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# Alternative substrates for the production of container-grown Mexican cempaxóchitl (*Tagetes erecta* L.)

**Hernández-García, B.D.R.[1]; Rodríguez-Elizalde, M.A.[1*]; Sánchez-Guzmán, P.[2]; Ruíz-Bello, A.[2]; Castro-Brindis, R.[1]**

[1] Universidad Autónoma Chapingo, Departamento de Fitotecnia, Carretera México-Texcoco Km. 38.5, Texcoco, Estado de México, México. C.P. 56227.

[2] Colegio de Postgraduados Campus Montecillo. Posgrado de Edafología, Carretera México-Texcoco Km 36.5, Montecillo, Estado de México, México. C.P. 56264.

* Correspondence: roelyma@gmail.com

## ABSTRACT

**Objective**: To evaluate substrate mixtures for the production of Mexican marigolds grown in containers in the community of Santa Cruz Itundujia, Oaxaca, Mexico.

**Methods**: Four mixtures were tested: 1) 70% ocote pine needles+30% soil, 2) 70% leaf mold+30% soil, 3) 70% river sand+30% soil, and 4) 70% sawdust+30% soil. Mexican marigold (*Tagetes erecta*) var. Inca II Deep Orange plants were established in pots under open field conditions. Height, number of leaves, plant width, branching, leaf area, and number of buds were evaluated in the different phenological stages of the plant (15, 45 and 90 days after transplant). Soil fertility parameters were analyzed, and physical analysis of the substrates was performed.

**Results**: The treatments produced differential results; ocote pine needles+soil and leaf mold+soil were the best for producing container-grown marigolds. The lowest results in yield variables were found with the river sand+soil mixture.

**Implications**: Using local and inexpensive substrates will impact production costs for marigold farmers. Currently, a variety of commercial mixes and substrates of foreign origin are available and used for the production of container-grown plants.

**Conclusions**: The best substrate for the cultivation of pot-grown *Tagetes erecta* var. Inca II Deep Orange under open field conditions were soil+ocote pine needles and soil+leaf mold. These materials are common, cheap and easily acquired in the region, which will facilitate the production of various ornamental species in containers based on the results of this research.

**Keywords**: Asteraceae, yield, sawdust, needle, Oaxaca.

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## INTRODUCTION

Cempaxochitl, also known as the Mexican marigold (*Tagetes erecta*), is a native Mexican plant mainly used as an ornamental due to its beautiful yellow and orange inflorescences and peculiar fragance (Mier *et al.*, 2019). Its use dates back to pre-Hispanic cultures as a medicinal, ceremonial, and gastronomic plant (Hernández, 1960). Currently, potted marigolds are important for gardening and for decorating altars and commemorative spaces (Serrato, 2022). In Mexico for the production of this plant, different mixtures of imported substrates such as peat, vermiculite and perlite are used, which increase production costs

(Kaushal and Kumari, 2020; Ördögh, 2021). Some ornamental farmers prefer mixtures of leaf mold with perlite or volcanic material (tezontle or tepojal) (Gayosso *et al.*, 2016). However, in the Mixteca Alta region of the state of Oaxaca, ornamental plants are rarely produced due to altitudes exceeding 1700 meters above sea level and the predominance of pine oak forests (López *et al.*, 2022). Therefore, it is necessary to seek local substrates that utilize residues from timber products (sawdust and pine needles) that are low-cost, readily available, and contribute to reducing organic waste in the area. In this work, mixtures of four local substrates from Santa Cruz Itundujia, Oaxaca, a community characterized by timber activity, were evaluated in order to choose the most suitable for the production of Mexican marigold.

## MATERIALS AND METHODS

The present study was carried out in Laguna area, municipality of Santa Cruz Itundijia, Putla district, of the State of Oaxaca in the Mixteca region, coordinates 97° 39’ west longitude and 16° 52’ north latitude (INEGI, 1991). Four readily available and inexpensive substrates in the area were selected: 1) ocote pine needles, 2) leaf mold, 3) river sand, and 4) sawdust. The ocote pine needles and sawdust were not fresh since they presented 50% degradation. The experiment was established in an open field, using the following proportions of substrates (Table 1) and regional soil, which was classified as Eutric Cambisol.

