Introduction

Medicinal plants contain a diversity of biologically active compounds that comprise several chemical classes, including terpenes, sapo-ninic glycosides, steroids, alkaloids, and flavonoids (Liang and Fang, 2006; Da Silva et al., 2006; De Sousa and De Almeida, 2005). Some of these compounds, primarily monoterpenes, are found in essential oils extracted from plants. Essential oils have distinctive fragrances and/or flavours and are used in cosmetic as well as medical applications. To this point, many of these oils exhibit biological properties (Craveiro et al., 1981), such as spasmylic (Lis-Balchín and Hart, 1999), anxiolytic (Pultrini et al., 2006), antinociceptive (Santos et al., 2005), and anticonvulsant (Almeida et al., 2003; De Almeida et al., 2011) activities.

Monoterpenes and other chemical compounds found in essential oils are structurally simple molecules, but the recently reported studies of their pharmacological properties (De Sousa et al., 2007a, b, c; De Sousa, 2011; Amaral et al., 2007; Silva et al., 2007; De Almeida et al., 2008) indicate that they have the complex profile of psychoactive drugs. (R)-(+-)Pulegone is a monoterpene found in essential oils from plants of the Labiatae family. In nature, pulegone occurs in both (+) and (-) forms. Dextrorotatory pulegone is obtained from oils from Mentha pulegium (pennyroyal), M. longifolia (horsemint), and others. Levorotatory pulegone is the major constituent of Agastache formosanum (hummingbird mint) oil (Kocovský et al., 1986). Pulegone is also present in essential oils that are known to be bioactive, such as the analgesic oil extracted from the Chinese herb Shizonepeta tenuifolia Briq. (Yamahara et al., 1980).

In our earlier studies, the structure-activity relationship of the analogues of rotundifolone, a monoterpane isolated from the essential oil of the leaves of Mentha x villosa (mojito mint), was investigated. In preliminary investigations, the monoterpane (R)-(+-)-pulegone presented significant antinociceptive activity in the acetic acid-induced writhing test (De Sousa et al., 2007c). This observation was further studied in the current work by evaluating the impact of (R)-(+-)-pulegone on the central nervous system (CNS).
Materials and methods

Chemicals

(R)-(+) -Pulegone was purchased from Aldrich Chemical Co. (Jacksonville, FL, USA). Sodium pentobarbital, pentylenetetrazole (PTZ), diazepam (DZP), morphine, and polyoxyethylene-sorbitan monooleate (Twee 80) were purchased from Sigma (St. Louis, MO, USA). (R)-(+) -Pulegone was mixed with 5% Tween 80 to produce an emulsion.

Animals

Male Swiss mice (28–34 g) were obtained from the animal research facility at the Federal University of Sergipe, Aracaju, Brazil. The animals were maintained at constant room temperature [(23 ± 1) °C] with a 12 h/12 h light-dark cycle (light provided from 6:00 am to 6:00 pm) and free access to food and water. All behavioural tests were conducted between 1:00 and 5:00 pm and were approved by the Institutional Ethics Committee for the Care and Use of Animals (approval #0503/05).

Behavioural effects

The behavioral screening of the mice was performed at 0.5, 1, and 2 h after intraperitoneal (ip) injection of (R)-(+) -pulegone, as described previously (De Almeida and De Oliveira, 2006).

Locomotor activity

Mice were divided into two groups of eight animals each and injected with vehicle (control) or (R)-(+) -pulegone (200 mg/kg ip). The spontaneous motor activity of the animals was assessed for an observation period of 5 min in an activity cage (controller model 7441 and grid-floor detecting arrangement cage model 7432; Ugo Basile, Comerio, VA, Italy) 30, 60, and 120 min after injection (De Sousa et al., 2007b).

Pentobarbital-induced sleeping time

Sodium pentobarbital at a hypnotic dose of 40 mg/kg ip was injected into three groups (n = 8) of mice 30 min after pretreatment with vehicle (ip, control), (R)-(+) -pulegone at a dose of 100 mg/kg ip, or (R)-(+) -pulegone at a dose of 200 mg/kg ip. The duration of sleep as assessed by the loss and recovery of the righting reflex was recorded (De Sousa et al., 2007a).

Pentylenetetrazole-induced convulsions

Mice were divided into five groups (n = 8). The control and positive control groups received 5% Tween 80 ip or DZP (4 mg/kg ip), respectively. The remaining groups received an injection of (R)-(+) -pulegone at doses of 100, 200, or 300 mg/kg ip. Thirty min after drug administration, the mice were injected with PTZ (60 mg/kg ip) and observed for at least 15 min to detect the occurrence of the first episode of forelimb clonus (Swinyard et al., 1989).

Formalin test

The formalin test is used to clarify possible mechanisms of the antinociceptive effect of a compound of interest (Vida, 1995). Animals were injected with (R)-(+) -pulegone (31.3–125 mg/kg ip), vehicle (ip, control), or morphine (10 mg/kg ip) 30 min prior to the injection of formalin (Wheeler-Aceto et al., 1990). They were then injected with 20 μl of 2.5% formalin (0.92% formaldehyde diluted in saline) in the subplantar area of the right hind paw. The duration of paw licking was measured 1–5 min (first phase) and 15–30 min (second phase) after the formalin injection. The amount of time spent licking the injected paw was considered as the nociceptive response.

