

Updated meta-analysis on the therapeutic effects of botanical extract interventions for chronic lower back pain

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Abstract. Chronic lower back pain (CLBP) severely affects an individual's quality of life and increases reliance on healthcare services. Previous meta-analyses have primarily examined the effects of essential oils and herbal remedies separately, without considering their combined therapeutic potential. The present meta-analysis integrated both treatment modalities to evaluate the efficacy of botanical extract-based therapies for CLBP management. A systematic review and meta-analysis were conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, with data extracted from randomized controlled trials (RCTs) conducted up to July 2024. A comprehensive search of several databases identified 13 RCTs that met the inclusion criteria, focusing on interventions using plant extracts, including various herbal formulations and essential oils. The meta-analysis demonstrated that botanical extract-based treatments, whether applied topically, combined with massage or administered orally, were more effective compared with a placebo in reducing pain, enhancing lumbar flexibility and extending walking duration in patients with CLBP. These findings support the role of botanical extracts as viable therapeutic options for CLBP management, emphasizing their potential integration into comprehensive pain management strategies. However, further research is necessary to explore their long-term efficacy and underlying mechanisms. The present study is registered in PROSPERO (registration no. CRD42024554015).

Introduction

Chronic lower back pain (CLBP) is a widespread and debilitating condition that notably affects the quality of life

of individuals and contributes to increased healthcare utilization (1). Globally, CLBP remains one of the leading causes of disability, with substantial socioeconomic impacts, including direct medical costs and the loss of productivity (2). Low back pain is increasingly becoming a major public health concern, with an estimated global lifetime prevalence of 70-85%. Despite its widespread occurrence, effective management remains a challenge (3), the underlying mechanisms of CLBP are often complex and multifactorial, making effective management challenging. Pharmacological interventions, such as non-steroidal anti-inflammatory drugs (NSAIDs), are commonly used but are often associated with limited efficacy and adverse side effects, underscoring the need for alternative approaches (4-6).

The management of chronic lower back pain often begins with the use of NSAIDs. However, prolonged use of NSAIDs can lead to adverse effects, such as gastrointestinal complications (7-9). As a result, there is an increasing focus on investigating adjunct therapies that can alleviate pain with fewer adverse reactions. For instance, massage therapy (10) has been acknowledged for its effectiveness in decreasing pain and enhancing functionality in individuals with CLBP, ultimately improving the mental and emotional health of patients (11,12).

Among the adjunct therapy options, botanical extracts (including Chinese herbs and essential oils), especially those applied topically, have shown promise due to their potential analgesic and anti-inflammatory properties. For instance, studies have indicated the effectiveness of substances such as capsaicin in managing pain through desensitization mechanisms, which do not induce notable systemic side effects (7,13-16). Furthermore, combining massage with botanical treatments, such as herbal compresses, has been traditionally used to amplify therapeutic benefits through mechanisms that increase local blood flow and provide thermal and aromatherapy benefits (12).

Given the limitations of current pharmacological therapies and the potential of integrative approaches, the primary aim of the present study was to evaluate the therapeutic potential of botanical extract-based interventions for managing CLBP. The present meta-analysis assessed evidence from clinical trials investigating the effects of plant-based treatments, including Chinese herbs and essential oils, and their application in conjunction with manual therapies such as massage.

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By analyzing the efficacy of different administration routes and treatment durations, the present study addressed critical questions regarding the optimal use of botanical therapies for pain relief and functional improvement.

Materials and methods

Data sources and selection criteria. In the present study, a thorough search for randomized controlled trials (RCTs) assessing botanical extract interventions for individuals with CLBP was conducted. This comprehensive search encompassed multiple databases, including PubMed (<https://pubmed.ncbi.nlm.nih.gov/>), Embase (<https://www-embase-com.sw.lib.csmu.edu.tw:8443/search/quick>), Cochrane Library (<https://www-cochranelibrary-com.sw.lib.csmu.edu.tw:8443/>) and Web of Science (<https://www-webofscience-com.sw.lib.csmu.edu.tw:8443/wos/woscc/basic-search>), from database inception to July 2024. Search terms including 'Chinese herbs', 'plant extracts', 'botanicals', 'essential oils', 'aromatherapy', 'lower back pain', 'chronic lower back pain', 'random', 'randomized' and 'randomised' were used, focusing specifically on clinical trials involving human participants. The methodology strictly followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (17). All identified publications were carefully reviewed, including an analysis of their bibliographies to uncover additional relevant studies. Selection was limited to studies published in English and excluded case reports, technical reports, conference papers, review articles, letters, editorials and laboratory research.