Inca II Deep Orange seeds were obtained from Freesias S. de R. L. de C. V. and black flexible plastic pots with a six-inch diameter were used.

### Development and fertilization

Fertilization was performed through the irrigation water with a soluble commercial formula of N-20 P-20 K-20 Harvest More® at a dose of 0.5 g $L^{-1}$ in the vegetative phase, gradually increasing to a dose of 1.0 g $L^{-1}$ in the flowering stage. Fertilization was carried out weekly, alternating with water irrigation. Foliar fertilizer was also applied for all treatments, using 0.3 ml $L^{-1}$ of Bayfolan forte® with 1 ml $L^{-1}$ of adherent per liter of water in the vegetative stage and reaching 1.0 ml $L^{-1}$ in the flowering stage.

For disease prevention (in the case of fungi), benomilo® (diluted with water to a concentration of 0.5 ml $L^{-1}$) was applied to the leaves every 15 days. No plagues were present during the experiment.

### Experimental design

The experiment used a randomized complete-block design with four treatments (ocote pine needles + soil, leaf mold + soil, river sand + soil and sawdust + soil) and 20 replicates per treatment. A total of 80 pots were established.

**Table 1**. Treatments used in the experiment

| Treatment 1 | Treatment 2 | Treatment 3 | Treatment 4 |
|---|---|---|---|
| Ocote pine needles (70%) + soil (30%) | Leaf mold (70%) + soil (30%) | River sand (70%) + soil (30%) | Sawdust (70%) + soil (30%) |

## Data analysis

The response to the treatments was evaluated by measuring the following variables: plant height, number of leaves, number of branches, width or breadth of the plant, leaf area, and number of buds. These variables were measured at different plant phenological stages (15 and 45 dat), finalizing with the flowering stage (90 dat).

The data were recorded using IMAGE-J software to determine the leaf area. The data were analyzed using the ANOVA analysis of variance and comparison of means (Tukey's test) in the Statistical Analysis System (SAS) software.

## Analysis of physical properties of substrates and soil fertility

Physical tests were performed on the substrates and mixtures used in the experiment according to NOM 021-RECNAT 2000 to determine aeration and moisture retention. Moreover, the fertility analysis of the soil used for the mixtures was carried out according to NOM 021-RECNAT 2000.

## RESULTS AND DISCUSSION

**Height**. Significant differences were found in this variable on the three sampling dates (Table 2). Fifteen days after transplanting (dat), treatment 1 (needles + soil) and 2 (leaf mold + soil ) were statistically higher than treatment 3 (sand + soil) and 4 (sawdust + soil). At 45 dat, the treatments containing needles (T1) and leaf mold (T2) had a 38% increase over the treatments containing sand (T3) and sawdust (T4). During the flowering phase (90 dat) the best treatments were T1 (needles + soil) and T4 (sawdust + soil) (Table 3). Leaf mold is inexpensive and easy to obtain in the community. One of the advantages of leaf mold is the contribution of nutrients and the presence of microorganisms such as bacteria and arbuscular fungi (Mantero *et al.*, 2019).

Treatment 3 (sand + soil) had the lowest height values during the three data collection periods (15 dat, 45 dat, and 90 dat), representing a lower development (Table 3). Sand is considered cheap and easy to acquire for ornamental producers; however, its characteristics, such as higher weight, porosity, and lower water retention, lead to lower plant development (*i.e.*, height) compared to substrates with a higher percentage of organic materials (Ördögh, 2021). Ampim *et al.* (2010) indicated that the disadvantages of using sand in the substrate

**Table 2**. Results of Pr > F in ANOVA.

| Variables | Days after transplant (dat) | | |
|---|---|---|---|
| | 15 | 45 | 90 |
| Height | 0.0001 | 0.0001 | 0.0001 |
| Number of leaves | 0.0032 | 0.0001 | 0.0001 |
| Branching | * | 0.0001 | 0.0001 |
| Plant width | 0.0001 | 0.0001 | 0.0001 |
| Number of flower buds | * | * | 0.0001 |
| Leaf area | 0.0001 | 0.0001 | 0.0001 |

* No data, $\alpha=0.05$.

are the low retention of nutrients and water, the weight of the mixture, and the limitation of providing good nutrition since it is an inert material.

