ISSN 1516-8840 / e-ISSN 1806-9193

Documentos

547

Pelotas, RS / October, 2025

OBJETIVOS DE DESENVOLVIMENTO SUSTENTÁVEL

2 FOME ZERO E AGRICULTURA SUSTENTÁVEL

Tagetes minuta L.in Southern Brazil: A broad overview of research at Cascata Experimental Station

Embrapa

Clima Temperado

Brazilian Agricultural Research Corporation
Embrapa Temperate Agriculture
Ministry of Agriculture and Livestock

ISSN 1516-8840 / e-ISSN 1806-9193

Documentos 547

October, 2025

Tagetes minuta L. in Southern Brazil: A broad overview of research at Cascata Experimental Station

Gustavo Schiedeck
Cristine da Fonseca
Kirley Marques Canuto

Embrapa Temperate Agriculture
Pelotas, RS
2025

Embrapa Clima Temperado
BR-392, km 78, Caixa Postal 403
CEP 96010-971, Pelotas, RS - Brazil
Fone: +55 (53) 3275-8100
www.embrapa.br/clima-temperado
www.embrapa.br/fale-conosco/sac

Executive edition and text revision
Bárbara Chevallier Cosenza

Bibliographic standardization
Cláudia Antunez Arrieche

Graphic design
Leandro Sousa Fazio

Layout
Nathália Santos Fick

Cover
Gustavo Schiedeck

Digital publication: PDF

Cataloguing-in-Publication
Embrapa Clima Temperado

Schiedeck, Gustavo.

Tagetes minuta L. in Southern Brazil: a broad overview of research at Cascata Experimental Station / Gustavo Schiedeck, Cristine da Fonseca, Kirley Marques Canuto. – Pelotas : Embrapa Clima Temperado, 2025.
PDF (38 p.) – (Documento / Embrapa Clima Temperado, ISSN 1806- 9193; 547).

1. Asteraceae - T. minuta . 2. Global market. 3. Research. 4. Essential oil. I. Fonseca, Cristine da. II. Canuto, Kirley Marques. III. Title. IV. Series.

CDD (21. ed.) 641.357

Claudia Antunez Arrieche (CRB-10/1594)

Authors

Gustavo Schiedeck
Agronomic Engineer, doctor in Agroecology, researcher at Embrapa Temperate Agriculture, Pelotas, RS, Brazil

Cristine da Fonseca
Agronomic Engineer, master's degree in Agronomy, agronomist at the Municipal Department of Environment and Sustainability (SEMAS),São Francisco de Paula, RS, Brazil

Kirley Marques Canuto
Pharmacist, doctor in Chemistry, researcher at Embrapa Tropical Agroindustry, Fortaleza, CE, Brazil

The author would like to thank the Research Support Foundation of the State of Rio Grande do Sul (Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul — FAPERGS) for its support in the completion of this work.

Foreword

The search for complementary income sources for family farming represents a challenge for research, but it can also be seen as an opportunity. Bioactive plants, considered medicinal, aromatic, and culinary herbs and spices, along with the direct commercialisation of raw plant material to industry, enable farming families to add value through the extraction of essential oils on a small to medium scale at the farm level.

Although the topic is not new, species selection is generally limited to more traditional ones, such as mint, rosemary, citronella, or eucalyptus, which are more readily absorbed by the market. However, the competition and scale of production required often render family-based ventures unfeasible.

Many species with market potential could be successfully explored, and *Tagetes minuta* L. is not an obvious choice. However, considering the increasing number of scientific studies on the biological properties of its essential oil, the multiple applications in different fields of knowledge, and, above all, the fact that it is a naturalised species in Brazil and well adapted to the Southern Region, its potential as a sustainable crop in Brazil is promising and should not be overlooked.

This document systematises the research results of the organic cultivation of *T. minuta* carried out at the Cascata Experimental Station, Embrapa Temperate Agriculture, in recent years. It discusses aspects ranging from transplanting time to essential oil composition. When possible, comparisons are made with results obtained in countries with greater expertise in *T. minuta* cultivation to identify similarities, competitive opportunities, and research needs. In this way, this document also aims to contribute to the achievement of the Sustainable Development Goals (SDGs) proposed by the UN 2030 Agenda, particularly in alignment with the promotion of sustainable agriculture (SDG 2).

Leonardo Ferreira Dutra
Head of Embrapa Temperate Agriculture

Contents

Introduction

In Brazil, as in many other countries, *Tagetes minuta* L. is invariably reported as an invasive species in fallow lands or areas prepared for the cultivation of economically important crops. However, its origin is linked to the Andean peoples' ancestral traditions (Hastorf; Bruno, 2020), especially in Peru, where its leaves are used as a condiment for meats in a traditional ceremony known as Pachamanca (Pacha = earth, manka = pot, cooking vessel) (Arellano; Arroyo, 2019; Chávez-Núñez et al., 2021). Currently, the revival of this ancestral gastronomy is also seen in academia and in the business world as a market opportunity, with several studies exploring the use of *T. minuta* in the development of beverages, sauces, and mixtures for meats and cheeses (Arturo, 2021; Cortez, 2025; Medina; Meza, 2018; Mena, 2022).

Among the countries cultivating *T. minuta*, India plays a prominent role. In 1999, the Central Institute of Medicinal & Aromatic Plants (CIMAP), in Lucknow, registered the variety Vanphool (Kumar et al., 1999). Two years later, on National Science Day, the Institute of Himalayan Bioresource Technology (IHBT), in Palampur, released the commercial variety Him Gold (Singh et al., 2001), followed by the array Him Swarnima in 2019 (Kumar; Singh, 2020), both from breeding projects. According to IHBT technical reports, *T. minuta* cultivation in India covers approximately 400 ha and involves over 500 farming families, who obtain returns two to three times higher than from traditional crops such as wheat or rice (CSIR-IHBT, 2019, 2020). In 2018, the price of *T. minuta* essential oil ranged from USD 100/kg to USD 140/kg, with net returns to farmers between USD 1,7/ha and USD 2,1/ha (Jyoti, 2018). South Africa also has a significant production of *T. minuta* essential oil, although it is primarily concentrated in private companies, and little information is available on this topic.

In Argentina, research on the selection and characterization of *T. minuta* genotypes, aiming at improved agronomic performance, has been ongoing for over a decade (Massuh, 2014; Massuh et al., 2017a, 2017b). In 2014, the National University of Córdoba (UNC) registered the cultivar Don Monje, and the cultivars Serrano and Aromisky are currently undergoing registration (Martinez et al., 2020).

Information about *T. minuta* essential oil market is scarce because the estimated global demand of 12 tons per year (CBI, 2015) is relatively low compared to essential oils of other species such as *Citrus sinensis* (50,000–55,000 tons) or *Mentha arvensis* (25,000–40,000 tons) (Bizzo; Rezende, 2022). Nevertheless, due to its limited supply, between 2013 and 2014, *T. minuta* essential oil of lower quality was traded at prices ranging from € 70/kg to € 80/kg, while high-quality oil reached values between € 150/kg and € 190/kg (CBI, 2015).

Based on current research trends on the species in some countries, its market potential, and its suitability as an alternative crop in the state of Rio Grande do Sul, southern Brazil, this publication seeks to systematize cultivation data on *Tagetes minuta* L. at Cascata Experimental Station, Embrapa Temperate Agriculture. The research carried out between 2015 and 2019 addressed aspects such as the phenology and growth cycle of the species, transplanting date, biomass production, essential oil yield and productivity, and the chemical composition of the essential oil according to harvest time.

Botany and ecology

Tagetes minuta L. is a species of the Asteraceae, tribe Tageteae, native to South America and naturalized in Brazil, where it is found virtually in all regions, especially in the South, Southeast, and Central-West (Carneiro; Ritter, 2018). Synonyms include *T. glandulifera* Schrank, *T. glandulosa* Link, *T. porophyllum* Vell., and *T. bonariensis* Persoon (Carneiro; Rebouças, 2025; Schiavinato et al., 2017).

It is an annual herb with erect growth habit, ranging from 0.4 to 2.0 m in height, with a well-developed taproot system with extensive branching. The leaves are simple, opposite, sessile, with an acute apex and translucent oil glands that appear as elongated punctate structures along the margins (Carneiro; Ritter, 2018).

The inflorescences are radiate capitula (bearing both ray and disc florets) and heterogamous (with flowers exhibiting distinct sexual arrangements), numerous, and arranged in dense corymbs. The involucre is cylindrical, slightly pubescent at the margins and glabrous on the remaining surface, with linear or elliptical oil glands. The ray florets are pistillate (possessing only a gynoecium) and have a white limb with two or three lobes, while the disc florets are perfect (with both androecium and gynoecium) and have a yellowish pubescent tubular corolla (Gutiérrez; Stampacchio, 2015).

The fruits are classified as cypselae – elongated, fusiform, and dark-colored – with a pappus composed of one or, rarely, two long awns (Carneiro; Ritter, 2018). The pappus is an apical tuft of trichomes or bristles that facilitates fruit dispersal and, due to its high morphological variability, it plays a significant role in species identification within the Asteraceae family (Roque; Bautista, 2008).

T. minuta has capitula with distinct floral arrangements, presenting pistillate and perfect hermaphroditic florets (Gutiérrez; Stampacchio, 2015), which enable both allogamous and autogamous pollination processes. According to Massuh et al. (2017b), the multiple cross-pollination pathways contribute to significant intra- and inter-populational variability. Kumar et al. (2020) reported a high frequency of bee activity during flowering, suggesting that insect-mediated cross-pollination is the primary mechanism. They also found that the seed set was significantly higher under cross-pollination conditions (94%) compared to self-pollination (46%). However, Bandana and Raina (2017) reported that seed production, seed size, and seed weight were not affected by the type of pollination. Nevertheless, seeds from cross-pollination showed greater vigour and resulted in taller seedlings with higher fresh and dry biomass. The thousand-seed weight (TSW) of the Him Gold variety is approximately 0.465 g, with an average germination rate of 87% under conditions of 25 °C of temperature and 85% of humidity (Pal et al., 2023).

Like other species in the genus, *T. minuta* has essential oil-secreting structures (Carneiro; Ritter, 2018). These secretory structures are distributed throughout nearly all plant organs, though they differ in form, size, and distribution. There are three types of structures: secretory ducts, which occur more frequently in supporting tissues such as roots, stems, petioles, and veins; secretory cavities, which occur in the leaf blade and involucral bracts of the floral capitula; and glandular trichomes, present on all organs except the roots (Simon et al., 2002).

The genus *Tagetes* was described by Carl von Linné in 1737. In 1753, Linné described the species as "*Tagetes* with a simple and straight stem, with scaly multiflorous peduncles" and incorporated the description by Johann Jakob Dillenius published in 1732, *minuto flore albicante*, a Latin expression for "with small whitish flowers". Thus, the specific epithet refers to the small, whitish flowers of the species.

The most widespread explanation for the origin of the genus name is associated with the myth of the Etruscan deity Tages (Quattrocchi, 2000), who is said to have emerged around 900 BC in the present-day region of Tuscany, Italy. According to this legend, a farmer ploughing the soil witnessed the appearance of a wise child from a deep furrow, who revealed various rules for interpreting the will of the gods. These teachings quickly spread throughout the region and formed the basis of the Etruscan religion (Grummond, 2006). However, Kaplan (1960) disagrees with this hypothesis and proposes an alternative one based on the works of Leonard Fuchs from 1542 and Matthiae de Lobel in 1576, suggesting that *Tagetes* derives from *Tagum*, the Latin name for the Tagus River, along the banks of which *T. erecta* and *T. patula* occurred spontaneously.

Nevertheless, the ecology and physiology of many Asteraceae species share similarities with the Tages myth, which could have influenced Linné in his nomenclatural choice. Environmental conditions strongly influence seed germination in Asteraceae, particularly about light availability. Many species are positively photoblastic or exhibit weak photoinhibition (Ferreira et al., 2001; Kumar; Sharma, 2012). In the case of *T. minuta*, some studies indicate evident positive photoblastism (Felippe; Polo, 1983; Forsyth; Van Staden, 1983; Karlsson et al., 2008). Thus, soil disturbance can expose seeds to light, promoting germination. Furthermore, *T. minuta* seeds do not exhibit dormancy (Martinez-Ghersa et al., 2000) and, under optimal light and temperature conditions, they can achieve germination rates exceedind 70% within just 4 to 6 days (Forsyth; Van Staden, 1983; Kumar et al., 2022b).

Like the myth of Tages, many Asteraceae species such as *Taraxacum officinale*, *Sonchus oleraceus*, *Bidens pilosa*, and *T. minuta*, exhibit high dispersal capacity. The presence of a pappus on the fruit facilitates dispersal by wind (anemochory) or enables adherence to the surface of animals (epizoochory) (Cortés-Flores et al., 2013; Roque; Bautista, 2008). Human activities also favour the spread of *T. minuta*, as its fruits easily adhere to clothing and the fur or feathers of domestic and farm animals. This fact is supported by Wang et al. (2023), who documented occurrences of *T. minuta* in anthropogenic areas, including residential backyards, abandoned lots, riverbanks, roadsides, and sites with livestock activity. Consequently, the high environmental adaptability and invasive potential of *T. minuta* have raised concerns in several countries (Ngondya; Munishi, 2021; Qi et al., 2022).

Pre-Columbian peoples of the Americas have long utilised *Tagetes* species in religious rituals, traditional medicine, and culinary practices (Neher, 1968). As a result of historical and cultural interactions between these native populations and Spanish and Portuguese colonisers, a wide variety of vernacular terms have been used referring to *T. minuta* (Table 1).

Table 1. Vernacular names for *Tagetes minuta* in different languages.

Language	Vernacular names	Reference
Quechua	Wakátay (Huacatay); Chinchu.	Aparco et al. (2022); Vita (2009); Weber et al. (2008).
Spanish	Chinchilla; Chilche; Chilchita; Chil-chil; Huacatay; Suico; Sueco; Suique; Suiquillo; Flor amar; Manzanilla de la Sierra; Margarita; Picón del rey; Quenchihué.	Gutiérrez; Stampacchio (2015); Martinez et al. (2020); Vita (2009).
Portuguese	Chinchilho; Chinchila; Cinchilho; Rabo-de-rojão; Vara-de-foguete; Vareta-de-rojão; Guizo-de- cascavel; Mata-pulgas; Cravo-de-defunto; Cravo-do-mato.	Carneiro e Ritter (2018); Carneiro e Rebouças (2025).
English	Mexican marigold; Muster John Henry; Stinking-Roger; Southern marigold; Aztec marigold.	Wiersema (2019).

Although many cultures across Central and South America may have their vernacular names for *T. minuta*, the Quechua language is one of the most significant languages, encompassing various ethnic groups, especially from Andean countries such as Peru, Bolivia, Chile, Colombia, and Ecuador. In the Southern Region of Brazil, the most well-known vernacular name is “chinchilho”, which closely resembles the term “chinchilla” used in neighbouring Argentina. The Portuguese vernacular name “cravo-de-defunto” is perhaps the least appropriate to refer to *T. minuta* in Brazil, since *T. patula* and *T. erecta* - exotic species with ornamental appeal - are also widely known by that name, despite being visibly distinct in terms of growth habit, capitulum size, and colouration (Carneiro; Ritter, 2018).

In Quechua dictionaries, “wakatay” or “huacatay” is the most frequently cited vernacular name for *T. minuta* (Gobierno Regional Cusco, 2005; Pérez, 2022b). However, some sources also reference the term “chinchu” (Vita, 2009; Weber et al., 1998), which could be the linguistic root of “chinchilho” or “chinchilla”. In Spanish, the verb “chinchar” means to disturb or annoy someone, to be irritating (Pérez, 2022a).

By linking the etymology of the scientific name, the vernacular name “chincho”, and the botanical characteristics of the species, it is possible to interpret “chinchilho” as “the herb with small white flowers, whose fruits cling to clothing and are bothersome”.

Biological properties and uses

Ancient Andean peoples utilised *T. minuta* for multiple purposes, including culinary use, traditional medicine, and pest control (De La Cruz et al., 2014; Hastorf; Bruno, 2020; Vasquéz; Peláez, 2014). Its biological properties have been extensively investigated and systematised in comprehensive literature reviews, highlighting its antibacterial, antifungal, antioxidant, insecticidal, acaricidal, nematicidal, and larvicidal potential, among others (Bandana et al., 2018; Joshi; Barbalho, 2022; Santos et al., 2017; Verma et al., 2024; Walia; Kumar, 2020).

In the industry, its use primarily occurs in fragrances, flavourings, cosmetic products, and food and beverage manufacturing (CBI, 2015; Wang et al., 2023; Singh et al., 2003; Walia; Kumar, 2020). Pigments from the aerial parts of *T. minuta* can also be used as natural dyes for textiles such as silk, wool, and cotton (Kumar et al., 2014).