Study selection. The screening and assessment of studies were independently conducted by two researchers, CCC and JYH, with a third researcher, RYT, verifying the accuracy of the process. To ensure comprehensive analysis, printed copies of all pertinent articles were acquired and scrutinized. The details of the study selection process are illustrated in the PRISMA flow diagram presented in Fig. 1.

Data extraction. Data extraction was independently conducted by two authors, SYL and RYT, using a standardized form in accordance with the protocols outlined in the Cochrane Handbook (18). The extracted data included key information such as the names of the study authors, year and country of publication, inclusion criteria for participants, participant demographics (including the total number and age range), study design, details of the interventions studied and the outcomes, as well as the methods used for their assessment.

Outcomes. The primary outcome of the present study was the evaluation of pain scales. The secondary outcomes included the type of plant extracts used, types of treatments, duration of treatment and impact of plant extracts on lumbar flexion, as well as their effect on walking duration.

Quality assessment. In total, two independent researchers, CCC and SYL, evaluated the potential biases in the included studies using the Cochrane Collaboration's Risk of Bias tool (18) for assessing methodological quality. Any discrepancies in the assessments were resolved through joint discussions with a third reviewer, RYT, to achieve consensus in the final

evaluation. Studies were determined to have a high risk of bias if they demonstrated issues in ≥ 1 domains specified by this assessment framework.

Statistical analysis. Data from each selected study were quantitatively analyzed using standard mean difference (SMD) and 95% confidence intervals (CIs) to compare outcomes between the intervention and control (placebo) groups. These SMD values were pooled using a random-effects model to account for inter-study variability. Statistical analyses were performed using Comprehensive Meta-Analysis software (version 3.0; Biostat, Inc.). Heterogeneity among the studies was assessed using the I^2 statistic, with values $>50\%$ indicating significant heterogeneity. Publication bias was evaluated through funnel plots and Egger's regression test. $P < 0.05$ was used to indicate a statistically significant difference. Additionally, subgroup analyses were conducted to identify potential sources of heterogeneity and sensitivity analyses were performed by systematically excluding individual studies to verify the robustness of the overall results.

Results

Study selection and characteristics of the included patients. The study screening and selection process is outlined in Fig. 1. Initially, four databases (PubMed, Embase, Cochrane Library and Web of Science) were explored and an additional source, the 'related articles' feature in PubMed, was utilized, which resulted in the identification of 168 articles. Upon the removal of duplicates, 125 articles were subjected to title and abstract screening, leading to the exclusion of 101 articles. A thorough full-text review of the remaining 24 articles led to the further exclusion of 11 articles due to the study outcomes being unrelated to the present research focus (19-21), lacking a placebo (22), addressing acute low back pain (23-26), being a non-RCT (27), including individuals aged ≤ 18 years (28) or being retracted (29). Consequently, the present meta-analysis ultimately comprised 13 articles (7,13,30-40). All the included articles were published in the English language. Table S1 provides an overview of the key characteristics of the trials under consideration, including participant demographics and study methodologies. The 13 trials were published from 1999-2024 and encompassed a total of 1,739 participants, with the number of participants per trial varying from 20-320. Among these selected RCTs, 9 utilized a double-blind approach, 1 was single-blind, 1 was assessor-blind and 2 did not specify the blinding method.