**Number of leaves**. For this variable, significant differences were also found in the dates sampled (Table 2), at 15 dat and 45 dat, the two best treatments were needles + soil and leaf mold + soil, while at 90 dat, the treatment containing needles + soil statistically outperformed the other treatments, with an increase of 44% over T2 (leaf mold + soil), 46% over T4 (sawdust + soil), and 73% over T3 (sand + soil) (Table 3). Leaves are an important anatomical part of *Tagetes erecta* and all plants because this is where photosynthesis occurs; this process provides photoassimilates to the plant necessary for cell growth (Azcón and Talón, 2013). However, it is necessary to provide a suitable medium for plant development. In this context, using ocote pine needles + soil favored leaf development. Gupta *et al.* (2023) indicated that pine needles contain 68%-69% holocellulose (cellulose and hemicellulose), 27%-31% lignin, and 4%-4.5% extracts that, when degraded, facilitate the development of different species in that substrate. When mixed with soil, the needles stored moisture and reduce water evaporation (Sahin and Yalcin, 2017).

**Branching**. These were measured at 45 dat and 90 dat due to the pruning and development of the plant (Table 3). Like the other variables, the analysis of variance showed significant differences between the means of the values obtained (Table 2). At 45 dat, ramifications were similar in treatments T1 (needles + soil) and T2 (leaf mold + soil); in contrast, treatments T3 (sand + soil) and T4 (sawdust + soil) had the lowest values. At 90 dat, branching was statistically lower in T3 (sand + soil) than the other treatments.

**Table 3**. Yield parameters of *Tagetes erecta* (Mexican cempaxóchitl) in four substrates.

| Treatment | Height (cm) | | | Number of leaves | | | Branching | | |
|---|---|---|---|---|---|---|---|---|---|
| | 15 | 45 | 90 | 15 | 45 | 90 | 15 | 45 | 90 |
| | dat | | | | | | | | |
| T1. Ocote pine needles+soil | 7.9a | 10.2a | 15.3a | 6.4a | 27.2a | 51.1a | 0 | 5.7a | 6.5a |
| T2. Leaf mold+soil | 7.4a | 10.2a | 10.6b | 6.5a | 28.3a | 28.3b | 0 | 5.4a | 6.2a |
| T3. River sand+soil | 4.2b | 6.3b | 9.4b | 5.0b | 11.6b | 13.5c | 0 | 2.9b | 3.3b |
| T4. Sawdust+soil | 4.6b | 6.3b | 13.4a | 5.4ab | 16.5b | 27.2b | 0 | 3.4b | 5.3a |
| MSD | 0.60 | 1.63 | 2.83 | 1.29 | 7.65 | 6.04 | | 1.57 | 1.40 |
| **Treatment** | **Width (cm)** | | | **Number of flower buds** | | | **Leaf area ($cm^2$)** | | |
| | 15 | 45 | 90 | 15 | 45 | 90 | 15 | 45 | 90 |
| | dat | | | | | | | | |
| T1. Ocote pine needles+soil | 8.10a | 14.55a | 18.45 ab | 0 | 0 | 5.45a | 19.68a | 90.67a | 62.49a |
| T2. Leaf mold+soil | 7.64a | 11.90b | 18.65 a | 0 | 0 | 5.90a | 9.85b | 43.68b | 52.04b |
| T3. River sand+soil | 5.45b | 8.58c | 8.90 c | 0 | 0 | 3.35b | 23.62a | 23.20c | 23.41c |
| T4. Sawdust+soil | 5.37b | 9.23c | 14.40 b | 0 | 0 | 4.70ab | 20.57a | 15.53c | 49.28b |
| MSD | 1.11 | 2.04 | 4.10 | | | 1.31 | 4.53 | 10.15 | 7.73 |

MSD=Minimum significant difference, dat=days after transplant. Different letters between dates and treatments show significant differences (Tukey $\alpha$=0.05) Mean ± standard error, n=20.