Despite its various applications, recent studies have highlighted the essential oil of *T. minuta* as a promising basis for developing innovative products to control high-priority public health agents. Bordón et al. (2025) demonstrated that the oil exhibits rapid and effective bactericidal action against *Escherichia coli* and *Staphylococcus aureus*, including resistant strains, with a mechanism of action associated with cell membrane destabilisation, suggesting a mode of action distinct from that of conventional antibiotics. Additionally, Sartor et al. (2025) reported high larvicidal toxicity against *Aedes aegypti*, the primary vector of dengue, Zika, and chikungunya viruses, with median lethal concentration (LC_{50}) values indicative of strong efficacy. The relevance of these findings is further enhanced by the fact that *T. minuta* offers a high essential oil yield and demonstrates excellent agronomic adaptability to Brazilian growing conditions, providing economic, ecological, and logistical advantages for large-scale application.

Research study conditions at Cascata Experimental Station (EEC)

The Cascata Experimental Station (EEC), Embrapa Temperate Agriculture, is located in the municipality of Pelotas, Rio Grande do Sul State (RS), Brazil, at a latitude of -31°37'24" South and a longitude of -52°31'37" West, at an average altitude of 180 meters. Cultivation results from the 2015/2016, 2016/2017, and 2018/2019 crop seasons were systematised.

Seedlings were produced in a greenhouse using expanded polystyrene trays with 128 cells, each cell being pyramidal with a volume of 29.67 cm³. The substrate consisted of a mixture of earthworm humus and carbonised rice husk in a 2:1 (v:v) ratio. Variations in transplanting time and harvest date were implemented across different crop seasons (Table 2).

Table 2. Crop season and date of sowing, transplanting, and harvest of *Tagetes minuta* L. at Cascata Experimental Station (EEC), Embrapa Temperate Agriculture, Pelotas, RS. Brazil.

Crop season	Sowing	Transplant	Harvest
2015/2016	30/September/2015	1/December/2015	19/April/2016
			27/April/2016
			05/May/2016
			12/May/2016
2016/2017	31/October/2016	20/December/2016	04/May/2017
			11/May/2017
			17/May/2017
			24/May/2017
			31/May/2017
			07/June/2017
	07/December/2016	18/January/2017	04/May/2017
			11/May/2017
			17/May/2017
			24/May/2017
			31/May/2017
			07/June/2017

Continued...

Table 2. Continued.

Crop season	Sowing	Transplant	Harvest
2016/2017	27/December/2016	13/February/2017	11/May/2017
			17/May/2017
			24/May/2017
			31/May/2017
			07/June/2017
	17/January/2017	07/March/2017	07/June/2017
2018/2019	11/December/2018	30/January/2019	17/May/2019
			30/May/2019

Soil variables

The cultivation areas were prepared using a disk harrow, with no lime application or fertilisation carried out. The soil in the area is classified as an Argisol (IBGE, 2023). In the 2015/2016 and 2016/2017 growing seasons, cultivation was carried out in a continuous area, where the soil presented the following chemical characteristics: pH in water of 5.1; organic matter 2.07%; phosphorus 65.6 mg dm^{-3}; potassium 116 mg dm^{-3}; calcium 3.2 $cmol_c$ dm^{-3}; magnesium 1.0 $cmol_c$ dm^{-3}; and base saturation of 51%. The adopted spacing was 0.25 m between rows and 0.20 m between plants, representing a density of 200,000 plants per hectare. Manual irrigation was applied during the first 15 days to ensure the establishment of seedlings. Manual weeding with a hoe was carried out between 20 and 25 days after transplanting. No insect or disease control products were used, nor topdressing fertilisation were applied to the experimental plots.

Climate and crop climatic variables

The climate of the region is classified as humid subtropical, characterised by a lack of a dry season, but with hot summers (Cfa), according to the Köppen classification (Alvares et al., 2013).

Weather variables were monitored using an automatic data acquisition system (datalogger), Campbell, model CR800. Daily air temperature (°C), relative air humidity (%), photosynthetically active radiation (MJ m^{-2}), and daily rainfall (mm) Were recorded. Using the average, maximum, and minimum air temperature values, groWing degree days (°C day^{-1}) Were calculated for the period from transplanting to harvest, folloWing the method described by Ometto (1981) and validated by Renato et al. (2013). A lower base temperature of 10°C was adopted (Kumar et al., 2010). Due to the lack of specific data on the upper base temperature for *T. minuta*, a threshold of 35°C was used, the same temperature at which development is impaired in sunflower, another species within the Asteraceae family (Castro; Farias, 2005).

The earliest transplanting of *T. minuta* in the experiments conducted at the EEC occurred on December 2, 2015, and the latest harvest on June 7, 2017. The climatic variables during the different cultivation periods are presented in Table 3.

As stated above, *Tagetes minuta* is native to South America and can be found from the southeastern United States to northern Patagonia in Argentina, and is now also found in several countries across Europe, Asia, Africa, and Australia (Gutiérrez; Stampacchio, 2015). One of the leading producers of *T. minuta* essential oil is India, where it is cultivated in regions with highly distinct climatic characteristics, at altitudes ranging from 490 m to over 2600 m above sea level (Walia et al., 2020b). In Brazil, studies on yield and the characterization of the essential oil have been carried out using plants collected from spontaneous populations or cultivated plots in the states of Bahia and Pernambuco (Craveiro et al., 1988), Ceará (Furtado et al., 2005; Macedo et al., 2013), the Federal District (Koketsu et al., 1976), Mato Grosso do Sul (Garcia et al., 2012), Paraná (Cepeda et al., 2023; Zimmermann et al., 2021), Santa Catarina (Sperandio et al., 2019), São Paulo (Albuquerque, 2018), and Rio Grande do Sul (Cunha et al., 2016; Fonseca, 2018; Gomes, 2017; Moreira, 2021; Oliveira et al., 2019; Rostignoli, 2019; Santos et al., 2021; Schiedeck, 2023; Siqueira et al., 1982). All these studies highlight the species' adaptive plasticity to different environments.

Table 3. Climatic variables according to the transplanting date and harvest period of *Tagetes minuta* in the 2015/2016, 2016/2017, and 2018/2019 growing seasons. Cascata Experimental Station (EEC), Embrapa Temperate Agriculture, Pelotas, RS. Brazil.

Transplant day	Harvest season	Harvests	Mean air temperature (°C)			Relative humidity (%)	Degree-day (Σ °C day)	PAR[1] (MJ m^{-2})	Photoperiod (hours)[2]		Rainfall (mm)
			Maximum	Mean	Minimum	Mean	Mean	Mean	Transplant	Harvest	Amount
02/December/2015	19/April to 12/May	4	27.27	21.35	16.60	90.27	1833.39	6.28	14.05	10.86	467.11
20/December/2016	04/May to 07/June	6	27.05	20.76	16.58	90.92	1825.25	5.80	14.22	10.42	1159.12
18/January/2017	04/May to 07/June	6	26.45	20.19	15.96	90.70	1406.71	5.61	13.91	10.42	926.96
30/January/2019	17/May to 30/May	2	24.96	19.70	14.99	85.73	1147.55	4.37	13.65	10.36	435.40
13/February/2017	11/May to 07/June	5	25.57	19.38	15.23	91.62	1076.25	4.90	13.24	10.35	841.52
07/March/2017	07/June	1	23.10	17.48	13.65	92.28	812.80	3.72	12.55	10.15	615.04
Mean			25.73	19.81	15.50	90.25	1350.33	5.11	13.60	10.47	740.86

[1] Photosynthetically active radiation, in megajoules per square meter.
[2] Calculated for the coordinates latitude -31°37'14.39'' South and longitude -52°31'19.02'' West.

As stated above, *Tagetes minuta* is native to South America and can be found from the southeastern United States to northern Patagonia in Argentina, and is now also found in several countries across Europe, Asia, Africa, and Australia (Gutiérrez; Stampacchio, 2015). One of the leading producers of *T. minuta* essential oil is India, where it is cultivated in regions with highly distinct climatic characteristics, at altitudes ranging from 490 m to over 2600 m above sea level (Walia et al., 2020b). In Brazil, studies on yield and the characterization of the essential oil have been carried out using plants collected from spontaneous populations or cultivated plots in the states of Bahia and Pernambuco (Craveiro et al., 1988), Ceará (Furtado et al., 2005; Macedo et al., 2013), the Federal District (Koketsu et al., 1976), Mato Grosso do Sul (Garcia et al., 2012), Paraná (Cepeda et al., 2023; Zimmermann et al., 2021), Santa Catarina (Sperandio et al., 2019), São Paulo (Albuquerque, 2018), and Rio Grande do Sul (Cunha et al., 2016; Fonseca, 2018; Gomes, 2017; Moreira, 2021; Oliveira et al., 2019; Rostignoli, 2019; Santos et al., 2021; Schiedeck, 2023; Siqueira et al., 1982). All these studies highlight the species' adaptive plasticity to different environments.

Earlier transplanting dates expose the plants to higher average temperatures, solar radiation, and longer photoperiods. Studies conducted at EEC revealed that the absolute maximum temperature reached 36.5°C in January 2016, and the absolute minimum was recorded at 2.6°C on May 1st of the same year. In India, crops are grown in temperatures ranging from 41°C to 2.6°C (Sharma et al., 2017; Sood et al., 2020). However, according to Singh et al. (2001), oil quality is better when air temperature remains between 12°C and 30°C during reproductive stages.

Photosynthetically active radiation (PAR) is directly related to plant growth and development; however, few studies have addressed this factor in *T. minuta*. For crops grown at EEC, average daily PAR in December was 1.7 times higher than in June, and this difference was reflected across all biomass parameters measured. Kumar et al. (2014) found that reduced light intensity in *T. minuta* can affect biomass accumulation, yield, productivity, and the composition of essential oil.

In the studies conducted at EEC, the average photoperiod in June was approximately 3 hours and 8 minutes shorter than that in December. The harvest in all three growing seasons occurred when the average photoperiod was 10 hours and 28 minutes. Luciani-Gresta (1975) observed that *T. minuta* flowers under a photoperiod between 10 and

13 hours, which is also influenced by light intensity and temperature. Evaluating transplant times, Kumar et al. (2012) observed the onset of flowering when day length ranged between 12 and 13 hours and harvested when it was between 11 and 12 hours. Similar results were reported by Ramesh and Singh (2008).

The total accumulated rainfall in the EEC experiments ranged from 435 to 1159 mm, depending on the year and growing season. In the study by Ramesh and Singh (2008), rainfall varied from 610 to 1407 mm across different growing seasons. In contrast, Walia et al. (2020b) cultivated *T. minuta* in areas with accumulated precipitation ranging from 204 to 2665 mm.

According to Singh et al. (2003), *T. minuta* requires a minimum of 500 mm of rainfall, well distributed throughout the cycle, and preferably in well-drained soils. Low oxygen availability to the roots in waterlogged soils is the leading cause of yield loss in *T. minuta* (Kumar et al., 2022a).

Harvesting

Plant growth and development were monitored on a weekly basis. The harvest point was defined as the stage when the cypselae (achenes) were released after manual shaking of the stems. In the 2015/2016 and 2016/2017 seasons, after the first harvest, weekly harvests were conducted until no more plants remained in the plots or the plants had reached advanced senescence, with aerial parts completely dry and unsuitable for essential oil extraction or measurement of leaf area.

At harvest, stem diameter was measured at the stem base using a digital calliper, and plant height was measured with a ruler from the stem base to the apex of the youngest shoot.

After harvest, the plants were manually separated into flowers, leaves, branches, and stem, and each fraction was weighed per plant. The leaf area of each plant was measured using a Li-COR LI-3100C area meter. For dry mass determination, the fresh fractions were placed in a forced-air circulation oven at 105°C for approximately 72 hours and weighed again once constant weight was achieved.

The phenological scale used to monitor the growth and development of *T. minuta* was proposed by Fonseca (2018), based on the phenological growth stage codes described by Hack et al. (1992).

Essential oil extraction

The essential oil was extracted from fresh flowers and leaves by hydrodistillation using a modified Clevenger apparatus. A total of 300 g of fresh biomass was used, maintaining the proportion between flowers and leaves as determined in the biomass fractioning at each harvest time. The approximate distillation time was 2 hours and 45 minutes, with the process being completed when no further increase in essential oil volume was observed in the separation burette. The oil from each sample was transferred to glass vials and stored in a freezer until the compounds were identified and characterised.

Essential oil yield (%) was calculated as the ratio between the extracted volume (mL) and the fresh mass of flowers and leaves (g). The essential oil productivity (kg ha^{-1}) was determined by multiplying the oil content of the distilled flower and leaf biomass by the biomass of flowers and leaves harvested from one hectare. To this end, the oil volume in millilitres obtained from distillation was converted into grams using the approximate density of 0.9 g cm^{-3} for *T. minuta* essential oil (Kumar et al., 2014).

The essential oil was analysed at the Laboratory of Natural Products Chemistry at Embrapa Tropical Agroindustry following the method previously described by Castro et al (2019). Gas chromatography coupled to mass spectrometry (GC-MS) analysis was carried out on an Agilent 7890B GC/5977A MSD chromatograph, operating with electron impact ionization at 70 eV, split injection mode (1:30), carrier gas flow at 1.50 mL min^{-1}, injector temperature at 250°C, and transfer line temperature at 250°C. The oven temperature program started at 70°C With a ramp of 4°C min^{-1} up to 180°C held for 27.5 minutes, folloWed by a ramp of 10°C min^{-1} up to 250°C, ending the run at 34.5 minutes.

Compound identification was carried out by analysing the fragmentation patterns in the mass spectra with those from the equipment's database (NIST version 2.0), as well as comparing their retention indices with those of known compounds obtained by injecting a mixture of standards and literature data (Adams, 1995). Quantification was carried out by normalization of the relative peak areas, obtained by gas chromatography coupled with a flame ionization detector (GC-FID). The equipment used was a Shimadzu GC-2010 Plus fitted with a VF-5MS methylpolysiloxane column (30 m × 0.25 mm × 0.25 µm, Varian), operating in split injection mode (1:30), using nitrogen as the carrier gas at a flow rate of 1.00 mL min^{-1}, With injector temperature at 250°C and detector temperature at 280°C. The oven temperature program Was as folloWs: initial temperature of 70°C With a ramp of 4°C min^{-1} to 180°C held for 27.5 minutes, folloWed by a ramp of 10°C min^{-1} to 250°C, ending the run at 34.5 minutes. Compound characterization Was based on retention index determination using a homologous series of n-alkanes (C7–C30).

Agronomic performance

Crop cycle

T. minuta can be propagated either by direct seeding, like broadcast sowing or in rows, or by seedling production (Pal et al., 2023; Sood et al., 2020). At the EEC, seedling production was chosen as it allows field preparation just a few days before transplanting. In the three crop seasons evaluated, seedlings were transplanted at ages ranging from 42 to 62 days and had an average height of approximately 10 cm. Although this is considered a relatively long duration compared to other species, it is a typical age for transplanting *T. minuta*. Different authors report transplanting seedlings at 30 days (Pandey et al., 2015), 45 days (Bandana et al., 2018; Ramesh; Singh, 2008), or even 60 days (Rathore et al., 2018; Walia et al., 2021).

The average crop cycle duration between transplanting and harvest in the cultivations carried out at the EEC is presented in Figure 1.

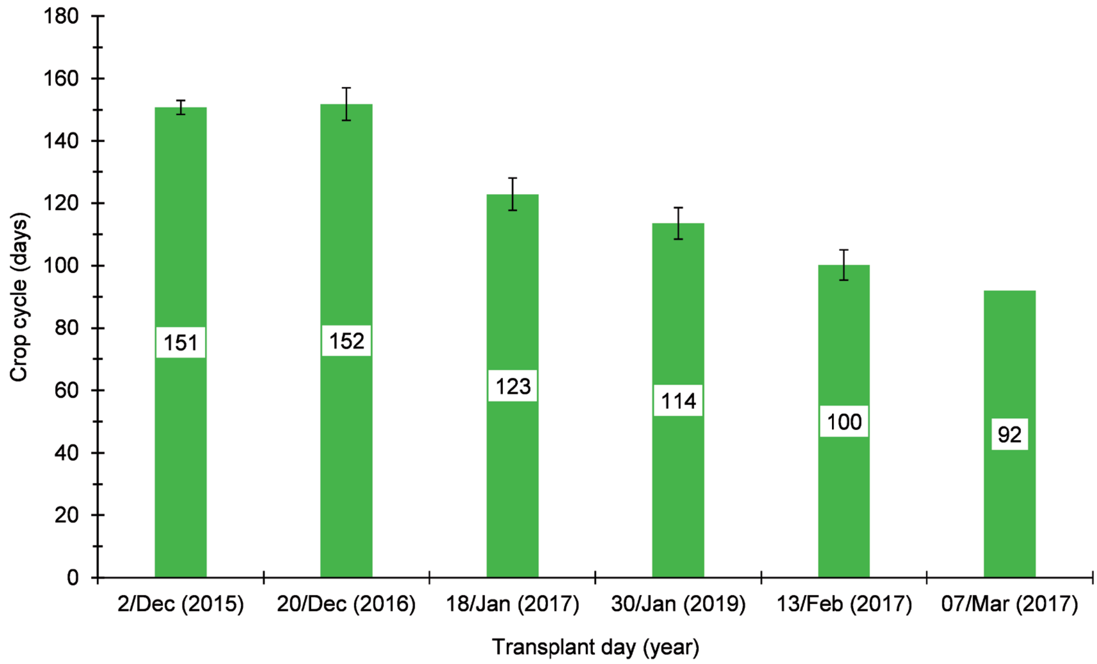

Figure 1. Average crop cycle of *Tagetes minuta* from transplanting to harvest. Data arranged in ascending order by month and day of transplanting. Vertical bars above the columns indicate the mean standard error. Cascata Experimental Station (EEC), Embrapa Temperate Agriculture, Pelotas, RS. Brazil.