Quality assessment. The risk of bias assessment using the Cochrane Collaboration's tool for evaluation identified a range of methodological strengths and weaknesses across the 13 included studies. Overall, most studies exhibited a low risk of bias in several domains. However, some concerns were noted, particularly in the domains of deviations from the intended interventions, the measurement of the outcome and missing outcome data. In total, 4 studies showed notable quality issues, including a high risk of bias in certain domains (33-36). Most studies (10/13) were RCTs, demonstrating generally low risk in this domain. Fig. S1 provides a detailed visual representation of these assessments. Fig. S1A illustrates the

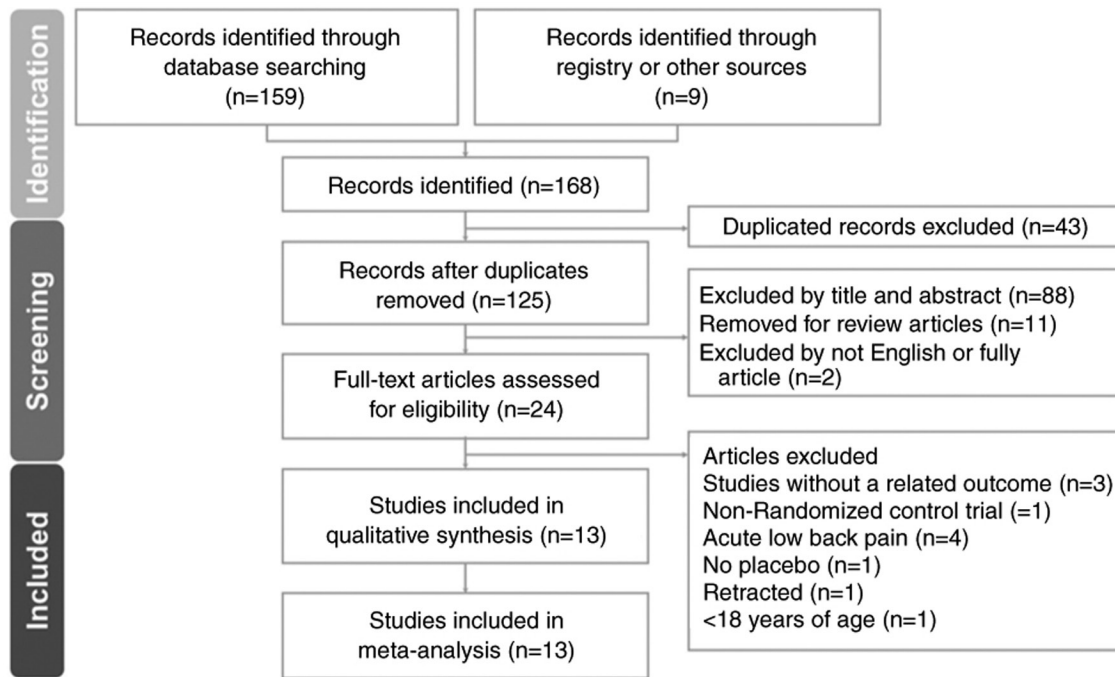


Figure 1. Flow chart illustrating the literature search and study selection.

risk of bias for each study across all domains, while Fig. S1B summarizes the proportion of studies with different levels of bias across the domains. Overall, this figure highlights the methodological rigor and the areas that needed improvement within the included studies. In summary, while the overall methodological quality of the included studies was moderate to high, specific areas such as the adherence to intervention protocols and the management of outcome data require careful consideration in future research.

Impact of the botanical extract on CLBP. The forest plot shown in Fig. 2 demonstrates that all interventions led to a reduction in pain compared with the placebo. In patients with CLBP, the interventions moderately decreased the pain scores (overall random effect, -0.644; 95% CI, -0.818 to -0.469; $P=0.000$) ($I^2=58.454\%$; $P=0.004$). Notably, as illustrated in Fig. 3A, interventions with Chinese herbs (overall random effect, -0.422; 95% CI, -0.553 to -0.291; $P=0.000$) ($I^2=0.000\%$; $P=0.617$) or essential oils (overall random effect, -0.916; 95% CI, -1.188 to -0.644; $P<0.001$) ($I^2=50.607\%$; $P=0.059$) alleviated CLBP compared with the placebo, with both small and large effects observed respectively, with a trend indicating that essential oils may be more effective than Chinese herbs. As detailed in Fig. 3B, the analysis of administration routes indicated that groups treated with botanical extracts experienced significantly lower pain levels compared with the placebo group across various applications: Topical application (overall random effect, -0.631; 95% CI, -0.919 to -0.343; $P<0.001$) ($I^2=59.308\%$; $P=0.043$), topical application combined with massage (overall random effect, -0.834; 95% CI, -1.228 to -0.439; $P<0.001$) ($I^2=67.271\%$; $P=0.027$), oral administration (overall random effect, -0.619; 95% CI, -0.919 to -0.319; $P<0.001$) ($I^2=45.796\%$; $P=0.158$) and subcutaneous injection (overall random effect, -0.174; 95% CI, -0.582 to 0.235;