The lateral development of a plant is due to the growth of axillary buds when apical dominance is inhibited or diminished. Auxins participate in this process and promote the formation of leaf primordia (Azcón and Talón, 2013). Additionally, Mann *et al.* (2023) indicated that the physicochemical properties of the growth medium and water quality influence the development and quality of *Tagetes erecta*. If a plant acquires essential nutrients from the medium (substrate or soil), apical and axillary bud development will increase; otherwise, growth will decrease, as occurred in the sand + soil mixture, which showed less branching development.

**Plant width**. ANOVA showed significant differences between the means of the treatments (Table 2).

At 15 dat, plant width in T1 (needles + soil) was 32% higher than T3 (sand + soil) and 33% higher than T4 (sawdust + soil). Moreover, at 45 dat, plant width increased in all treatments, with T1 (needles + soil) as the highest, and T3 (sand + soil) and T4 (sawdust + soil) as the lowest. At the flowering stage, the best widths were found in T1 (leaf mold + soil) and T2 (needles + soil), while the lowest was T3 (sand + soil). These values represent a 100% increase in width in the needle treatment compared to the sand treatment (Table 3). Plant yield and growth depend on the fertility of the medium and fertilizer supply (Souri *et al.*, 2018). As a substrate, leaf mold provides enough nutrients such as N, P, K, Ca, and S due to the decomposition of organic litter. *Tagetes erecta* is susceptible to nutrient deficiency since supplying it with only 100 mg kg$^{-1}$ of nitrogen reduced growth and flower production (Mantero *et al.*, 2019). Because of this, marigold plants in this study were fertilized with optime nitrogen additions. According to Kaushal and Kumari (2020), leaf mold and pine bark provide nitrogen and good moisture retention to the substrate, which could explain the results of the present experiment.

**Number of flower buds**. The emission of flower buds is a response to the change of activity and the differentiation of the vegetative meristem to a reproductive meristem, originating the flower components (Taiz and Zeiger, 2006). Therefore, flower buds were only registered at 90 dat, when more than 50% of flowering occurred (Table 3). The results showed that plants in T3 (river sand + soil) presented fewer flower buds than the other treatments (Figure 1). The best treatments were T2 (leaf mold + soil) and T1 (needles + soil). These data agree with Ördögh (2021), who studied different proportions of sand mixed with peat moss in the development of *Tagetes patula*; their findings indicate that substrates with a higher percentage of peat moss were more effective in the species' development and flower bud production. In contrast, the substrates with sand did not promote the adequate development of *Tagetes patula*.

**Leaf area**. Leaf area is the measure of the total leaf surface of a plant, where photosynthesis takes place (Fang *et al.*, 2019). At 15 dat, the plants presented differential leaf areas, and T2 (leaf mold + soil) had the lowest (Table 3). In all treatments, leaf area increased at 45 dat and 90 dat; however, T1 (needles + soil) presented the best values. The overall analysis of the evaluated variables in *Tagetes erecta* suggests that plant development was lower and deficient in T3 (sand + soil), resulting in small plants. From a commercial point of view, these plants are not viable due to their inferior quality (Figure 1).

**Figure 1**. Marigold (cempaxóchitl) development in (a) ocote pine needles + soil and (b) sand + soil.

**Physical characteristics of substrates**. When using substrates, aeration capacity, and moisture retention capacity are important because they are closely linked to bulk density and total porosity (Bashir *et al.*, 2021).

Moisture retention capacity was obtained by saturating samples of the substrates and applying water column tensions (10 cm, 50 cm, and 100 cm). The amount of water retained at each tension was measured, and the corresponding curves were constructed. The results are shown in Table 4.

Since moisture retention with a water column can only be applied in substrates with organic materials, moisture retention in the river sand and the river sand + soil mixture was determined by Field Capacity (FC) and Permanent Wilting Point (PWP) (pressure between 0.3 bar - 15 bar) (Table 5).