The crop cycle of *T. minuta* was reduced by the delay in transplanting. Plants transplanted in December exhibited a cycle 30 to 50 days longer than those transplanted in January and February, and up to 60 days longer than those transplanted in March. This behaviour was also reported by Kumar et al. (2012) in their study on the effect of transplanting date on the cycle of *T. minuta*. According to the authors, the species is a short-day plant, and by delaying transplanting, the plants are exposed to a shorter photoperiod, which stimulates flowering and, consequently, shortens the cycle. In India, cultivation of *T. minuta* when transplanting was carried out in June resulted in an average cycle of 100 to 120 days until harvest (Kumar et al., 2012; Syamasundar; Rao, 2013; Walia et al., 2021). This cycle is similar to that observed at the EEC when transplanting is carried out between January and February.

The relationship between transplanting date and crop cycle duration could be calculated by converting transplanting dates into Julian days. The Julian day is a sequential method of counting dates that allows their use in regression models (Figure 2).

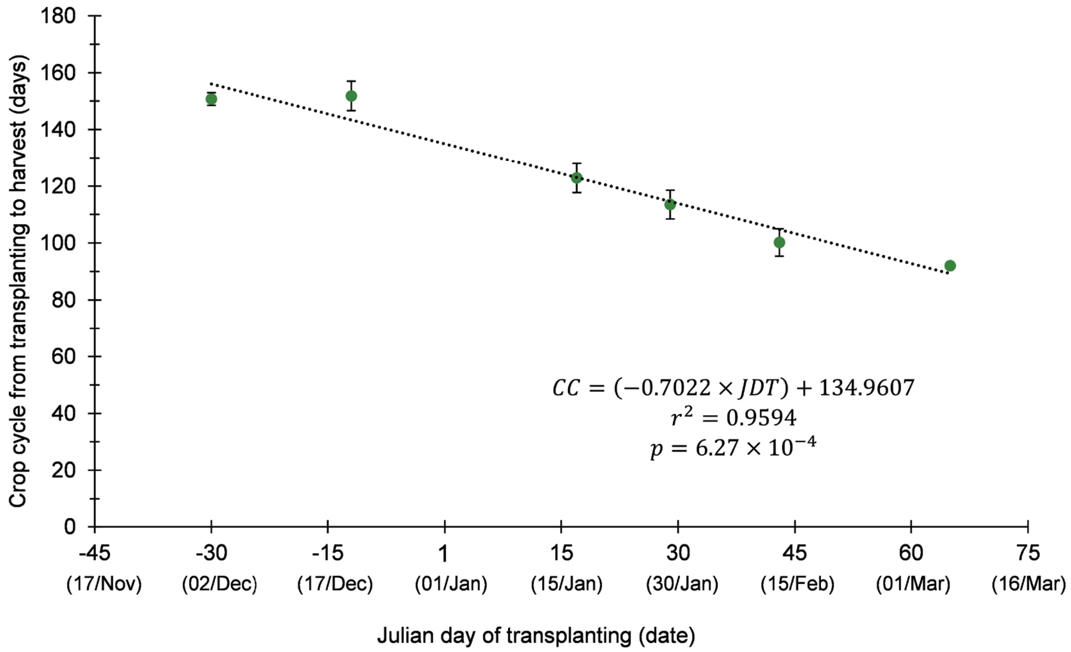

Figure 2. Estimated crop cycle (CC) from transplanting to harvest based on the transplanting date in Julian days (JDT). Corresponding calendar dates are shown in parentheses. Dates before January 1st were considered negative Julian days, while dates after were considered positive. Vertical bars over the points indicate the mean standard error. Cascata Experimental Station (EEC), Embrapa Temperate Agriculture, Pelotas, RS. Brazil.

The Julian day of transplanting explained more than 95% of the variation in the duration of the *T. minuta* cycle. Thus, future cultivations will be able to predict the approximate harvest date rapidly and straightforwardly.

The study conducted by Fonseca (2018) at the EEC monitored the development cycle of *T. minuta* at various transplanting and harvesting dates. Based on these observations, a phenological scale was developed, from sowing to plant senescence (Figure 3).

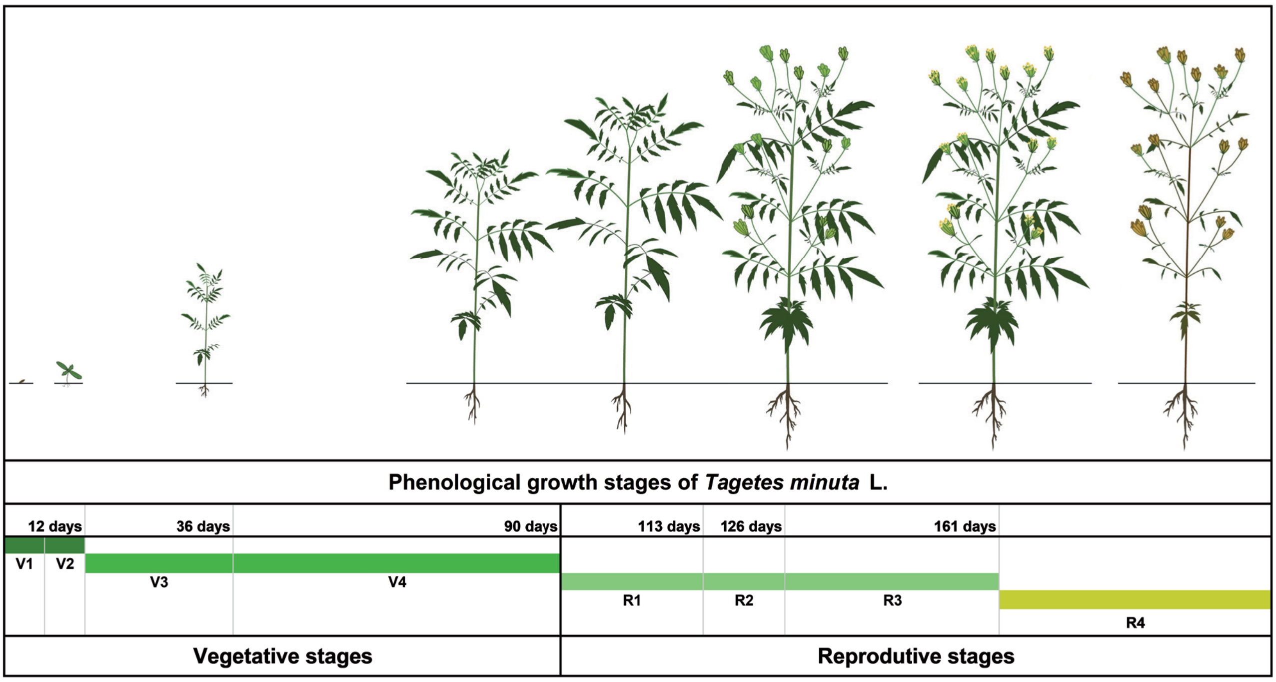

Figure 3. Proposed phenological scale of *T. minuta* based on sowing on December 27 and transplanting on February 13. V1 – Germination, V2 – Emergence, V3 – True leaves, V4 – Leaf and stem growth, R1 – Onset of floral head development (bud onset), R2 – Full flowering, R3 – Fruit dispersal, R4 – Senescence. Source: adapted from Fonseca (2018).

Illustration: Larissa Fonseca Silveira.

The duration of *T. minuta* phenophases is strongly related to the growing season (Kumar et al., 2010; Ramesh; Singh, 2008). Fonseca (2018) carried out the transplant 48 days after sowing, during stage V4. Considering the periods after transplanting, the onset of floral head development (R1) occurred at 65 days, full flowering (R2) at 78 days, and the beginning of fruit dispersal (R3) at 113 days. According to the author, the optimal harvest period for maximising essential oil yield and productivity is at the R2 and R3 phenological stages. Harvesting at these stages agree with the findings of other authors (Gupta; Khajuria, 2007; Singh et al., 2006; Singh et al., 2003).

Biomass production

The transplanting day influenced the growth and development of *T. minuta*. Except for the transplant carried out on December 2, 2015, during the 2015/2016 season, earlier transplants resulted in greater plant biomass accumulation, leaf area index, plant height, and stem diameter (Table 4). The biomass of the plants transplanted in early December 2015 may have been negatively affected by the low volume and uneven distribution of rainfall throughout the growth cycle. Approximately 80% of the total rainfall volume occurred in the last 36 days of cultivation, which also impacted the photosynthetically active solar radiation, with a daily average of only 2.42 MJ m^{-2} during this period.

Table 4. Agronomic performance of Tagetes minuta at different harvest periods during the 2015/2016, 2016/2017, and 2018/2019 crop seasons. Cascata Experimental Station (EEC), Embrapa Temperate Agriculture, Pelotas, RS. Brazil.

Transplant day	Harvest Season	Number of samples	Cycle[1] (days)		Total dry mass (t ha^{-1})		Flowers dry mass (t ha^{-1})		Leaves dry mass (t ha^{-1})		LAI[2]		Plant height (m)[3]		Stem diameter (cm)	
			Mean	se	Mean	se	Mean	se	Mean	se	Mean	se	Mean	se	Mean	se
02/December/2015	19/April to 12/May	16	150.75	2.22	17.91	1.52	2.69	0.22	1.73	0.17	2.27	0.17	-	-	-	-
20/December/2016	04/May to 07/June	6	151.83	5.17	20.89	2.00	4.52	0.58	3.45	0.25	3.45	0.26	2.16	0.06	16.62	0.80
18/January/2017	04/May to 07/June	6	122.83	5.17	18.11	1.22	4.15	0.43	3.34	0.18	3.08	0.16	2.11	0.04	14.53	0.55
30/January/2019	17/May to 30/May	2	113.50	5.03	13.24	2.06	4.65	1.01	1.95	0.51	1.89	0.66	-	-	-	-
13/February/2017	11/May to 07/June	5	100.20	4.81	5.85	0.69	1.78	0.28	1.35	0.11	1.91	0.20	1.23	0.04	8.97	0.41
07/March/2017	07/June	1	92.00	-	4.27	-	1.45	-	1.14	-	1.40		0.48	0.04	5.16	0.38

(1) From transplanting to harvest.

(2) Leaf area index.

(3) Plant height and stem diameter were estimated based on the average of 24 plants. The 'se' indicates the mean standard error.

Higher total biomass production, as well as increased accumulation of flowers and leaves in early-season crops, has also been reported in other studies (Kumar et al., 2012; Ramesh; Singh, 2008). Plants that are transplanted later remain in the field for a shorter period because flowering, the optimal time for harvesting, is stimulated by the reduction in photoperiod. Additionally, late crops accumulate fewer growing degree days and are exposed to fewer hours of sunlight, which negatively affects their growth (Kumar et al., 2010).

Plants transplanted at the EEC during the second half of December were harvested when they were over 2 m tall, while those transplanted in March reached the harvest point when they were less than 50 cm tall. Kumar et al. (2012) found that early-transplanted plants were harvested at a height of 2.26 m, while those transplanted 74 days later reached only 1.16 meters.

Plant height and biomass productivity are also affected by planting density. At the EEC, crops were carried out with a spacing of 25 cm between rows and 20 cm between seedlings, representing a planting density of 200,000 plants per hectare. In India, denser plantings are typically carried out with a spacing of 30 cm by 30 cm, or approximately 111,000 plants per hectare (Kumar et al., 2012; Singh et al., 2008). Some studies suggest that denser plantings tend to produce taller plants, although biomass accumulation increases only up to a specific limit (Pal et al., 2023; Walia; Kumar, 2021a).

Comparison biomass productivity across different studies can be challenging due to the lack of information regarding the calculation basis (fresh or dry mass) or the biomass fraction considered (total, useful, with or without stems or branches). One way to minimise this issue is through regression equations, as presented in Figure 4.

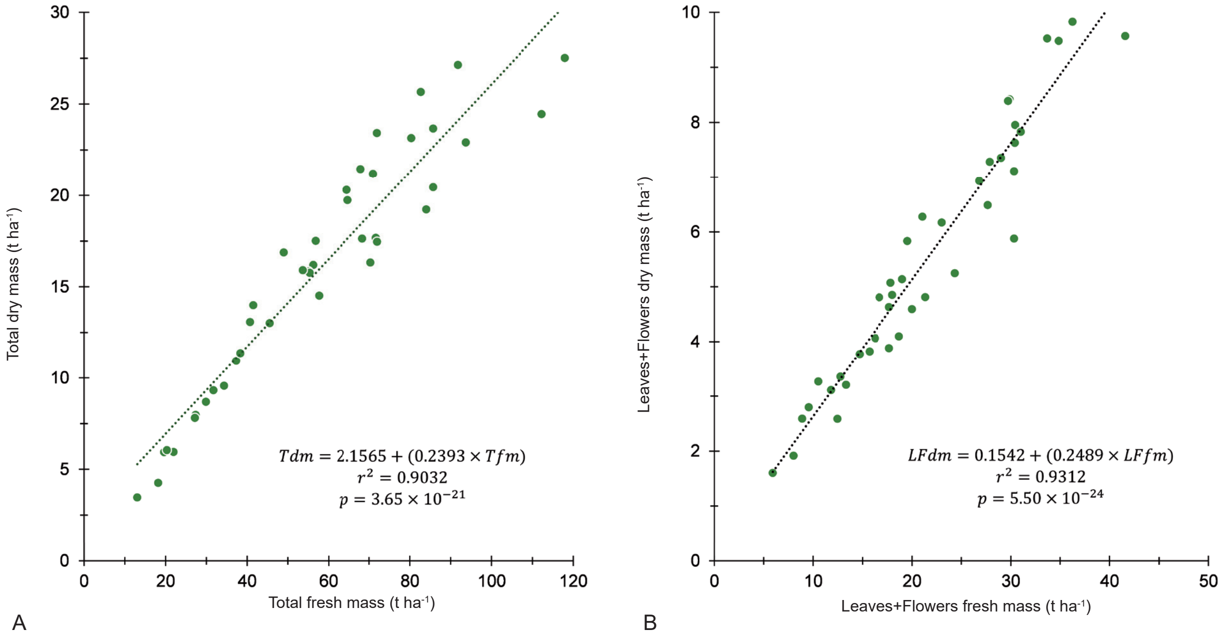

Figure 4. Estimation of total dry mass (Tdm) and leaves and flowers dry mass (LFdm) from total fresh mass (Tfm) and leaves and flowers fresh mass (LFfm) of *Tagetes minuta* L. Cascata Experimental Station (EEC), Embrapa Temperate Agriculture, Pelotas, RS. Brazil.

Studies carried out at the EEC revealed the highest average values of leaf and flower fresh mass harvested, at 30.4 t ha^{-1} and 7.7 t ha^{-1} on a dry basis, respectively, When transplanting occurred betWeen December 20 and January 18. Using 30 cm × 30 cm spacing, Kumar et al. (2012) obtained 18.5 t ha^{-1} of leaf and floWer fresh mass, While Singh et al. (2008) achieved 8.15 t ha^{-1} on a dry basis. When soWing Was done broadcast or in roWs spaced 60 cm apart, With a final stand of 200,000 plants per hectare, Pal et al. (2023) obtained 28.1 t ha^{-1} of fresh mass of *T. minuta*.

Certain cultivation practices also affect the performance of the species. Weed density has a negative correlation with *T. minuta* biomass, particularly in the early stages of development, due to competition for nutrients, water, and light. Weeding at 25 and 50 days after transplanting can increase biomass by about 2.5 times compared to no control measures (Walia et al., 2021). At the EEC, only one manual weeding was carried out between 20 and 25 days after transplanting. Manual weeding is a labour-intensive activity and may make it infeasible to cultivate crops in larger areas. For weeding with motorised implements to be feasible, the spacing between cultivation rows must be increased to at least 50 cm, which would reduce plant population per hectare and, consequently, biomass production. Therefore, further studies are needed to assess whether the lower plant density could be offset by a greater number and frequency of weeding with motorized implements.