$P=0.404$) ($I^2=0.000\%$; $P>0.999$). These findings suggest that topical applications combined with massage offered simpler and safer therapeutic approaches compared with oral administration and were more effective in alleviating pain. As shown in Fig. 3C, combining the results of Fig. 3A and B and further analyzing the treatment routes revealed that oral administration (overall random effect, -0.493; 95% CI, -0.742 to -0.244; $P<0.001$) ($I^2=0.000\%$; $P=0.394$) or topical use (overall random effect, -0.392; 95% CI, -0.576 to -0.208; $P<0.001$) ($I^2=0\%$; $P=0.743$) of herbal medicine produced a small effect in alleviating CLBP. By contrast, the topical application combined with massage of Chinese herbs resulted in a moderate effect (overall random effect, -0.604; 95% CI, -0.986 to -0.222; $P=0.002$) ($I^2=0\%$; $P=>0.999$). However, topical use (overall random effect, -0.911; 95% CI, -1.328 to -0.494; $P<0.001$) ($I^2=36.494\%$; $P=0.207$), topical application combined with massage (overall random effect, -0.948; 95% CI, -1.535 to -0.361; $P=0.002$) ($I^2=76.703\%$; $P=0.014$) and oral administration (overall random effect, -0.945; 95% CI, -1.396 to -0.494; $P<0.001$) ($I^2=0.000\%$; $P>0.999$) of essential oil significantly alleviated CLBP. As shown in Fig. 3D, the analysis of treatment duration revealed that using botanical extracts for >3 weeks (overall random effect, -0.546; 95% CI, -0.719 to -0.373; $P<0.001$) ($I^2=28.760\%$; $P=0.209$) or for <3 weeks (overall random effect, -0.839; 95% CI, -1.204 to -0.474; $P<0.001$) ($I^2=75.275\%$; $P=0.001$) resulted in a moderate reduction in pain compared with the placebo.

Sensitivity analysis and impact of botanical extract on CLBP. To assess the robustness of the findings, a one-study removal sensitivity analysis was conducted by systematically excluding each study one at a time and recalculating the overall effect estimate. As illustrated in Fig. 4, the results showed that no single study significantly altered the overall pooled effect,