**Table 4**. Physical characteristics and moisture retention of the substrates.

| Materials and mixtures | BD (g cm$^{-3}$) | Total porosity | Aeration | Moisture retention | UW | EAW | RW | HAW |
|---|---|---|---|---|---|---|---|---|
| Ocote pine needles | 0.14 | 80 | 21 | 59 | 27 | 12 | 31 | 25 |
| Ocote pine needles + soil | 0.32 | 69 | 15 | 54 | 21 | 16 | 18 | 41 |
| Sawdust | 0.05 | 80 | 63 | 18 | 41 | 4 | 6 | 13 |
| Sawdust + soil | 0.15 | 83 | 52 | 31 | 45 | 20 | 28 | 13 |
| Leaf mold | 0.13 | 83 | 28 | 55 | 8 | 4 | 5 | 60 |
| Leaf mold + soil | 0.24 | 73 | 24 | 49 | 34 | 20 | 20 | 24 |
| River sand + soil | 0.88 | 52 | 14 | 38 | * | * | * | * |

BD=Bulk density, UW=Unavailable water, EAW=easily available water, RW=Reserve water, HAW=Hardly available water, *=Data in Table 5.

**Table 5**. Moisture retention in sand.

| Material and mixture | Field Capacity (FC) (%) | Permanent Wilting Point (PMP) (%) |
|---|---|---|
| River sand | 11 | 7 |
| River sand + soil | 19 | 10 |

The bulk density of sawdust was low due to the size and organic nature of the particles and the porous space between them. In both sawdust and soil + sawdust mixture, unavailable water (UW) was high because it was lost by draining (Table 4).

River sand is a heavy material, so mixing it with the soil produced a high bulk density compared to the other materials and mixtures. The total porosity of this mixture was low, resulting in low aeration and moisture retention (Table 4). Table 5 shows the low interval between the Field Capacity (FC) and the Permanent Wilting Point (PWP) of the sand and the soil + sand mixture, which implies a low margin of water availability for the plant. The treatment with sand showed the lowest results in plant response. According to Barbaro *et al.* (2017), the bulk density values should be considered when choosing a suitable substrate. This value should allow easy handling, transport, and anchoring of the plant. Moreover, the total void space must be greater than 85% to facilitate air and water flow. According to the void size and the nature of the material, total porosity can be divided into aeration porosity and moisture retention. These two parameters are higher in needles and leaf mold and in their mixtures with soil (Table 4), which is reflected in the distribution of unavailable water (UW), easily available water (EAW), reserve water (RW), and hardly available water (HAW). According to Taiz and Zeiger (2006), the root system is directly affected by the hydric state of the soil (or substrate). The absence of easily available water (EAW) between the field capacity and permanent wilting percentage (Azcón and Talón, 2013) causes stomata closure. This results in a reduction in the photosynthetic rate, which determines plant growth. In the case of the sand treatment, this development was limited due to its low water retention. However, clay particles are smaller than sand particles, thus providing a greater surface area to retain water and smaller channels between particles. Regarding field capacity, sand only contains one-third of the amount of water that clay does (Azcón and Talón, 2013).

Of note, the characteristics of the materials (ocote pine needles, leaf mold, sawdust, river sand, and soil) may vary between these and their mixture with soil. Therefore, it is also important to consider the soil's characteristics and properties.

**Soil analysis**. The soil used in the experiment was a silty loam soil (9.7% Sand, 65% Silt, and 25.3% Clay) with high organic matter content (11.47) and nitrogen (0.45%) content, pH=6.3, and high cation exchange capacity (CEC) CEC=28 cmol(+)$Kg^{-1}$. The wet color was 7.5R 3/3 dark brown, the dry color was 7.5YR 4/3 brown, and its bulk density was 1.25 g $cm^3$. The soil was classified as an Eutric Cambisol and presented favorable characteristics for the development of Mexican marigolds. According to Upadhya *et al.* (2022), *Tagetes erecta* requires high nutrient concentrations for its growth, especially N. The high cation exchange capacity (CEC) allows good retention of nutrients, and the slightly acidic pH favors their availability. In addition, the silty loam texture allows good root development.

## CONCLUSIONS

Based on the results, the best substrate for the cultivation of pot-grown *Tagetes erecta* var. Inca II Deep Orange under open field conditions were soil + ocote pine needles and soil + leaf mold.

The use of substrates with materials generated from the timber industry in the community of Santa Cruz Itundujia, Oaxaca, will reduce the production costs of mexican marigold by taking advantage of waste materials that are common in the region. Similarly, this substrate can be used as a base for the production of various ornamental species produced in containers.

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