Regarding soil conditions, Singh et al. (2001) state that *T. minuta* prefers slightly acidic soils, with a pH between 5.5 and 7.0. Although no specific studies on *T. minuta* exist in Brazil, inferences can be made based on information available for *Calendula officinalis* (Asteraceae), for which a pH of 5.5 is recommended in the state of Rio Grande do Sul (Sociedade Brasileira de Ciência do Solo, 2016).

Soil fertilisation is a widespread practice in countries that commercially cultivate *T. minuta*. Several authors report positive responses to fertilisation, especially with nitrogen, on plant height and total biomass (Pandey et al., 2015; Walia; Kumar, 2021b), flower productivity (Sharma et al., 2017), and essential oil yield and productivity (Omidbaigi et al., 2008; Pandey et al., 2015; Rao et al., 2006). In general, organic fertilisation is performed before cultivation with 15 to 30 t ha^{-1} of cattle manure (Singh et al., 2003; Walia; Kumar, 2021b) or 5 t ha^{-1} of poultry manure (Pandey et al., 2015). Nitrogen fertilisation is traditionally carried out using urea, With 30 to 40 kg ha^{-1} at planting and 60 to 80 kg ha^{-1} as a top-dressing, divided into tWo applications. Phosphorus and potassium are supplied at planting With 60 kg ha^{-1} of P_2O_5 (single superphosphate) and 40 kg ha^{-1} of K_2O (potassium chloride) (Upadhyay et al., 2021; Walia et al., 2021).

The production of secondary metabolites by plants is an evolutionary response to survival and adaptation to the environment conditions, and biotic or abiotic stress factors often act as inducers of their synthesis (Alami et al., 2024). In the case of using highly soluble nitrogen fertilizers, it tends to increase plant biomass production; however, beyond a certain threshold, they may reduce the production of essential compounds (Hao et al., 2024; Qiao et al., 2018; Song et al., 2023; Sun et al., 2020).

In *T. minuta*, the results regarding the effects of fertilisation on essential oil composition are still conflicting. While some studies report no significant effect of nutrient sources or levels (Pandey et al., 2015; Singh; Rao, 2005), others show that nitrogen applications ranging from 120 to 150 kg ha^{-1} tend to reduce the content of Dihydrotagetone and increase the content of cis-beta-Ocimene in the essential oil (Graven et al., 1991; Singh et al., 2008; Walia; Kumar, 2021b).

The *T. minuta* crops at the EEC were planted in areas to take advantage of the residual effect of organic fertilisation carried out in previous crops. Thus, further studies could be set to evaluate adjustments in the organic production system for the plants to express their full productive potential and assess the impact on essential oil quality.

Yield and productivity of essential oil

During the crop seasons conducted at the EEC, the yield and productivity of essential oil varied according to the transplanting and harvesting times of the plants (Table 5).

Table 5. Yield (%) and productivity (kg ha^{-1}) of essential oil from *Tagetes minuta* at different transplanting dates and harvest periods. Cascata Experimental Station (EEC), Embrapa Temperate Agriculture, Pelotas, RS. Brazil.

Transplant	Harvest period	Number of samples	Essential oil					
			Yield (v/w, %)				Productivity (kg/ha)(1)	
			Fresh		Dry			
			Mean	se	Mean	se	Mean	se
02/December/2015	19/April to 12/May	16	0.53	0.07	2.03	0.21	75.30	7.65
20/December/2016	04/May to 07/June	6	0.94	0.09	3.55	0.29	249.69	22.97
18/January/2017	04/May to 07/June	6	0.85	0.09	3.09	0.34	204.89	20.77
30/January/2019	17/May to 30/May	2	0.90	0.05	3.53	0.01	158.75	37.90
13/February/2017	11/May to 07/June	5	0.87	0.11	3.41	0.36	98.35	17.41
07/March/2017	07/June	1	1.00	–	4.80	–	111.71	–

*The volumes in milliliters obtained through distillation were converted into grams considering the approximate density of *T. minuta* essential oil as 0.9 g cm^{-3}.

The data collected at the EEC enabled the development of tools that may be useful in future studies. Considering the hydrodistillation of only flowers and leaves in a Clevenger apparatus, it is possible to estimate essential oil yield on a dry basis using the following linear equation (r^2 = 0.90, p = 2.61×10^{-12}):

$$Y_D = 0.22 + (3.56 \times Y_F)$$

where Y_D is the essential oil yield on a dry basis (%) and Y_F is the yield on a fresh basis (%). It is also possible to estimate essential oil productivity with the following multiple linear equation (r^2 = 0.95, p = 2.51×10^{-23}):

$$P_{adj} = -158{,}39 + (7{,}01 \times LF_{fm}) + (199{,}34 \times Y_F)$$

where P_{adj} is the essential oil productivity (kg ha^{-1}) adjusted by the average oil density (0.9 g cm^{-3}), LF_{fm} is the fresh mass of leaves and flowers (t ha^{-1}), and Y_F is the essential oil yield on a fresh basis (%) obtained through hydrodistillation using a Clevenger apparatus.

However, comparing essential oil yield and productivity between studies is often difficult due to a lack of details regarding the type and preparation of the distilled plant material and the distillation method. Walia and Kumar (2020) compiled production information from various studies and observed essential oil yield variation between 0.25% and 0.78%, with productivity ranging from 29.52 kg ha^{-1} to 68 kg ha^{-1}, depending on the cultivation season, spacing, and groWing method (direct seeding or transplanting). Kumar et al. (2012) achieved higher results when using 30 cm × 30 cm spacing and applying 30 t ha^{-1} of cattle manure to the soil: the yield ranged betWeen 1.19% and 1.58% on a fresh basis, and the essential oil productivity ranged from 110 kg ha^{-1} to 180 kg ha^{-1}.

Nevertheless, the cultivation system developed at the EEC has proven to be quite competitive compared to those recommended in other countries. Seedlings transplanted between December 20 and January 18 and plants harvested between May 4 and June 7 resulted in an average essential oil yield of 0.85±0.07% on a fresh basis and 3.40±0.36% on a dry basis. During this period, the average productivity was 227.29±16.23 kg ha^{-1}.

The high yield obtained in the latest transplanting and harvesting period was due to the plants having a dry mass ratio of flowers to leaves of 2.4:1. In contrast, in the other periods the average was 1.3:1. Since the oil content is generally higher in flowers than in leaves (Kumar et al., 2012, 2014), a greater proportion of flowers in the distilled material tends to increase the yield. This value is similar to that reported by Sartor et al. (2025), who collected *T. minuta* flowers in June and obtained a yield of 4.9% on a dry weight basis.

Chemical composition of essential oil

The essential oil of *T. minuta* obtained at the EEC is rich in cis-Tagetone, cis-beta-Ocimene, and Dihydrotagetone; however, the proportion between these compounds changes according to the harvest time (Table 6 and Figure 5).

Table 6. Mean composition (%) and standard error (se) of *Tagetes minuta* essential oil obtained by hydrodistillation of flowers and leaves harvested between April and June. Cascata Experimental Station (EEC), Embrapa Temperate Agriculture, Pelotas, RS. Brazil.

Compound	Molecular formula	RIcal[(1)]	April		May		June	
			Mean (%)	se	Mean (%)	se	Mean (%)	se
Monoterpenes								
Sabinene	$C_{10}H_{16}$	975	0.81	0.03	0.41	0.04	0.23	0.04
Limonene	$C_{10}H_{16}$	1029	8.16	0.67	3.68	0.35	2.16	0.36
cis-beta-Ocimene	$C_{10}H_{16}$	1037	12.21	1.96	23.88	0.67	26.71	1.49
Oxygenated monoterpenes								
Dihydrotagetone	$C_{10}H_{18}O$	1052	41.48	3.88	18.55	1.65	12.52	2.30
Linalool	$C_{10}H_{18}O$	1096	0.15	0.04	0.10	0.01	–	–
cis-beta-Ocimene epoxide	$C_{10}H_{16}O$	1132	0.25	0.02	0.18	0.01	–	–
trans-Tagetone	$C_{10}H_{16}O$	1144	5.90	0.25	5.32	0.19	4.91	0.31
cis-Tagetone	$C_{10}H_{16}O$	1152	27.40	3.04	45.25	1.66	49.37	2.38
Elsholtzione	$C_{10}H_{14}O_2$	1202	0.14	0.03	–	–	–	–
Sesquiterpenes								
Caryophyllene	$C_{15}H_{24}$	1419	0.40	0.05	0.24	0.02	0.22	0.03
Humulene	$C_{15}H_{24}$	1454	0.42	0.06	0.21	0.02	0.15	0.02
Bicyclogermacrene	$C_{15}H_{24}$	1500	0.48	0.04	0.33	0.03	0.40	0.02

Continued...

Table 6. Continued.

Compound	Molecular formula	RIcal(1)	April		May		June	
			Mean (%)	se	Mean (%)	se	Mean (%)	se
Oxygenated sesquiterpenes								
Spathulenol	$C_{15}H_{24}O$	1578	0.26	0.07	0.08	0.01	–	–
Caryophyllene oxide	$C_{15}H_{24}O$	1583	0.20	0.04	0.18	0.02	0.15	0.04
Monoterpenes	–	–	21.18	–	27.97	–	29.10	–
Oxygenated monoterpenes	–	–	75.34	–	69.41	–	66.81	–
Sesquiterpenes	–	–	1.30	–	0.79	–	0.77	–
Oxygenated sesquiterpenes	–	–	0.47	–	0.26	–	0.15	–
Total	–	–	98.29	–	98.42	–	96.83	–

(1) Retention index calculated

(–) Information not available or not applicable.

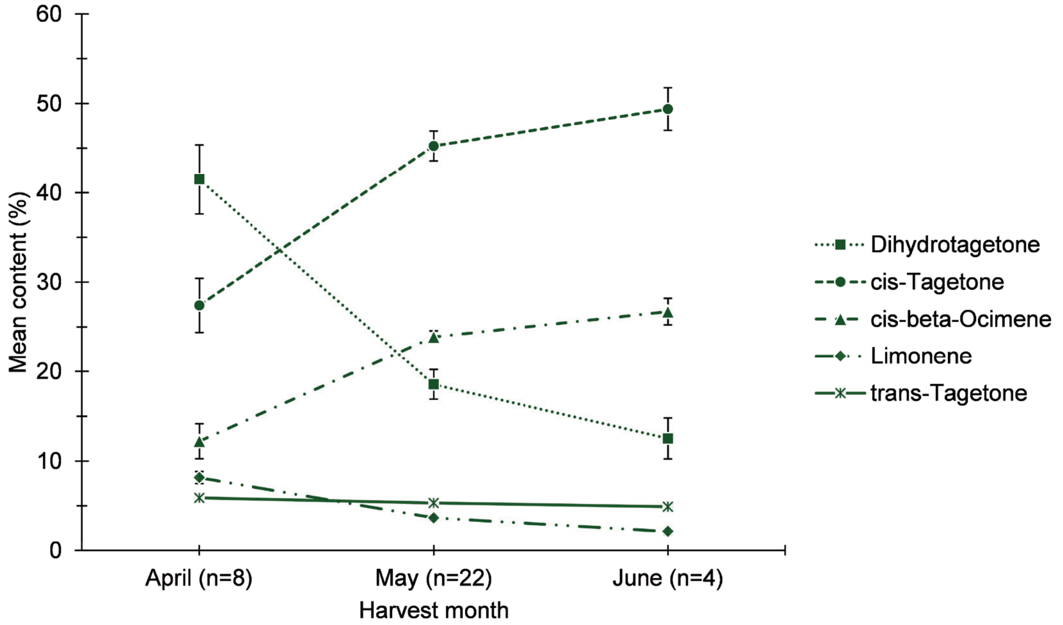

Figure 5. Seasonal variation of major compounds in the *Tagetes minuta* essential oil obtained by hydrodistillation of flowers and leaves harvested between April and June. Vertical bars over the points indicate the mean standard error. Cascata Experimental Station, Embrapa Temperate Climate, Pelotas, RS. Cascata Experimental Station (EEC), Embrapa Temperate Agriculture, Pelotas, RS. Brazil.

The composition of essential oils is affected by biotic and abiotic factors (Khare et al., 2020; Kumar et al., 2022a). Studies have shown that transplanting time (Kumar et al., 2012), plant pinching (Rathore et al., 2018), fertilisation (Walia; Kumar, 2021b), harvest stage (Kumar et al., 2020; Tiwari et al., 2016), post-harvest drying of plant material (Walia et al., 2020a), as well as the distillation method (Babu; Kaul, 2007; Rao et al., 2006) can all influence the chemical composition of *T. minuta* essential oil. Furthermore, comparisons of essential oil compositions between studies must consider variations in the precision of analytical equipment and methodologies used for analysis and compound identification (Rubiolo et al., 2010; Sadgrove et al., 2022; Syafri et al., 2022).

Another important aspect to consider is the occurrence of chemotypes. In South Africa, Tankeu et al. (2013) identified two chemotypes for *T. minuta* essential oil, whereas in Argentina, Gil et al. (2000)

identified three distinct chemotypes. Chemotypes result from evolutionary adaptation processes in which diversification of biosynthetic pathways occurs (Sadgrove; Jones, 2015). Thus, within the same species, some populations may exhibit very distinct chemical profiles compared to others, including variations in the concentrations of major and minor compounds, as well as the presence or absence of specific compounds. Environmental and genetic factors can stimulate these changes and confer different biological properties to the essential oil (Benomari et al., 2023).

More than 95% of the essential oil composition of *T. minuta* produced at the EEC is composed of five compounds, which on average follow this descending order: cis-Tagetone > Dihydrotagetone > cis-beta-Ocimene > trans-Tagetone > Limonene. A similar result was reported by Lizarraga et al. (2017) in Argentina, analysing essential oil from wild populations in the province of Tucumán.

It is noteworthy that the proportion between the main compounds of the essential oil changes drastically with the phenological evolution of the plants. Between April and June, the Dihydrotagetone content was reduced by 3.3 times, and the cis-Tagetone and cis-beta-Ocimene contents were increased by 1.8 times and 2.2 times, respectively. Harvests carried out in April showed an approximate ratio of 2:1:3 between cis-Tagetone, cis-beta-Ocimene, and Dihydrotagetone. In contrast, the ratio shifted to 4:2:1 in June.

This shift in the ratio of major constituents is also reported in other studies (Chamorro et al., 2008; Kumar et al., 2020) and is linked to the composition of essential oils in different plant parts. According to Kumar et al. (2020), leaves are richer in Dihydrotagetone, while the flowers are richer in cis-Tagetone and cis-beta-Ocimene. Therefore, when harvesting occurs at the beginning of flowering, the Dihydrotagetone present in the leaves tends to predominate in the composition, whereas during full bloom, cis-Tagetone and cis-beta-Ocimene become predominant.

Several abiotic factors also influence the essential oil composition of *T. minuta* (Kumar et al., 2022a). Plants exposed to higher levels of water stress tend to produce more oxygenated monoterpenes (Babaei et al., 2021). Shading reduces the levels of cis-beta-Ocimene and Dihydrotagetone, while increasing those of Tagetones and Ocimenones, with little effect on Limonene content (Kumar et al., 2014). Intercropping *T. minuta* with maize increased the levels of cis-beta-Ocimene, cis- and trans-Tagetone, and cis- and trans-Ocimenone compared to monocropping (Walia; Kumar, 2021a).

Regarding the effects of fertilisation on essential oil composition, studies show conflicting results. Omidbaigi et al. (2008) applied nitrogen doses between 50 and 200 kg ha^{-1} and found an increase in trans-Tagetone, but no clear trend in Limonene, cis-Tagetone, or Dihydrotagetone levels. In *T. terniflora*, nitrogen fertilisation did not affect essential oil composition (Cruz et al., 2014). Conversely, Upadhyay et al. (2021) reported that increasing nitrogen doses reduced cis-Tagetone content, tended to increase the Dihydrotagetone and cis-beta-Ocimene, and had no effect on Limonene.

According to Pandey et al. (2015), fertilisation with different organic sources did not change the composition of *T. minuta* oil. In that study, supplementation with mineral fertiliser did not affect Dihydrotagetone levels, but increased the concentrations of Limonene, cis-beta-Ocimene, and cis-Tagetone.

In another study, mineral fertilisation with 120 kg ha^{-1} of nitrogen and 60 kg ha^{-1} of sulphur resulted in the highest levels of cis-beta-Ocimene compared to unfertilised control plants (Walia; Kumar, 2021b). It Was also found that the inoculation of rhizobacteria can increase the concentration of cis-beta-Ocimene, Limonene, and cis- and trans-Tagetone in the essential oil of *T. minuta* (Santoro et al., 2015).

