandirituba in May 2015 in Pinhais – PR, also obtained a capitula yield of 800 kg ha $^{-1}$.

Table 2. Yield of dry floral capitula (kg ha^{-1}), essential oil content (%), and essential oil yield (kg ha^{-1}) of chamomile sown on different sowing dates in autumn/winter in a Humid Subtropical climate in Santa Maria, RS.

Sowing date	Capitula yield	Essential oil content	Essential oil yield
March 28, 2018	968.00 a*	0.53 a	5.03 a
May 14, 2018	230.50 b	0.67 b	1.50 b
Mean	599.00	0.60	3.26
CV (%)	23.55	18.90	16.93

*Means followed by different letters in the column differ significantly by the Scott-Knott test at 5% error probability

The essential oil content was 20.9% higher on May 14, obtaining 0.53% and 0.67% for the two sowing dates, respectively, higher than the 0.4% minimum oil content established by the Brazilian Pharmacopoeia (Corrêa Júnior, 1994), demonstrating that it is possible to obtain good quality oil in a Subtropical climate. This result can be associated with the lower air temperature during the reproductive subperiod (IF-PF), with the maximum temperature peak lower than 30°C and lower rainfall in the reproductive stage, allowing the harvest of floral capitula to occur at the most appropriate time. Seidler-Lozykowska (2010) showed that high air temperatures and intense solar radiation had a negative effect on the essential oil content when cultivating chamomile in Poland, which probably occurred in this experiment, according to the present results.

Amaral et al. (2014) stated that, for the cultivar Mandirituba, the age of the floral capitula at harvest is determinant for the essential oil yield. In a harvest performed 85 days after emergence, the essential oil content was 0.44%, whereas, at 113 days after emergence, it was 0.16%, suggesting better quality in the first harvests. Therefore, the mixture of floral capitula from different harvest moments, with the last ones performed toward the end of the crop cycle, on the first sowing date, may have resulted in lower essential oil content. It should be noted that the number of harvests performed differed for each sowing date, with five for the first date (March 28, 2020) or in several moments of the reproductive period. In turn, for the second sowing date (May 14, 2020), there were only two harvests, which may have resulted in harvests at more appropriate moments. The sample for oil extraction, due to resource limitation, consisted of a mixture of floral capitula obtained from each of the five and two harvest moments on the first and second sowing dates, respectively.

No statistical difference was verified for the plant spacing and weed management factors, with a mean essential oil content of 0.6% for plant spacing and weed management. Hadi et al. (2004) also observed no significant statistical difference in the essential oil content when testing different plant spacings, except for the sowing date. Other studies, such as those by Napela and Carvalho (2007), testing different levels of poultry litter, and Mapeli et al. (2005), testing different levels of phosphorus and nitrogen, also verified no variation in the essential oil content with the variation in fertilization. The variations related to plant management, such as plant spacing, fertilization, and hoeing, either did not influence or little influenced the essential oil content of chamomile. Thus, the meteorological conditions, especially air temperature throughout the crop cycle in the IF-PF subperiod, are factors that lead to greater alterations in the essential oil content, allowing or not the occurrence of favorable conditions in order to obtain the minimum essential oil content required for the commercialization of dry chamomile capitula.

The essential oil yield varied according to the sowing date and plant spacing. According to Matsushita et al. (2017), the yield of floral capitula and the essential oil content reflects directly on essential oil production. The yield of the floral capitula (968 kg ha^{-1}) was higher for the first sowing date in relation to the second date (230.5 kg ha^{-1}), while the essential oil content had a difference of only 21% from the second to the first date, not compensating the higher essential oil yield in relation to the first sowing date (March 28) due to the lower capitula yield. In practice, it means that the industry should pay more for later harvests due to their better quality in order to encourage producers to extend the supplying period of raw material despite the lower yield, thus reducing the seasonal idleness of the oil-extracting infrastructure.

Regarding plant spacing, a reduction in the essential oil yield was verified with the increase in plant spacing in the row. The higher mean yield of essential oil (4.00 kg ha^{-1}) obtained in the smallest plant spacing (Figure 3) is similar to the values found by Hadi et al. (2004), who obtained higher essential oil yields at the lowest sowing densities tested (0.5 x 0.2 m and 0.5 x 0.3m). Even not observing a significant statistical difference in plant spacing for the yield of the floral capitula in the crop year of 2018, the mean yield was 674 kg ha^{-1} in the 0.05 m spacing, whereas, with the largest plant spacing (0.2 m), it was 561 kg ha^{-1}, demonstrating that smaller spacings result in higher flower and essential oil yields.

Reduced plant spacings in chamomile cultivation could constitute an alternative for the rural producer to increase the production yield and reduce the human resources involved in hoeing and harvest management due to the higher plant homogeneity. It allows making better use of the soil and optimizing production with the offer of a quality product to the market, as a higher content of impurities due to the presence of parts of other plants devalues the product in the market.

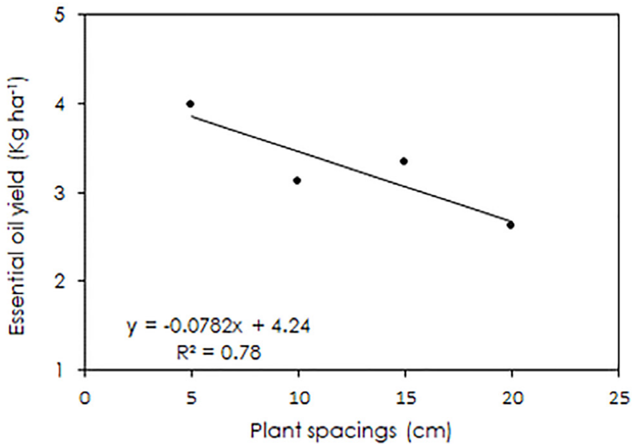

Figure 3. Essential oil yield of chamomile (kg ha^{-1}) in different plant spacings in rows spaced 0.3 m, in autumn 2018, in a Humid Subtropical climate conditions in the Central region of Rio Grande do Sul.

Autumn sowing exposes the chamomile crop to meteorological conditions more favorable to plant growth than later sowing. The crop production potential is defined by air temperatures, mild or not, especially in the vegetative period and in the IF-PF subperiod, in terms of oil content. Rainfall at flowering and the availability of solar radiation throughout the crop cycle are also important for production. The yield also depends on the management applied in view of the number of hoeing interventions performed in years of atypical and milder meteorological conditions, influencing weed occurrence. Small plant spacings serve as important management complements, favoring plant growth harmony and preventing weed growth and survival.

More appropriate management implies greater environmental conservation in view of the issues faced with herbicide use in agricultural cultivation. Agrochemical-free activities in chamomile cultivation expose the worker to better conditions of welfare and working safety.

Conclusions

The sowing date and plant spacing influence the yield of dry floral capitula, the essential oil content, and the essential oil yield of the chamomile cultivar Mandirituba under Humid Subtropical conditions in the central region of the state of Rio Grande do Sul.

Autumn sowings, such as those performed on March 18, 2017, April 28, 2017, and March 28, 2018, resulted in higher yields of floral capitula compared to winter sowings, which resulted in a shorter cycle.

The essential oil content in the Humid Subtropical climate keeps above the minimum required for commercialization regardless of the sowing date, plant spacing, and hoeing management.

Smaller plant spacings (0.05, 0.10, 0.15, and 0.20) allow the satisfactory production of chamomile capitula even with a greater presence of weed species.

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