Hot plate test

Animals were placed on a hot plate maintained at (47 ± 0.5) °C. The time elapsed between placing the animals on the hot plate and the animals either licking their fore or hind paws or jumping off the surface was considered to be the response latency. Mice with baseline latencies of more than 15 s were excluded from the study. Response latency testing was measured prior to ip administration (baseline) of (R)-(+) -pulegone (31.3–125 mg/kg), vehicle (control), or morphine (10 mg/kg) 30 and 60 min after each treatment. The cut-off time for the hot plate test latency was set at 30 s to avoid tissue injury (Woolfe and Macdonald, 1944).
Possible antagonism of the antinociceptive effect of (R)-(+) pulegone by pretreatment with naloxone

Naloxone (NLX) was administered subcutaneously (sc) to all experimental animals at a dose of 5 mg/kg. After 15 min, the test group received 125 mg/kg ip of (R)-(+) pulegone, while the control group received ip vehicle and the standard group received morphine (10 mg/kg ip). The evaluations were made by submitting the animals to the formalin test.

Statistical analysis

Statistical analyses were performed using the analysis of variance (ANOVA) followed by the Dunnett’s multiple comparison test. A probability level of 0.05 was regarded as significant.

Results and Discussion

(R)-(+) Pulegone is a monoterpene ketone. Its chemical structure is shown in Fig. 1. (R)-(+) Pulegone demonstrated a central depressant effect in mice at a dose of 200 mg/kg ip, as observed by decreased locomotor activity, increased passivity, and sedation 0.5 h after administration. Administration of this compound also caused palpebral ptosis (not shown) and a significant decrease in spontaneous motor activity 0.5 and 1 h after administration (Fig. 2). The CNS-depressant effect of (R)-(+) pulegone was confirmed by an increase of the pentobarbital-induced sleeping time and was observed at both 100 and 200 mg/kg ip (Fig. 3).

Interestingly, Umezu (2010) showed that pulegone promoted ambulation, a CNS-stimulant action, in imprinting control region (ICR) mice via the dopaminergic system. However, it is important to consider that different experimental conditions, including the type and age of the animals employed and the purity of the compound used in the study, may lead to different experimental results. In the evaluation of the anticonvulsant profile, (R)-(+) pulegone (300 mg/kg ip) significantly increased the latency of PTZ-induced convulsions and had an effect similar to that of DZP, a standard anticonvulsant drug (Fig. 4).

PTZ is the prototype pharmacological agent in the class of systemic convulsants. This drug is used in screening tests for anticonvulsants in part because the antiabsence drug ethosuximide, which is effective against PTZ-induced seizures, fails to alter maximal electroshock (MES) thresholds. Therefore, it has become common practice to presume that drugs that are effective against PTZ seizures have the potential to serve as thera-
The antinociceptive activity of (R)-(+)–pulegone was assessed using several pain models. The formalin test is a model of acute and tonic pain and is considered a more valid model for clinical pain than tests with mechanical or thermal stimulation (Amaral et al., 2007). (R)-(+)–Pulegone (31.3–125 mg/kg ip) dose-dependently inhibited both phases of the formalin test in a manner similar to that of morphine (Figs. 5A, B). The first phase results from the direct chemical stimulation of the nociceptive afferent fibers, mainly C fibers, and leads to the release of substance P (Heapy et al., 1987). This release can be inhibited by centrally acting analgesics such as morphine. The second phase results from the action of inflammatory mediators (e.g., prostaglandins, serotonin, histamine, and bradykinin) that are released locally (Murray et al., 1988; Rujjanawate et al., 2003), as well as from enhanced synaptic transmission in the spinal cord (Vida, 1995; França et al., 2001). Therefore, the results suggest that (R)-(+)–pulegone has a central antinociceptive effect.

This pharmacological property was confirmed by the hot plate test, which specifically measures central thermal nociceptive responses (Parkhouse and Pleuvry, 1979). Animals were treated with (R)-(+)–pulegone at doses of 31.3, 62.5, and...
125 mg/kg or vehicle. The latency measurements were performed before all treatments (basal), 30 and 60 min after administration. The antinocicceptive effect of the compound was observed by an increase in the reaction time of the mice subjected to the hot plate, as shown in Fig. 6. The observed reaction time latency indicates that (R)-(+) pulegone exerts its actions via a supraspinal component (Yaksh and Ruby, 1976). Hence, this monoterpene contributes to the analgesic effect of essential oils that contain pulegone, such as those derived from *Shizonepeta tenuifolia* Briq. (Yamahara et al., 1980).

Several essential oils are reported to exhibit CNS-depressant activity (Almeida et al., 2003). Monoterpenes are the major components of these oils. The central activity of other monoterpenes that have a ketone group as part of their structure [e.g., carvone (De Sousa et al., 2007a) and α,β-epoxy-carvone (De Almeida et al., 2008)] has been demonstrated. Compounds derived from monoterpane ketones, such as hydroxydihydrocarvone, also have antinociceptive effects (De Sousa et al., 2006). Therefore, the results observed with (R)-(+) pulegone are consistent with those reported for other monoterpane ketones that belong to the same chemical class.

Animals were next pretreated with naloxone, an opioid antagonist that opposes the effects of opioid agonists such as morphine. The result of this test showed that naloxone was unable to cancel the antinociceptive effect of (R)-(+) pulegone in the formalin test (Figs. 7A, B). On the other hand, the effect of morphine was blocked, suggesting nonparticipation of the opioid system in the modulation of pain by (R)-(+) pulegone. These results are consistent with those found for another monoterpane ketone, (−)-carvone.
This monoterpene also has antinociceptive actions with nonparticipation of the opioid system. However, the antinociceptive activity is associated with decreased peripheral nerve excitability (Gonçalves et al., 2008), suggesting that (R)-(+)pulegone may potentially act through a similar mechanism.

The present study demonstrated the pharmacological profile of (R)-(+)pulegone in several behavioural models and indicated that this compound has psychoactive properties. The study also indicated that the antinociceptive actions of (R)-(+)pulegone were most likely unrelated to classical opioid receptor stimulation.

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