Additionally, the extraction method can also affect the composition of essential oils. Due to differences in solubility, steam distillation tends to lose significant fractions of oxygenated monoterpenes to the hydrolate. In turn, hydrodistillation extracts higher concentrations of sesquiterpenes and phenolic compounds than steam distillation (Rao et al., 2006).

Understanding this dynamic is important for targeting the appropriate markets for the oil (Tankeu et al., 2013). In general, the five major constituents of the essential oil obtained at the EEC have applications in the flavor and fragrance industry (Breme et al., 2009; EPA, 2025; NCBI, 2025a). Some authors note that concentrations between 35% and 50% of cis-beta-Ocimene are more valued in international markets (Walia; Kumar, 2020, 2021c).

Studies on the use of essential oil as a botanical pesticide show that certain fractions of *T. minuta* oil are biologically more effective than others. In a survey on aphids, Tomova et al. (2005) found that oxygenated monoterpenes and sesquiterpenes were more effective in reducing reproduction than monoterpenes. According to the authors, when comparing isolated compounds, Caryophyllene had a greater effect than Limonene or Ocimene. Table 7 presents some of the biological effects already proven in scientific literature for the compounds present in the composition of *T. minuta* essential oil obtained at the EEC.

Table 7. Biological properties and uses of the compounds present in the composition of the essential oil of *T. minuta* obtained by hydrodistillation of flowers and leaves harvested at the Cascata Experimental Station (EEC).

Classes	Compounds	Biological properties and uses	References
Hydro carbons	Sabinene	Medicine: antifungal, anti-inflammatory Industry: fragrances, flavourings, fine chemicals.	Cao et al. (2018).
	Limonene	Medicine: antimicrobial, antiviral, antioxidant, anti-inflammatory, antitumor, antidepressant, neuroprotective, anthelmintic. Agriculture: pesticide, herbicide. Industry: fragrances, flavourings, cosmetic products, food manufacturing.	Wang et al. (2024); Lin et al. (2024); Rutnik et al. (2022); Sharmeen et al. (2021); Pavela (2016); Gupta et al. (2023); NCBI (2025b).
	cis-beta-Ocimene	Public health: vector insect larvicide. Agriculture: attractive to pollinators, nematicidal. Industry: fragrances, flavourings.	Farré-Armengol et al. (2017); Govindarajan; Benelli (2016b); Adekunle et al. (2007); NCBI (2025c).
	Caryophyllene	Medicine: anti-inflammatory, antimicrobial, antioxidant, analgesic, anticonvulsant, anti-anxiety, antidepressant, anticancer, gastroprotective, neuroprotective, cardioprotective. Agriculture: pesticide, insect attractant. Industry: fragrances, flavourings.	Rutnik et al. (2022); Janadri et al. (2025); Bahi et al. (2014); Tomova et al. (2005); Lee; Ko (2021); Duarte et al. (2024); NCBI (2025d).
	Humulene	Medicine: anticancer, anti-inflammatory, anti-allergic, antidepressant, anti-anxiety, antioxidant. Industry: fragrances, flavourings.	Rutnik et al. (2022); Duarte et al. (2024); Ben Miri (2025); NCBI (2025e).
	Bicyclo germacrene	Public health: vector insect larvicide.	Govindarajan; Benelli (2016a).
Alcohols	Linalool	Medicine: anti-inflammatory, antioxidant, antimicrobial, anti-anxiety, neuroprotective, anticancer, sedative, analgesic, anticonvulsant. Agriculture: attractive to pollinators, pesticide, repellent, fumigant. Industry: fragrances, flavourings, cosmetic products.	Rutnik et al. (2022); Aprotosoaie et al. (2014); Sharmeen et al. (2021); Kamatou; Viljoen (2008); Campos et al. (2019); Ben Miri (2025); NCBI (2025f).
	Spathulenol	Medicine: anaesthetic, vasodilator agent. Agriculture: pesticide.	Benelli et al. (2020); El-Solimany et al. (2024); NCBI (2025g).
Oxides	cis-beta-Ocimene epoxide	Industry: fragrances, flavourings.	Agrebi et al. (2012).
	Caryophyllene oxide	Medicine: anti-inflammatory, anticancer, analgesic, antioxidant, chemopreventive. Agriculture: pesticide. Industry: fragrances, flavourings.	Rutnik et al. (2022); Duarte et al. (2024); Di Sotto et al. (2020); El-Solimany et al. (2024); Singh et al. (2014); Tung et al. (2008); NCBI (2025h).

Continued...

Table 7. Continued.

Classes	Compounds	Biological properties and uses	References
Ketones	Dihydrotagetone	Agriculture: nematicidal.	Adekunle et al. (2007); Joshi et al. (2005); Cruz Flores et al. (2021); NCBI (2025i).
	trans-Tagetone	Medicine: antifungal. Industry: fragrances.	Joshi et al. (2005); Oliveira et al. (2019); Cruz Flores et al. (2021).
	cis-Tagetone	Industry: fragrances.	Joshi et al. (2005); Cruz Flores et al. (2021).
	Elsholtzione	Agriculture: fumigant, pesticide.	Li et al. (2024).

Despite the individual properties of each compound, there is substantial evidence that the biological effects of the whole mixture of essential oil are more significant than the effects of the isolated compounds, whether in medicinal or agricultural applications. This is due to synergistic interactions among major, minor, and even those considered inert constituents (Bunse et al., 2022; Chen et al., 2021; Jiang et al., 2009; Ntalli et al., 2010). Often, the compounds of the essential oil fulfil different roles within a product. For example, while one compound may exert a biocidal effect, another may enhance its cuticular penetration, thereby amplifying its efficacy (Tak; Isman, 2017).

Final remarks

Brazil has not been producing essential oil from *T. minuta* on a large commercial scale, as stated over 35 years ago by Craveiro et al. (1988). This incorrect statement has recently been clarified (Schiedeck, 2024). However, the research conducted at the Cascata Experimental Station (EEC) demonstrates that the cultivation of this species has a productive potential equivalent to or even greater than that observed in countries with more established expertise.

In India, cultivation practices such as fertilisation, irrigation, and pinching have been recommended to enhance the performance of the species and, consequently, improve the economic outcome (Singh et al., 2003). None of these practices has yet been tested at the EEC, suggesting significant potential for further development. Nevertheless, India and Argentina currently maintain a technological advantage over Brazil by already having genotype selection programs, which focus on higher productivity and identified chemotypes. In Brazil, seed use is still based on spontaneous populations, which exhibit morphological variability and lack standardised chemical profiles.

Despite its limited presence in the global market, *T. minuta* essential oil is gaining increasing attention, driven by research highlighting its potential in various industrial segments. In this context, the findings from the work carried out at the EEC provide a valuable contribution to the diversification of the essential oil production chain, pointing toward emerging market opportunities and future demands.

References

ADAMS, R. P. **Identification of essential oil components by gas chromatography/mass spectrometry**. 2 ed. Carol Stream: Allured Pub. Corp., 1995. 469 p.

ADEKUNLE, O. K.; ACHARYA, R.; SINGH, B. Toxicity of pure compounds isolated from *Tagetes minuta* oil to *Meloidogyne incognita*. **Australasian Plant Disease Notes**, v. 2, n. 1, p. 101-104, 2007. DOI: https://doi.org/10.1071/DN07042

AGREBI, A.; AGNANIET, H.; BIKANGA, R.; MAKANI, T.; ANGUILÉ, J. J.; LEBIBI, J.; CASABIANCA, H.; MORÈRE, A.; MENUT, C. Essential oil of *Plectranthus tenuicaulis* for flavour and fragrance: Synthesis of derivatives from natural and synthetic 6,7-epoxyocimenes. **Flavour and Fragrance Journal**, v. 27, n. 2, p. 188–195, 2012. DOI: https://doi.org/10.1002/ffj.3087

ALAMI, M. M.; GUO, S.; MEI, Z.; YANG, G.; WANG, X. Environmental factors on secondary metabolism in medicinal plants: exploring accelerating factors. **Medicinal Plant Biology**, v. 3, n. 1, p. e016, 2024. DOI: https://doi.org/10.48130/mpb-0024-0016

ALBUQUERQUE, Y. E. **Atividade antimicrobiana e antibiofilme de óleos essenciais contra micro-organismos orais**. Araraquara, 2018. 123 f. Tese (Doutorado em Ciências Odontológicas) - Faculdade de Odontologia de Araraquara, Universidade Estadual Paulista, Araraquara.

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; GONÇALVES, J. L. de M.; SPAROVEK, G. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, v. 22, n. 6, p. 711–728, 2013. DOI: https://doi.org/10.1127/0941-2948/2013/0507

APARCO, R. H.; LAIME, M. C. L.; TADEO, F. T. Metabolitos bioactivos y actividad antioxidante in vitro del aceite esencial extraído de dos especies del género Tagetes. **Revista Colombiana de Ciencias Químico-Farmacéuticas**, v. 50, n. 3, p. 726–739, 2022. DOI: https://doi.org/10.15446/rcciquifa.v50n3.93429

APROTOSOAIE, A. C.; HĂNCIANU, M.; COSTACHE, I.; MIRON, A. Linalool: a review on a key odorant molecule with valuable biological properties. **Flavour and Fragrance Journal**, v. 29, n. 4, p. 193–219, 2014. DOI: https://doi.org/10.1002/ffj.3197

ARELLANO, L.; ARROYO, D. Revalorización y visibilización de la gastronomía ancestral andina a través del turismo cultural, caso de estudio: La Pachamanca (olla de tierra). **Journal of Tourism and Heritage Research**, v. 2, n. 4, p. 1–23, 2019.

ARTURO, P. L. **Bebida a partir de la chinchilla (*Tagetes minuta*) y su uso en la gastronomía con valor agregado**. Ambato, 2021. 64 f. Monografia (Licenciatura en Gestión de Alimentos y Bebidas) – Facultad de Dirección de Empresas, Universidad Regional Autónoma de Los Andes, Ambato.

BABAEI, K.; MOGHADDAM, M.; FARHADI, N.; PIRBALOUTI, A. G. Morphological, physiological and phytochemical responses of Mexican marigold (*Tagetes minuta* L.) to drought stress. **Scientia Horticulturae**, v. 284, n. March, p. 110116, 2021. DOI: https://doi.org/10.1016/j.scienta.2021.110116

BABU, K. G. D.; KAUL, V. K. Variations in quantitative and qualitative characteristics of wild marigold (*Tagetes minuta* L.) oils distilled under vacuum and at NTP. **Industrial Crops and Products**, v. 26, n. 3, p. 241–251, 2007. DOI: https://doi.org/10.1016/j.indcrop.2007.03.013

BAHI, A.; AL MANSOURI, S.; AL MEMARI, E.; AL AMERI, M.; NURULAIN, S. M.; OJHA, S. β-Caryophyllene, a CB2 receptor agonist produces multiple behavioral changes relevant to anxiety and depression in mice. **Physiology & Behavior**, v. 135, p. 119–124, 2014. DOI: https://doi.org/10.1016/j.physbeh.2014.06.003

BANDANA, K.; RAINA, R. Pollination studies in *Tagetes minuta*, an important medicinal and aromatic plant. **Medicinal Plants - International Journal of Phytomedicines and Related Industries**, v. 9, n. 2, p. 140, 2017. DOI: https://doi.org/10.5958/0975-6892.2017.00021.1

BANDANA, K.; RAINA, R.; KUMARI, M.; RANI, J. *Tagetes minuta*: an overview. **International Journal of Chemical Studies**, v. 6, n. 2, p. 3711–3717, 2018.

BEN MIRI, Y. Essential oils - chemical composition and diverse biological activities: a comprehensive review. **Natural Product Communications**, v. 20, n. 1, p. 1-29, 2025. DOI: https://doi.org/10.1177/1934578X241311790

BENELLI, G.; PAVELA, R.; DRENAGGI, E.; DESNEUX, N.; MAGGI, F. Phytol, *(E)*-nerolidol and spathulenol from *Stevia rebaudiana* leaf essential oil as effective and eco-friendly botanical insecticides against *Metopolophium dirhodum*. **Industrial Crops and Products**, v. 155, n. June, p. 112844, 2020. DOI: https://doi.org/10.1016/j.indcrop.2020.112844

BENOMARI, F. Z.; SARAZIN, M.; CHAIB, D.; PICHETTE, A.; BOUMGHAR, H.; BOUMGHAR, Y.; DJABOU, N. Chemical variability and chemotype concept of essential oils from Algerian wild plants. **Molecules**, v. 28, n. 11, p. 4439, 2023. DOI: https://doi.org/10.3390/molecules28114439

BIZZO, H.; REZENDE, C. O mercado de óleos essenciais no Brasil e no mundo na última década. **Química Nova**, v. 45, n. 8, p. 949–958, 2022. DOI: https://doi.org/10.21577/0100-4042.20170889

BREME, K.; TOURNAYRE, P.; FERNANDEZ, X.; MEIERHENRICH, U. J.; BREVARD, H.; JOULAIN, D.; BERDAGUÉ, J. L. Identification of odor impact compounds of *Tagetes minuta* L. essential oil: comparison of two GC-olfactometry methods. **Journal of Agricultural and Food Chemistry**, v. 57, n. 18, p. 8572–8580, 2009. DOI: https://doi.org/10.1021/jf9016509

BUNSE, M.; BUNSE, M.; DANIELS, R.; GRÜNDEMANN, C.; HEILMANN, J.; KAMMERER, D. R.; KEUSGEN, M.; LINDEQUIST, U.; MELZIG, M. F.; MORLOCK, G. E.; SCHULZ, H.; SCHWEIGGERT, R.; SIMON, M.; STINTZING, F. C.; WINK, M. Essential oils as multicomponent mixtures and their potential for human health and well-being. **Frontiers in Pharmacology**, v. 13, n. August, p. 1–25, 2022. DOI: https://doi.org/10.3389/fphar.2022.956541

CAMPOS, E. V. R.; PROENÇA, P. L. F.; OLIVEIRA, J. L.; BAKSHI, M.; ABHILASH, P. C.; FRACETO, L. F. Use of botanical insecticides for sustainable agriculture: future perspectives. **Ecological Indicators**, v. 105, n. April 2018, p. 483–495, 2019. DOI: https://doi.org/10.1016/j.ecolind.2018.04.038

CAO, Y.; ZHANG, H.; LIU, H.; LIU, W.; ZHANG, R.; XIAN, M.; LIU, H. Biosynthesis and production of sabinene: current state and perspectives. **Applied Microbiology and Biotechnology**, v. 102, n. 4, p. 1535–1544, 2018. DOI: https://doi.org/10.1007/s00253-017-8695-5

CARNEIRO, C. R.; REBOUÇAS, N. C. **Tagetes**. Flora e Funga do Brasil. 2025. Available at: https://floradobrasil.jbrj.gov.br/FB16341. Accessed on: 5 fev. 2025.

CARNEIRO, C. R.; RITTER, M. R. A tribo Tageteae (Asteraceae) no sul do Brasil. **Iheringia, Série Botânica**, v. 73, n. 2, p. 114–134, 2018. DOI: https://doi.org/10.21826/2446-8231201873204

CASTRO, C. de; FARIAS, J. R. B. Ecofisiologia do girassol. In: LEITE, R. M. V. B. C.; BRIGHENTI, A. M.; CASTRO, C. (Ed.). **Girassol no Brasil**. Londrina: Embrapa Soja, 2005. p. 163–218.

CASTRO, K. N. C.; CANUTO, K. M.; BRITO, E. S.; COSTA-JÚNIOR, L. M.; DE ANDRADE, I. M.; MAGALHÃES, J. A.; BARROS, D. M. A. In vitro efficacy of essential oils with different concentrations of 1,8-cineole against *Rhipicephalus (Boophilus) microplus*. **Revista Brasileira de Parasitologia Veterinária**, v.27, n. 2, p. 203–210, 2018. DOI: https://doi.org/10.1590/S1984-29612018001

CBI. **CBI Product Factsheet:** *Tagetes minuta* oil in Europe. CBI Market Information Database. 9 p. 2015.

CEPEDA, D. F.; ASCARI, J.; OLIVEIRA, M. S. de; ANTONIOLI, G.; BARCELLOS, T.; ANHOLETO, L. A.; NUNES, P. H. Effect of *Tagetes minuta* essential oil on the central nervous system of unfed *Rhipicephalus sanguineus* sensu lato 'tropical lineage' ticks. **Experimental and Applied Acarology**, v. 91, n. 4, p. 697–714, 2023. DOI: https://doi.org/10.1007/s10493-023-00867-3

CHAMORRO, E. R.; BALLERINI, G.; SEQUEIRA, A. F.; VELASCO, G. A.; ZALAZAR, M. F. Chemical composition of essential oil from *Tagetes minuta* L. leaves and flowers. **Journal of the Argentine Chemical Society**, v. 96, n. 1–2, p. 80–86, 2008.

CHÁVEZ-NÚÑEZ, D. J.; CHÁVEZ-NÚÑEZ, K. W.; De La CRUZ-OCAÑA, J.; GARCÍA-MENDOCILLA, G. F. Análisis de la Pachamanca, una técnica de cocción ancestral en el centro poblado de Maynay. **Scientific Research Journal CIDI**, v. 1, n. 2, p. 203–227, 2021. DOI: https://doi.org/10.53942/srjcidi.v1i2.64

CHEN, Y.; LUO, J.; ZHANG, N.; YU, W.; JIANG, J.; DAI, G. Insecticidal activities of *Salvia hispanica* L. essential oil and combinations of their main compounds against the beet armyworm *Spodoptera exigua*. **Industrial Crops and Products**, v. 162, n. January, p. 113271, 2021. DOI: https://doi.org/10.1016/j.indcrop.2021.113271

CORTÉS-FLORES, J.; ANDRESEN, E.; CORNEJO-TENORIO, G.; IBARRA-MANRÍQUEZ, G. Fruiting phenology of seed dispersal syndromes in a Mexican Neotropical temperate forest. **Forest Ecology and Management**, v. 289, p. 445–454, 2013. DOI: https://doi.org/10.1016/j.foreco.2012.10.038

CORTEZ, F. C. G. **Evaluación de características sensoriales, físicoquímicas y microbiológicas de un queso mozzarella elaborado con diferentes porcentajes de huacatay (*Tagetes minuta* L.)**. Cajamarca, 2025. 126 f. Monografia (Ingeniero en Industrias Alimentarias) – Facultad de Ciencias Agrarias, Universidad Nacional de Cajamarca, Cajamarca.

CRAVEIRO, A. A.; MATOS, F. J. A.; MACHADO, M. I. L.; ALENCAR, J. W. Essential oils of *Tagetes minuta* from Brazil. **Perfumer and Flavorist**, v. 13, n. 35, p. 35–36, 1988.

CRUZ, M. Á. S.; CEDILLO, F. D.; MEDINA, D. H.; RODRÍGUEZ, A. C. Two agronomical aspects of *Tagetes terniflora* HBK for essential oil production. **Journal of Agricultural Chemistry and Environment**, v. 3, n. 1, p. 9–13, 2014. DOI: https://doi.org/10.4236/jacen.2014.31002

CRUZ FLORES, O.; ESPINOZA RUIZ, M.; SANTIESTEBAN HERNÁNDEZ, A.; CRUZ-LÓPEZ, L. Caracterización química de los volátiles de *Tagetes nelsonii*. **Polibotánica**, n. 51, p. 203–211, 2021. DOI: https://doi.org/10.18387/polibotanica.51.13

CSIR-IHBT. Council of Scientific and Industrial Research, Institute of Himalayan Bioresource Technology. **Annual Report 2017-18**. Palampur: CSIR-IHBT, 2019. Available at: https://www.ihbt.res.in/images/Annual_Reports/AR2017_18.pdf.pdf. Accessed on: 2 abr. 2025.

CSIR-IHBT. Council of Scientific and Industrial Research, Institute of Himalayan Bioresource Technology. **Annual Report 2019-20**. Palampur: CSIR-IHBT, 2020. Available at: https://library.ihbt.res.in/AR/AR%202019-20.pdf. Accessed on: 2 abr. 2025.

CUNHA, J. A.; SCHEEREN, C. A.; OLIVEIRA, A. M.; SUTILI, F. J.; PINHEIRO, C. G.; BALDISSEROTTO, B.; HEINZMANN, B. M. Toxixity of *Tagetes minuta* essential oil in silver catfish (*Rhamdia quelen*). **International Journal of Pharmacy and Pharmaceutical Sciences**, v. 8, n. 6, p. 11–13, 2016.

DE LA CRUZ, M. G.; BALDEÓN MALPARTIDA, S.; BELTRÁN SANTIAGO, H.; JULLIAN, V.; BOURDY, G. Hot and cold: medicinal plant uses in Quechua speaking communities in the high Andes (Callejón de Huaylas, Ancash, Perú). **Journal of Ethnopharmacology**, v. 155, n. 2, p. 1093–1117, 2014. DOI: https://doi.org/10.1016/j.jep.2014.06.042

DI SOTTO, A.; MANCINELLI, R.; GULLÌ, M.; EUFEMI, M.; MAMMOLA, C. L.; MAZZANTI, G.; DI GIACOMO, S. Chemopreventive potential of caryophyllane sesquiterpenes: an overview of preliminary evidence. **Cancers**, v. 12, n. 10, p. 3034, 2020. DOI: https://doi.org/10.3390/cancers12103034

DUARTE, P. F.; NASCIMENTO, L. H. do; BANDIERA, V. J.; FISCHER, B.; FERNANDES, I. A.; PAROUL, N.; JUNGES, A. Exploring the versatility of hop essential oil (*Humulus lupulus* L.): bridging brewing traditions with modern industry applications. **Industrial Crops and Products**, v. 218, n. April, p. 118974, 2024. DOI: https://doi.org/10.1016/j.indcrop.2024.118974

EL-SOLIMANY, E. A.; ABDELHAMID, A. A.; THABET, M. A.; GAD, M. A. Effective and eco-friendly botanical insecticidal agents against *Spodoptera frugiperda* (Noctuidae: Lepidoptera) using the essential oil of *Stevia rebaudiana*. **Journal of Natural Pesticide Research**, v. 10, n. August, p. 100103, 2024. DOI: https://doi.org/10.1016/j.napere.2024.100103

EPA. United States Environmental Protection Agency. **CompTox Chemicals Dashboard**. 2025. Available at: https://comptox.epa.gov/dashboard/. Accessed on: 9 mar. 2025.

FARRÉ-ARMENGOL, G.; FILELLA, I.; LLUSIÀ, J.; PEÑUELAS, J. β-Ocimene, a key floral and foliar volatile involved in multiple interactions between plants and other organisms. **Molecules**, v. 22, n. 7, p. 1148, 2017. DOI: https://doi.org/10.3390/molecules22071148

FELIPPE, G. M.; POLO, M. Germinação de ervas invasoras: efeito de luz e escarificação. **Revista Brasileira de Botânica**, v. 6, n. 1, p. 55–60, 1983.

FERREIRA, A. G.; CASSOL, B.; ROSA, S. G. T. da; SILVEIRA, T. S. da.; STIVAL, A. L.; SILVA, A. A. Germinação de sementes de Asteraceae nativas no Rio grande do Sul. **Acta Botanica Brasilica**, v. 15, n. 2, p. 231–242, 2001. DOI: http:// doi.org/10.1590/S0102-33062001000200009

FONSECA, C. da. **Fenologia e caracterização fitoquímica do óleo essencial de Tagetes minuta L. (Asteraceae)**. 2018. 113 f. Dissertação (Mestrado em Agronomia) – Programa de Pós-Graduação em Sistemas de Produção Agrícola Familiar, Faculdade de Agronomia Eliseu Maciel, Universidade Federal de Pelotas, Pelotas.

FORSYTH, C.; VAN STADEN, J. Germination of *Tagetes minuta* L. I. Temperature effects. **Annals of Botany**, v. 52, n. 5, p. 659–666, 1983. DOI: https://doi.org/10.1093/oxfordjournals.aob.a086622

FURTADO, R. F.; LIMA, M. G. A. de; ANDRADE NETO, M.; BEZERRA, J. N. S.; SILVA, M. G. de V. Atividade larvicida de óleos essenciais contra *Aedes aegypti* L. (Diptera: Culicidae). **Neotropical Entomology**, v. 34, n. 5, p. 843–847, 2005. DOI: https://doi.org/10.1590/S1519-566X2005000500018

GARCIA, M. V.; MATIAS, J.; BARROS, J. C.; LIMA, D. P. de; LOPES, R. da S.; ANDREOTTI, R. Chemical identification of *Tagetes minuta* Linnaeus (Asteraceae) essential oil and its acaricidal effect on ticks. **Revista Brasileira de Parasitologia Veterinária**, v. 21, n. 4, p. 405–411, 2012. DOI: https://doi.org/10.1590/S1984-29612012000400011

GIL, A.; GHERSA, C. M.; LEICACH, S. Essential oil yield and composition of *Tagetes minuta* accessions from Argentina. **Biochemical Systematics and Ecology**, v. 28, p. 261–274, 2000.

GOMES, F. T. **Avaliação do perfil químico do óleo essencial de populações espontâneas de *Tagetes minuta* L. (Asteraceae) na região sul do Rio Grande do Sul**. 2017. 45 f. Dissertação (Mestrado em Agronomia) – Programa de Pós-Graduação em Sistemas de Produção Agrícola Familiar, Faculdade de Agronomia Eliseu Maciel, Universidade Federal de Pelotas, Pelotas.

GOBIERNO REGIONAL CUSCO. **Diccionario Quechua - Español - Quechua**. 2. ed. Cusco: *Gobierno Regional Cusco*, 2005. 928 p.

GOVINDARAJAN, M.; BENELLI, G. Eco-friendly larvicides from Indian plants: effectiveness of lavandulyl acetate and bicyclogermacrene on malaria, dengue and Japanese encephalitis mosquito vectors. **Ecotoxicology and Environmental Safety**, v. 133, p. 395–402, 2016a. DOI: https://doi.org/10.1016/j.ecoenv.2016.07.035

GOVINDARAJAN, M.; BENELLI, G. *Artemisia absinthium*-borne compounds as novel larvicides: effectiveness against six mosquito vectors and acute toxicity on non-target aquatic organisms. **Parasitology Research**, v. 115, n. 12, p. 4649–4661, 2016b. DOI: https://doi.org/10.1007/s00436-016-5257-1

GRAVEN, E. H.; WEBBER, L.; BENIANS, G.; VENTER, M.; GARDNER, J. B. Effect of soil type and nutrient status on the yield and composition of Tagetes oil (*Tagetes minuta* L.). **Journal of Essential Oil Research**, v. 3, n. 5, p. 303–307, 1991. DOI: https://doi.org/10.1080/10412905.1991.9697948

GRUMMOND, N. T. Prophets and priests. In: GRUMMOND, N. T. de; SIMON, E. (org.). **The Religion of the Etruscans**. 1st. ed. Austin: University of Texas Press, 2006. p. 27–44.

GUPTA, I.; SINGH, R.; MUTHUSAMY, S.; SHARMA, M.; GREWAL, K.; SINGH, H. P.; BATISH, D. R. Plant essential oils as biopesticides: applications, mechanisms, innovations, and constraints. **Plants**, v. 12, n. 16, p. 2916, 2023. DOI: https://doi.org/10.3390/plants12162916

GUPTA, R.; KHAJURIA, S. Correlation matrix and optimization of phenophases in *Tagetes minuta* grown in subtropical environment of Jammu, India. **Asian Journal of Soil Science**, v. 2, n. 2, p. 65–68, 2007.

GUTIÉRREZ, D. G.; STAMPACCHIO, M. L. Tagetes. In: ZULOAGA, F. O.; BELGRANO, M. J.; ANTON, A. M. (Org.). **Flora argentina: flora vascular de la República Argentina**. Buenos Aires: Estudio Sigma SRL, 2015. p. 118–129.

HACK, H.; BLEIHOLDER, H.; BUHR, L.; MEIER, U.; SCHNOCK-FRICKE, U.; WEBER, E.; WITZENBERGER, A. Einheitliche codierung der phänologischen entwicklungsstadien mono-und dikotyler pflanzen.-Erweiterte BBCH-Skala, Allgemein-. **Nachrichtenblatt des Deutschen Pflanzenschutzdienstes**, v. 44, n. 12, p. 265–270, 1992.

HAO, D.; LUAN, Y.; WANG, Y.; XIAO, P. Unveiling nitrogen fertilizer in medicinal plant cultivation. **Agronomy**, v. 14, n. 8, p. 1647, 2024. DOI: https://doi.org/10.3390/agronomy14081647

HASTORF, C. A.; BRUNO, M. C. The flavors archaeobotany forgot. **Journal of Anthropological Archaeology**, v. 59, n. June, p. 101189, 2020. DOI: https://doi.org/10.1016/j.jaa.2020.101189

IBGE. Instituto Brasileiro de Geografia e Estatística. **Pedologia**. 2023. Available at: https://bdiaweb.ibge.gov.br/#/consulta/pedologia%3E. Accessed on: 29 jan. 2025.

JANADRI, S.; KUMAR, R. R.; MANJUNATHA, P. M.; SHARMA, U. R.; VADA, S.; MADHU, M. V.; ANGADI, P. P. A systemic review of beta-Caryophyllene. **Defence Life Science Journal**, v. 10, n. 1, p. 65–71, 2025. DOI: https://doi.org/10.14429/dlsj.19817

JIANG, Z.; AKHTAR, Y.; BRADBURY, R.; ZHANG, X.; ISMAN, M. B. Comparative toxicity of essential oils of *Litsea pungens* and *Litsea cubeba* and blends of their major constituents against the cabbage looper, *Trichoplusia ni*. **Journal of Agricultural and Food Chemistry**, v. 57, n. 11, p. 4833–4837, 2009. DOI: https://doi.org/10.1021/jf900274r

JOSHI, R. K.; BARBALHO, S. M. Volatile composition and biological activities of Tagetes (Marigold): an overview. **International Journal of Pharmacognosy & Chinese Medicine**, v. 6, n. 1, p. 1–13, 2022. DOI: https://doi.org/10.23880/ipcm-16000226

JOSHI, V. P.; SINGH, B.; KAUL, V. K.; MAHMOOD, U. Chemical transformation of 3,7-dimethyl,5-one,1-octene (dihydrotagetone), into new odour molecules. **Flavour and Fragrance Journal**, v. 20, n. 6, p. 592–595, 2005. DOI: https://doi.org/10.1002/ffj.1493

JYOTI, A. **Hill farmers drawing towards fragrance of bright wild marigold flowers**. 2018. Available at: https://www.dailypioneer.com/2018/india/hill-farmers-drawing-towards-fragrance-of-bright-wild-marigold-flowers.html. Accessed on: 21 abr. 2025.

KAMATOU, G. P. P.; VILJOEN, A. M. Linalool – a review of a biologically active compound of commercial importance. **Natural Product Communications**, v. 3, n. 7, p. 1183–1192, 2008.

KAPLAN, L. Historical and ethnobotanical aspects of domestication in Tagetes. **Economic Botany**, v. 14, n. 3, p. 200–202, 1960. DOI: https://doi.org/10.1007/BF02907950

KARLSSON, L. M.; TAMADO, T.; MILBERG, P. Inter-species comparison of seed dormancy and germination of six annual Asteraceae weeds in an ecological context. **Seed Science Research**, v. 18, n. 1, p. 35–45, 2008. DOI: https://doi.org/10.1017/S0960258508888496

KHARE, S.; SINGH, N. B.; SINGH, A.; HUSSAIN, I.; NIHARIKA, K.; YADAV, V.; BANO, C.; YADAV, R. K.; AMIST, N. Plant secondary metabolites synthesis and their regulations under biotic and abiotic constraints. **Journal of Plant Biology**, v. 63, n. 3, p. 203–216, 2020. DOI: https://doi.org/10.1007/s12374-020-09245-7

KOKETSU, M.; MOURA, L. L.; MAGALHÃES, M. T. Essential oils of *Cymbopogon densiflorus* and *Tagetes minuta* L. grown in Brazil. **Anais da Academia Brasileira de Ciências**, v. 48, n. 4, p. 743–746, 1976.

KUMAR, A.; GAUTAM, R. D.; KUMAR, A.; BISHT, A.; SINGH, S. Floral biology of wild marigold (*Tagetes minuta* L.) and its relation to essential oil composition. **Industrial Crops and Products**, v. 145, n. November 2019, p. 111996, 2020. DOI: https://doi.org/10.1016/j.indcrop.2019.111996

KUMAR, A.; GAUTAM, R. D.; KUMAR, A.; SINGH, S.; SINGH, S. Understanding the effect of different abiotic stresses on wild marigold (*Tagetes minuta* L.) and role of breeding strategies for developing tolerant lines. **Frontiers in Plant Science**, v. 12, n. February, p. 754457, 2022a. DOI: https://doi.org/10.3389/fpls.2021.754457

KUMAR, A.; GAUTAM, R. D.; SINGH, S.; CHAUHAN, R.; KUMAR, A.; SINGH, S. Comparative study of the effects of different soluble salts on seed germination of wild marigold (*Tagetes minuta* L.). **Journal of Applied Research on Medicinal and Aromatic Plants**, v. 31, n. 6, p. 100421, 2022b. DOI: https://doi.org/10.1016/j.jarmap.2022.100421

KUMAR, A.; SINGH, S. **Wild marigold (*Tagetes minuta*) variety Him Swarnima (CSIR-IHBT-TM-09)**. Palampur: CSIR-IHBT, 2020. Available at: https://www.ihbt.res.in/images/TechnicalBulletin/HimSwarnima.pdf. Accessed on: 11 mar. 2025.

KUMAR, R.; DAYAL, R.; ONIAL, P. Utilization of *Tagetes minuta* aerial parts as a source of natural dyes for textile coloration. **Waste and Biomass Valorization**, v. 5, n. 4, p. 699–707, 2014. DOI: https://doi.org/10.1007/s12649-013-9266-3

KUMAR, R.; RAMESH, K.; PATHANIA, V.; SINGH, B. Effect of transplanting date on growth, yield and oil quality of *Tagetes minuta* L. in Mid Hill of North-Western Himalaya. **Journal of Essential Oil Bearing Plants**, v. 15, n. 3, p. 405–414, 2012. DOI: https://doi.org/10.1080/0972060X.2012.10644068

KUMAR, R.; RAMESH, K.; SINGH, R. D.; PRASAD, R. Modulation od wild marigold (*Tagetes minuta* L.) phenophases towards the varying temperatura regimes: a field study. **Journal of Agrometeorology**, v. 12, n. 2, p. 234–240, 2010.

KUMAR, R.; SHARMA, S. Effect of light and temperature on seed germination of important medicinal and aromatic plants in north western Himalayas. **International Journal of Medicinal and Aromatic Plants,** v. 2, n. 3, p. 468–475, 2012.

KUMAR, R.; SHARMA, S.; RAMESH, K.; PATHANIA, V.; PRASAD, R. Irradiance stress and plant spacing effect on growth, biomass and quality of wild marigold (*Tagetes minuta* L.) – an industrial crop in western Himalaya. **Journal of Essential Oil Research**, v. 26, n. 5, p. 348–358, 2014. DOI: https://doi.org/10.1080/10412905.2014.935497

KUMAR, S.; BANSAL, R. P.; BAHL, J. R.; RAM, M.; KHANUJA, S. P. S.; SHASANY, A. K.; DAROKAR, M. P.; GARG, S. N.; NAQVI, A. A.; SHARMA, S. Registration of *Tagetes minuta* variety Vanphool for north Indian plains. **Journal of Medicinal and Aromatic Plant Sciences**, v. 21, n. 1, p. 52–53, 1999.

LEE, H.-Y.; KO, M.-J. Thermal decomposition and oxidation of β-caryophyllene in black pepper during subcritical water extraction. **Food Science and Biotechnology**, v. 30, n. 12, p. 1527–1533, 2021. DOI: https://doi.org/10.1007/s10068-021-00983-z

LI, B.; WANG, J.; QI, Y.; ZHANG, Y.; JIN, M.; DU, S. Essential oils profiles in *Melicope pteleifolia* and *Melicope patulinervia* and their insecticidal activities against two storage insect species. **International Journal of Food Properties**, v. 27, n. 1, p. 15–29, 2024. DOI: https://doi.org/10.1080/10942912.2024.2425610

LIN, H.; LI, Z.; SUN, Y.; ZHANG, Y.; WANG, S.; ZHANG, Q.; CAI, T.; XIANG, W.; ZENG, C.; TANG, J. D-Limonene: promising and sustainable natural bioactive compound. **Applied Sciences**, v. 14, n. 11, p. 4605, 2024. DOI: https://doi.org/10.3390/app14114605

LIZARRAGA, E.; MERCADO, M. I.; GALVEZ, C.; RUIZ, A. I.; PONESSA, G. I.; CATALAN, C. A. N. Morpho anatomical characterization and essential oils of *Tagetes terniflora* and *Tagetes minuta* (Asteraeae) growing in Tucumán (Argentina). **Boletín de la Sociedad Argentina de Botánica**, v. 52, n. 1, p. 55–68, 2017.

LUCIANI-GRESTA, F. Sur le comportement photopériodique du *Tagetes minuta* L. de Sicile. **Bulletin de la Société Botanique de France**, v. 122, n. 9, p. 363–365, 1975. DOI: https://doi.org/10.1080/00378941.1975.10839335

MACEDO, I. T. F.; OLIVEIRA, L. M. B. de; CAMURÇA-VASCONCELOS, A. L. F.; RIBEIRO, W. L. C.; SANTOS, J. M. L. dos; MORAIS, S. M. de; PAULA, H. C. B. de; BEVILAQUA, C. M. L. In vitro effects of *Coriandrum sativum*, *Tagetes minuta*, *Alpinia zerumbet* and *Lantana camara* essential oils on *Haemonchus contortus*. **Revista Brasileira de Parasitologia Veterinária**, v. 22, n. 4, p. 463–469, 2013.

MARTINEZ, F.; MASSUH, Y.; AGUILAR, J. J.; OJEDA, M. S.; CONTIGIANI, M. S.; NÚÑEZ MONTOYA, S. C.; KONIGHEIM, B. S. Cultivars of *Tagetes minuta* L. (Asteraceae) as a source of potential natural products with antiviral activity. **Journal of Herbal Medicine**, v. 24, n. January 2019, p. 100397, 2020. DOI: https://doi.org/10.1016/j.hermed.2020.100397

MARTINEZ-GHERSA, M. A.; GHERSA, C. M.; BENECH-ARNOLD, R. L.; MAC DONOUGH, R.; SANCHEZ, R. A. Adaptive traits regulating dormancy and germination of invasive species. **Plant Species Biology**, v. 15, p. 127–137, 2000.

MASSUH, Y. **Estudios de caracteres morfológicos y bioquímicos en suico (*Tagetes minuta* L.)**. 2014. 143 f. Tese (Doutorado em Ciencias Biológicas) - Facultad de Ciencias Exactas, Físicas Y Naturales, Universidad Nacional de Córdoba, Córdoba.

MASSUH, Y.; CRUZ-ESTRADA, A.; GONZÁLEZ-COLOMA, A.; OJEDA, M. S.; ZYGADLO, J. A.; ANDRÉS, M. F. Nematicidal activity of the essential oil of three varieties of *Tagetes minuta* from Argentina. **Natural Product Communications**, v. 12, n. 5, p. 705–707, 2017a. DOI: https://doi.org/10.1177/1934578X1701200515

MASSUH, Y.; TORRES, L. E.; OCAÑO, S. F.; BRUENTTI, P.; CHAVES, A. G.; ZYGADLO, J. A.; OJEDA, M. S. Generation and characterization of a population of *Tagetes minuta* of broad genetic base - obtaining selected individuals. **Phyton**, v. 86, n. 1, p. 214–223, 2017b. DOI: https://doi.org/10.32604/phyton.2017.86.214

MEDINA, M. C.; MEZA, Y. R. **Estudio de índices reológicos y diferencias organolépticas en la elaboración de salsas de chincho (*Tagetes eliptica*) - huacatay (*Tagetes minuta*)**. 2018. 109 f. Monografia (Ingeniería en Industrias Alimentarias) – Facultad de Ingeniería en Industrias Alimentarias, Universidad Nacional del Centro del Peru, Huancayo.

MENA, A. de las M. G. **Concentración del aceite esencial de huacatay (*Tagetes minuta*), tiempo y temperatura en conservación de carne de vacuno (*Bos taurus*)**. 2022. 52 f. Monografia (Ingeniería en Industrias Alimentarias) – Facultad de Ingenieria de Industrias Alimentareas y Biotecnología, Universidad Nacional de Frontera, Sullana.

MOREIRA, D. A. **Atividade desinfetante in vitro de nanocápsulas do óleo essencial de *Tagetes minuta* L. para o manejo da ordenha**. 2021. 60 f. Dissertação (Mestrado em Agroecossistemas) - Programa de Pós-Graduação em Agroecossistemas, Universidade Federal de Santa Catarina, Florianópolis.

NCBI. National Center for Biotechnology Information. **PubChem**. 2025a. Available at: https://pubchem.ncbi.nlm.nih.gov. Accessed on: 9 mar. 2025.

NCBI. National Center for Biotechnology Information. **PubChem Compound Summary for CID 22311, Limonene, (+/-)-**. 2025b. Available at: https://pubchem.ncbi.nlm.nih.gov/compound/Limonene. Accessed on: 31 mar. 2025.

NCBI. National Center for Biotechnology Information. **PubChem Compound Summary for CID 5320250, beta-Ocimene, (3Z)-**. 2025c. Available at: https://pubchem.ncbi.nlm.nih.gov/compound/beta-Ocimene_-_3Z. Accessed on: 31 mar. 2025.

NCBI. National Center for Biotechnology Information. **PubChem Compound Summary for CID 5281515, Caryophyllene**. 2025d. Available at: https://pubchem.ncbi.nlm.nih.gov/compound/Caryophyllene. Accessed on: 31 mar. 2025.

NCBI. National Center for Biotechnology Information. **PubChem Compound Summary for CID 5281520, Humulene**. 2025e. Available at: https://pubchem.ncbi.nlm.nih.gov/compound/Humulene. Accessed on: 31 mar. 2025.

NCBI. National Center for Biotechnology Information. **PubChem Compound Summary for CID 6549, Linalool, (+/-)-**. 2025f. Available at: https://pubchem.ncbi.nlm.nih.gov/compound/Linalool. Accessed on: 31 mar. 2025.

NCBI. National Center for Biotechnology Information. **PubChem Compound Summary for CID 92231, Spathulenol**. 2025g. Available at: https://pubchem.ncbi.nlm.nih.gov/compound/Spathulenol. Accessed on: 31 mar. 2025.

NCBI. National Center for Biotechnology Information. **PubChem Compound Summary for CID 1742210, beta-CARYOPHYLLENE OXIDE**. 2025h. Available at: https://pubchem.ncbi.nlm.nih.gov/compound/beta-CARYOPHYLLENE-OXIDE. Accessed on: 31 mar. 2025.

NCBI. National Center for Biotechnology Information. **PubChem Compound Summary for CID 102706, 2,6-Dimethyloct-7-en-4-one**. 2025i. Available at: https://pubchem.ncbi.nlm.nih.gov/compound/2_6-Dimethyloct-7-en-4-one. Accessed on: 31 mar. 2025.

NEHER, R. T. The ethnobotany of Tagetes. **Economic Botany**, v. 22, n. 4, p. 317–325, 1968.

NGONDYA, I. B.; MUNISHI, L. K. Impact of invasive alien plants *Gutenbergia cordifolia* and *Tagetes minuta* on native taxa in the Ngorongoro crater, Tanzania. **Scientific African**, v. 13, p. e00946, 2021. DOI: https://doi.org/10.1016/j.sciaf.2021.e00946

NTALLI, N. G.; FERRARI, F.; GIANNAKOU, I.; MENKISSOGLU-SPIROUDI, U. Phytochemistry and nematicidal activity of the essential oils from 8 greek lamiaceae aromatic plants and 13 terpene components. **Journal of Agricultural and Food Chemistry**, v. 58, n. 13, p. 7856–7863, 2010. DOI: https://doi.org/10.1021/jf100797m

OLIVEIRA, D. H. de; ABIB, P. B.; GIACOMINI, R. X.; LENARDÃO, E. J.; SCHIEDECK, G.; WILHELM, E. A.; LUCHESE, C.; SAVEGNAGO, L.; JACOB, R. G. Antioxidant and antifungal activities of the flowers' essential oil of *Tagetes minuta*, (Z)-tagetone and thiotagetone. **Journal of Essential Oil Research**, v. 31, n. 2, p. 160–169, 2019. DOI: https://doi.org/10.1080/10412905.2018.1519465

OMETTO, J. C. **Bioclimatologia vegetal**. São Paulo: Agronômica Ceres, 1981. 425 p.

OMIDBAIGI, R.; DADMAN, B.; FATTAHI, F. Influence of nitrogen fertilizer on the herb yield, essential oil content and composition of *Tagetes minuta* L. **Journal of Essential Oil Bearing Plants**, v. 11, n. 1, p. 45–52, 2008. DOI: https://doi.org/10.1080/0972060X.2008.10643596

PAL, P. K.; MAHAJAN, M.; THAKUR, B. K.; KAPOOR, P.; SHIVANI. Achievement of higher biomass, yield and quality of essential oil of *Tagetes minuta* L. through optimizing the sowing method and seeding rate. **Frontiers in Plant Science**, v. 14, n. June, p. 1–14, 2023. DOI: https://doi.org/10.3389/fpls.2023.1133370

PANDEY, V.; PATEL, A.; PATRA, D. D. Amelioration of mineral nutrition, productivity, antioxidant activity and aroma profile in marigold (*Tagetes minuta* L.) with organic and chemical fertilization. **Industrial Crops and Products**, v. 76, p. 378–385, 2015. DOI: https://doi.org/10.1016/j.indcrop.2015.07.023

PAVELA, R. History, presence and perspective of using plant extracts as commercial botanical insecticides and farm products for protection against insects - a review. **Plant Protection Science**, v. 52, n. 4, p. 229–241, 2016. DOI: https://doi.org/10.17221/31/2016-PPS

PÉREZ, J. C. **Nuevo diccionario Español - Quechua, Quechua - Español.** v. 1. Lima: Universidad de San Martin de Porres, 2022a. 1945 p.

PÉREZ, J. C. **Nuevo diccionario Español - Quechua, Quechua - Español.** v. 2. Lima: Universidad de San Martin de Porres, 2022b. 1346 p.

QI, Y.; XIAN, X.; ZHAO, H.; WANG, R.; HUANG, H.; ZHANG, Y.; YANG, M.; LIU, W. Increased invasion risk of *Tagetes minuta* L. in China under climate change: a study of the potential geographical distributions. **Plants**, v. 11, n. 23, p. 3248, 2022. DOI: https://doi.org/10.3390/plants11233248

QIAO, C.; XU, B.; HAN, Y.; WANG, J.; WANG, X.; LIU, L.; LIU, W.; WAN, S.; TAN, H.; LIU, Y.; ZHAO, X. Synthetic nitrogen fertilizers alter the soil chemistry, production and quality of tea. A meta-analysis. **Agronomy for Sustainable Development**, v. 38, n. 10, p. 1–10, 2018. DOI: https://doi.org/10.1007/s13593-017-0485-z

QUATTROCCHI, U. **CRC world dictionary of plant names**. v.3. Boca Raton: CRC Press, 2000. p. 1599-2259.

RAMESH, K.; SINGH, V. Effect of planting date on growth, development, aerial biomass partitioning and essential oil productivity of wild marigold (*Tagetes minuta*) in mid hills of Indian Western Himalaya. **Industrial Crops and Products**, v. 27, n. 3, p. 380–384, 2008. DOI: https://doi.org/10.1016/j.indcrop.2007.08.004

RAO, B. R. R.; KAUL, P. N.; BHATTACHARYA, A. K.; RAJPUT, D. K.; SYAMASUNDAR, K. V.; RAMESH, S. Comparative chemical composition of steam-distilled and water-soluble essential oils of South American marigold (*Tagetes minuta* L.). **Journal of Essential Oil Research**, v. 18, n. 6, p. 622–626, 2006a. DOI: https://doi.org/10.1080/10412905.2006.9699184

RATHORE, S.; WALIA, S.; KUMAR, R. Biomass and essential oil of *Tagetes minuta* influenced by pinching and harvesting stage under high precipitation conditions in the western Himalayas. **Journal of Essential Oil Research**, v. 30, n. 5, p. 360–368, 2018. DOI: https://doi.org/10.1080/10412905.2018.1486744

RENATO, N. dos S.; SILVA, J. B. L.; SEDIYAMA, G. C.; PEREIRA, E. GF. Influência dos métodos para cálculo de graus-dia em condições de aumento de temperatura para as culturas de milho e feijão. **Revista Brasileira de Meteorologia**, v. 28, n. 4, p. 382–388, 2013. DOI: https://doi.org/10.1590/S0102-77862013000400004

ROQUE, N.; BAUTISTA, H. **Asteraceae:** caracterização e morfologia floral. Salvador: EDUFBA, 2008. 73 p.

ROSTIGNOLI, B. A. F. **Avaliação fitoqímica e da atividade antioxidante de *Equisetum giganteum* e *Tagetes minuta***. 2019. 43 f. Monografia (Bacharel em Química) - Centro de Ciências Naturais e Exatas, Departamento de Química, Universidade Federal de Santa Maria, Santa Maria.

RUBIOLO, P.; SGORBINI, B.; LIBERTO, E.; CORDERO, C.; BICCHI, C. Essential oils and volatiles: sample preparation and analysis: a review. **Flavour and Fragrance Journal**, v. 25, n. 5, p. 282–290, 2010. DOI: https://doi.org/10.1002/ffj.1984

RUTNIK, K.; HRNČIČ, M. K.; KOŠIR, I. J. Hop essential oil: chemical composition, extraction, analysis, and applications. **Food Reviews International**, v. 38, n. sup1, p. 529–551, 2022. DOI: https://doi.org/10.1080/87559129.2021.1874413

SADGROVE, N.; JONES, G. A contemporary introduction to essential oils: chemistry, bioactivity and prospects for Australian agriculture. **Agriculture**, v. 5, n. 1, p. 48–102, 2015. DOI: https://doi.org/10.3390/agriculture5010048

SADGROVE, N.; PADILLA-GONZÁLEZ, G.; PHUMTHUM, M. Fundamental chemistry of essential oils and volatile organic compounds, methods of analysis and authentication. **Plants**, v. 11, n. 6, p. 1-34, 2022. DOI: https://doi.org/10.3390/plants11060789

SANTORO, M. V.; CAPPELLARI, L.; GIORDANO, W.; BANCHIO, E. Systemic induction of secondary metabolite biosynthesis in medicinal aromatic plants mediated by rhizobacteria. In: EGAMBERDIEVA, D.; SHRIVASTAVA, S.; VARMA, A. (org.). **Plant-growth-promoting rhizobacteria (PGPR) and medicinal plants**. (Soil Biology). Cham: Springer International Publishing, 2015. v. 42, p. 263–285. DOI: https://doi.org/10.1007/978-3-319-13401-7

SANTOS, D. C. dos; BARBOZA, A. da S.; SCHNEIDER, L. R.; CUEVAS-SUÁREZ, C. E.; RIBEIRO, J. S.; DAMIAN, M. F.; CAMPOS, A. C.; LUND, R. G. Antimicrobial and physical properties of experimental endodontic sealers containing vegetable extracts. **Scientific Reports**, v. 11, n. 1, p. 6450, 2021. DOI: https://doi.org/10.1038/s41598-021-85609-4

SANTOS, D. C. dos; SCHNEIDER, L. R.; DA SILVA BARBOZA, A.; DINIZ CAMPOS, Â.; LUND, R. G. Systematic review and technological overview of the antimicrobial activity of *Tagetes minuta* and future perspectives. **Journal of Ethnopharmacology**, v. 208, n. February, p. 8–15, 2017. DOI: https://doi.org/10.1016/j.jep.2017.06.046

SARTOR, E. de B.; SCHORR, R. R.; BETIM, F. C. M.; ANJOS, C. A. dos; OLIVEIRA, C. F. de; DALARMI, L.; MONTRUCCHIO, D. P.; DIAS, J. de F. G.; MIGUEL, O. G.; MIGUEL, M. D. Chemical composition and larvicidal activity of the essential oil of *Tagetes minuta* Linnaeus from the southern Brazilian highlands. **Brazilian Journal of Pharmaceutical Sciences**, v. 61, p. 1–10, 2025. DOI: https://doi.org/10.1590/s2175-97902025e24072

SCHIAVINATO, D. J.; GUTIÉRREZ, D. G.; BARTOLI, A. Typifications and nomenclatural clarifications in South American Tagetes (Asteraceae, Tageteae). **Phytotaxa**, v. 326, n. 3, p. 175–188, 2017. DOI: https://doi.org/10.11646/phytotaxa.326.3.2

SCHIEDECK, G. **Coeficientes técnicos, rendimento e custos de obtenção do óleo essencial no extrativismo de *Tagetes minuta* L**. Pelotas: Embrapa Clima Temperado, 2023. 17 p. (Embrapa Clima Temperado. Boletim de Pesquisa e Desenvolvimento, 370). Available at: http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1158042. Accessed on: 10 dez. 2024.

SCHIEDECK, G. **A comprehensive analysis of *Tagetes minuta* L. essential oil from Brazil**. Pelotas: Embrapa Clima Temperado, 2024. 30 p. (Embrapa Clima Temperado. Documentos, 544). Available at: http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1167445. Accessed on: 10 dez. 2024.

SHARMA, M. M.; BEER, K.; SINGH, O. P.; SHEKHAR, C. Effect of nitrogen and phosphorus levels on flower yield of marigold (*Tagetes minuta* L.) var Vanfool. **The Bioscan**, v. 12, n. 1, p. 291–294, 2017.

SHARMEEN, J.; MAHOMOODALLY, F.; ZENGIN, G.; MAGGI, F. Essential oils as natural sources of fragrance compounds for cosmetics and cosmeceuticals. **Molecules**, v. 26, n. 3, p. 1-24, 2021. DOI: https://doi.org/10.3390/molecules26030666

SIMON, P. M.; KATINAS, L.; ARAMBARRI, A. M. Secretory structures in *Tagetes minuta* (Asteraceae, Helenieae). **Boletín de la Sociedad Argentina de Botánica**, v. 37, n. 3–4, p. 181–191, 2002.

SINGH, A.; KHANUJA, S. P. S.; ARYA, S. J. K.; SINGH, S.; YADAW, A. Essential oil quality and yield with respect to harvest index in *Tagetes minuta* cultivated in sub tropical plains of North India. **Journal of Essential Oil Research**, v. 18, n. 4, p. 362–365, 2006. DOI: https://doi.org/10.1080/10412905.2006.9699114

SINGH, M.; RAO, R. S. G. Effects of nitrogen, potassium and soil moisture regime on growth, herbage, oil yield and nutrient uptake of South American marigold (*Tagetes minuta* L.) in a semi-arid tropical climate. **The Journal of Horticultural Science and Biotechnology**, v. 80, n. 4, p. 488–492, 2005. DOI: https://doi.org/10.1080/14620316.2005.11511965

SINGH, M.; TRIPATHI, R. S.; SINGH, S.; YASEEN, M. Influence of row spacing and nitrogen levels on herb and essential oil production and oil quality of *Tagetes minuta* L. **Journal of Spices and Aromatic Crops**, v. 17, n. 3, p. 251–254, 2008.

SINGH, T. P.; SINGH, R. K.; MALIK, P. Analgesic and anti-inflammatory activities of *Annona squamosa* Linn bark. **Journal of Scientific and Innovative Research**, v. 3, n. 1, p. 60–64, 2014. DOI: https://doi.org/10.31254/jsir.2014.3110

SINGH, V.; AHUJA, P. S.; GUPTA, A. K.; SINGH, V.; SINGH, K.; KAUL, V. K.; SINGH, B.; SOOD, R. P. **Himgold (IHBT.Marigold.I):** an improved cultivar of *Tagetes minuta*. Palampur: Institute of Himalayan Bioresource Technology, 2001. 16 p. Available at: https://www.ihbt.res.in/images/TechnicalBulletin/Himgold.pdf. Accessed on: 10 dez. 2024.

SINGH, V.; SINGH, B.; KAUL, V. K. Domestication of wild marigold (*Tagetes minuta* L.) as a potential economic crop in western Himalaya and north Indian plains. **Economic Botany**, v. 57, n. 4, p. 535–544, 2003. DOI: https://doi.org/10.1663/0013-0001(2003)057[0535:DOWMTM]2.0.CO;2

SIQUEIRA, N. C. S.; BAUER, L.; SILVA, G. A. A. B.; SANT'ANA, B. M. S.; ALICE, C. B.; BACHA, C. T. M. Óleo essencial de *Tagetes minuta* L. (Compositae) espontânea no Rio Grande do Sul. **Ciência e Natura**, v. 4, p. 91–93, 1982.

SOCIEDADE BRASILEIRA DE CIÊNCIA DO SOLO. **Manual de calagem e adubação para os Estados do Rio Grande do Sul e Santa Catarina**. 11. ed. [s. l.]: Comissão de Química e Fertilidade do Solo - RS/SC, 2016. 376 p.

SONG, C.; SALONER, A.; FAIT, A.; BERNSTEIN, N. Nitrogen deficiency stimulates cannabinoid biosynthesis in medical cannabis plants by inducing a metabolic shift towards production of low-N metabolites. **Industrial Crops and Products**, v. 202, n. April, p. 116969, 2023. DOI: https://doi.org/10.1016/j.indcrop.2023.116969

SOOD, M.; KUMAR, N.; CHANDEL, S. Management of *Tagetes minuta* under different sowing methods and plant densities in Mid-Hill condition of Himachal Pradesh (India). **International Journal of Current Microbiology and Applied Sciences**, v. 9, n. 5, p. 1516–1523, 2020. DOI: https://doi.org/10.20546/ijcmas.2020.905.172

SPERANDIO, J.; VELEIRINHO, B.; HONORATO, L. A.; CAMPESTRINI, L. H.; KUHNEN, S. In vitro antibacterial and cytotoxicity activities of *Tagetes minuta* L. essential oil towards bovine mastitis treatment. **Arquivo Brasileiro de Medicina Veterinaria e Zootecnia**, v. 71, n. 4, p. 1251–1259, 2019. DOI: https://doi.org/10.1590/1678-4162-10681

SUN, Y.; GUO, J.; LI, Y.; LUO, G.; LI, L.; YUAN, H.; MUR, L. A. J.; GUO, S. Negative effects of the simulated nitrogen deposition on plant phenolic metabolism: A meta-analysis. **Science of the Total Environment**, v. 719, p. 1-9, 2020. DOI: https://doi.org/10.1016/j.scitotenv.2020.137442

SYAFRI, S.; JASWIR, I.; YUSOF, F.; ROHMAN, A.; AHDA, M.; HAMIDI, D. The use of instrumental technique and chemometrics for essential oil authentication: A review. **Results in Chemistry**, v. 4, n. August, p. 100622, 2022. DOI: https://doi.org/10.1016/j.rechem.2022.100622

SYAMASUNDAR, K. V.; RAO, B. R. R. Wild marilgold (*Tagetes minuta* L.): cultivation technology and essential oil composition. In: BARUAH, A.; NATH, S. C. (Org.). **Natural Essential Oils, Fragrances and Flavours**. 1. ed. Jaipur: Aavishkar Publisher, 2013. p. 228–248.

TAK, J.-H.; ISMAN, M. B. Enhanced cuticular penetration as the mechanism of synergy for the major constituents of thyme essential oil in the cabbage looper, *Trichoplusia ni*. **Industrial Crops and Products**, v. 101, p. 29–35, 2017. DOI: https://doi.org/10.1016/j.indcrop.2017.03.003

TANKEU, S. Y.; VERMAAK, I.; VILJOEN, A. M.; SANDASI, M.; KAMATOU, G. P. P. Essential oil variation of *Tagetes minuta* in South Africa: a chemometric approach. **Biochemical Systematics and Ecology**, v. 51, p. 320–327, 2013. DOI: https://doi.org/10.1016/j.bse.2013.10.003

TIWARI, A.; GOSWAMI, P.; BISHT, B. S.; CHAUHAN, A.; VERMA, R. S.; PADALIA, R. C. Essential oil composition of African marigold (*Tagetes minuta* L.) harvested at different growth stages in foothills agroclimatic conditions of North India. **American Journal of Essential Oils and Natural Products**, v. 4, n. 3, p. 23–26, 2016.

TOMOVA, B. S.; WATERHOUSE, J. S.; DOBERSKI, J. The effect of fractionated Tagetes oil volatiles on aphid reproduction. **Entomologia Experimentalis et Applicata**, v. 115, n. 1, p. 153–159, 2005. DOI: https://doi.org/10.1111/j.1570-7458.2005.00291.x

TUNG, Y.-T.; CHUA, M.-T.; WANG, S.-Y.; CHANG, S.-T. Anti-inflammation activities of essential oil and its constituents from indigenous cinnamon (*Cinnamomum osmophloeum*) twigs. **Bioresource Technology**, v. 99, n. 9, p. 3908–3913, 2008. DOI: https://doi.org/10.1016/j.biortech.2007.07.050

UPADHYAY, R. K.; PANDEY, P.; PADALIA, R. C.; VENKATESHA, K. T.; KUMAR, D.; CHAUHAN, A.; TIWARI, A. K.; SINGH, S.; SINGH, S. S. New agro-technology to increase the productivity of wild marigold (*Tagetes minuta* L.). **International Journal of Tropical Agriculture**, v. 39, n. 3, p. 203–208, 2021.

VASQUÉZ, M. G.; PELÁEZ, F. P. Especies vegetales utilizadas por pobladores de Berlín, Bagua Grande (Amazonas, Perú) 2011-2012. **Revista Rebiolest**, v. 2, n. 2, p. 61-75, 2014.

VERMA, N.; AGGARWAL, N.; SOOD, P. Exploring the phytochemistry and biological potential of *Tagetes minuta* (L.): a comprehensive review. **South African Journal of Botany**, v. 168, p. 175–195, 2024. DOI: https://doi.org/10.1016/j.sajb.2024.03.004

VITA, J. A. **Diccionario de Peruanismos. El habla castellana del Perú**. Lima: Universidad Alas Peruanas, 2009. 491 p.

WALIA, S.; BANERJEE, T.; KUMAR, R. Efficacy of weed management techniques on weed control, biomass yield, and soil herbicide residue in transplanted wild marigold (*Tagetes minuta* L.) under high rainfall conditions of western Himalaya. **Agronomy**, v. 11, n. 11, p. 2119, 2021. DOI: https://doi.org/10.3390/agronomy11112119

WALIA, S.; BHATT, V.; KUMAR, R. Influence of drying processing on essential oil yield and composition of wild marigold (*Tagetes minuta* L.) in the western Himalayas. **Journal of Essential Oil-Bearing Plants**, v. 23, n. 4, p. 686–696, 2020a. DOI: https://doi.org/10.1080/0972060X.2020.1810137

WALIA, S.; KUMAR, R. Wild marigold (*Tagetes minuta* L.) an important industrial aromatic crop: liquid gold from the Himalaya. **Journal of Essential Oil Research**, v. 32, n. 5, p. 373–393, 2020. DOI: https://doi.org/10.1080/10412905.2020.1813211

WALIA, S.; KUMAR, R. Elucidating the yield and quality response of *Tagetes minuta* L. intercropped with *Zea mays* L. under different spacing in the western Himalayas. **Industrial Crops and Products**, v. 171, n. 6, p. 113850, 2021a. DOI: https://doi.org/10.1016/j.indcrop.2021.113850

WALIA, S.; KUMAR, R. Nitrogen and sulfur fertilization modulates the yield, essential oil and quality traits of wild marigold (*Tagetes minuta* L.) in the Western Himalaya. **Frontiers in Plant Science**, v. 11, n. January, 2021b. DOI: https://doi.org/10.3389/fpls.2020.631154

WALIA, S.; KUMAR, R. Wild marigold (*Tagetes minuta* L.) biomass and essential oil composition modulated by weed management techniques. **Industrial Crops and Products**, v. 161, n. 6, p. 113183, 2021c. DOI: https://doi.org/10.1016/j.indcrop.2020.113183

WALIA, S.; MUKHIA, S.; BHATT, V.; KUMAR, R.; KUMAR, R. Variability in chemical composition and antimicrobial activity of *Tagetes minuta* L. essential oil collected from different locations of Himalaya. **Industrial Crops and Products**, v. 150, n. 6, p. 112449, 2020b. DOI: https://doi.org/10.1016/j.indcrop.2020.112449

WANG, J.; CAO, K.; LIU, J.; ZHAO, Y. Biological characteristics and resource utilization of *Tagetes minuta* L. **Journal of Resources and Ecology**, v. 14, n. 3, p. 533–541, 2023. DOI: https://doi.org/10.5814/j.issn.1674-764x.2023.03.009

WANG, H.; LU, Q.; CHEN, X.; QIAN, Y.; QIAN, B.; TAN, H. Global trends and biological activity hotspots of D-limonene in essential oils: a 30-year bibliometric study. **Naunyn-Schmiedeberg's Archives of Pharmacology**, v. 398, n. 5, p. 5491-5507, 2024. DOI: https://doi.org/10.1007/s00210-024-03607-5

WEBER, D. J.; ZAMBRANO, F. C.; VILLAR, T. C.; DÁVILA, M. B. **Rimaycuna Quechua de Huanuco. Diccionario del quechua del Huallaga con índices castellano e inglés**. 2 ed. Lima: Instituto Linguístico de Verano, 2008. 797 p.

WIERSEMA, J. H. ***Tagetes minuta* L.** GRIN Taxonomy. US National Plant Germplasm System. 2019. Available at: https://www.gbif.org/species/101322391. Accessed on: 10 fev. 2025.

ZIMMERMANN, R. C.; ARAGÃO, C. E. de C.; ARAÚJO, P. J. P. de; BENATTO, A.; CHAABAN, A.; MARTINS, C. E. N.; AMARAL, W. do; CIPRIANO, R. R.; ZAWADNEAK, M. A. C. Insecticide activity and toxicity of essential oils against two stored-product insects. **Crop Protection**, v. 144, n. January, p. 105575, 2021. DOI: https://doi.org/10.1016/j.cropro.2021.105575

Embrapa

CGPE 19321