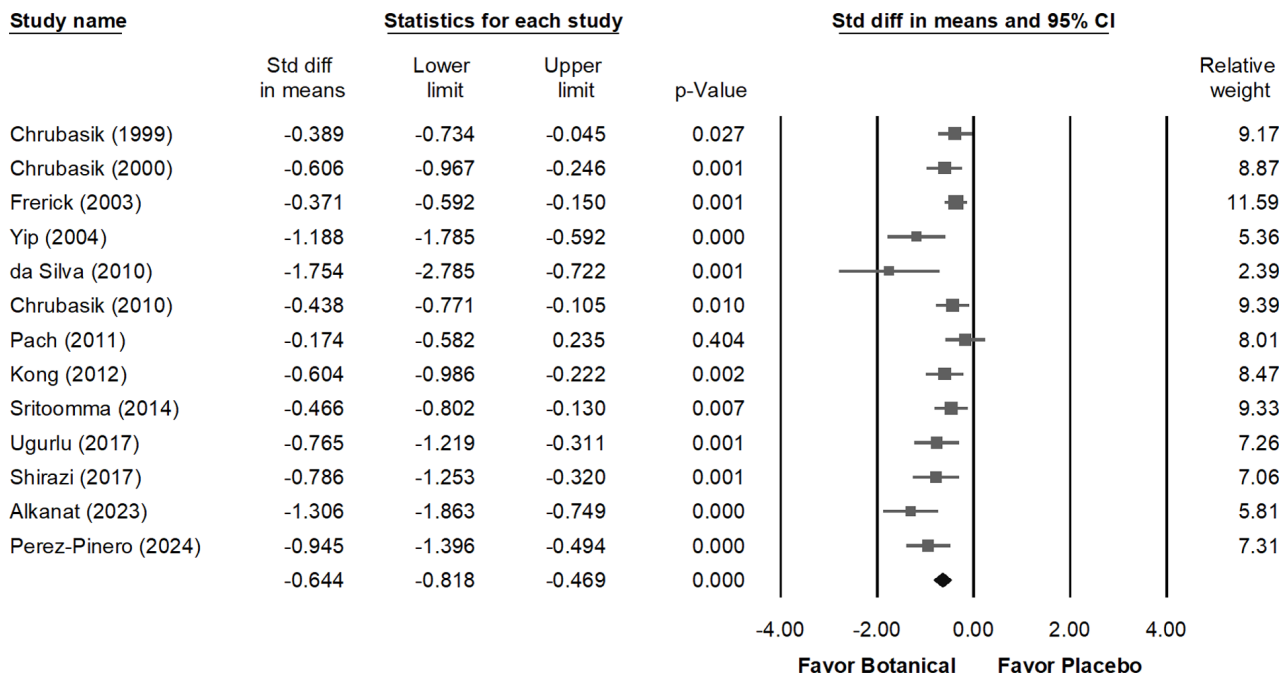


Figure 2. Effects of botanical extracts on chronic lower back pain. The reduction in pain scale scores following the intervention is indicated by the square, which represents the standardized mean difference shifting to the left. The horizontal line extending through the square denotes the 95% CI, while the diamond symbol reflects the overall pooled effect size. The heterogeneity among the 13 included RCTs is reported as $I^2=58.454\%$ and $P=0.004$.

confirming the stability of the meta-analysis findings. The effect sizes remained within the confidence intervals across all iterations, indicating that the primary results were not driven by any specific study.

Impact of botanical extract on lumbar flexion and walking time. The forest plots shown in Fig. 5 demonstrate that botanical extracts provided a moderate improvement in walking time (overall random effect, -0.682; 95% CI, -0.961 to -0.402; $P<0.001$) ($I^2=45.428\%$; $P=0.119$) and significantly enhanced lumbar flexion (overall random effect, -0.885; 95% CI, -1.245 to -0.524; $P<0.001$) ($I^2=50.733\%$; $P=0.087$) compared with the placebo.

Publication bias. Egger's regression analysis provided evidence of significant publication bias within the dataset ($P=0.00064$). A funnel plot showing the SMDs for the efficacy of botanical interventions in reducing CLBP is presented in Fig. S2A. Additionally, Fig. S2B corresponds to the sensitivity analysis shown in Fig. 4G and illustrates the results of Egger's regression analysis ($P=0.00002$). In conclusion, these findings raise concerns about the credibility of the meta-analysis.

Discussion

The present systematic review and meta-analysis, based on a thorough evaluation of both recent and established research, highlighted the therapeutic effects of botanical interventions on CLBP. These findings indicated that botanical extracts significantly improved the management of chronic musculoskeletal pain, improving lumbar flexion and extending the walking time for individuals with CLBP. These interventions may offer an effective alternative to conventional pharmacological

methods, which often coincide with notable adverse effects. The results of the present study also aligned with clinical guidelines for chronic low back pain management in primary care (41) for managing CLBP, which recommend prioritizing non-pharmacological treatments as the first-line therapy.

The present study addressed a critical gap in the existing literature by providing a comprehensive analysis of botanical extracts for the management of CLBP. While previous meta-analyses have predominantly focused on single interventions, such as the application of topical essential oils (42,43) for musculoskeletal disorders, they have largely overlooked the broader therapeutic landscape of botanical-based treatments. Earlier studies primarily examined the analgesic properties of individual essential oils, including lavender (32), peppermint (44) and rosemary (35), assessing their short-term pain-relieving effects through massage or direct skin absorption. However, these investigations did not explore the synergistic effects of botanical combinations, nor did they assess the varying efficacy of different administration routes. By adopting a more integrative approach, the present meta-analysis evaluated a diverse range of botanical therapies, encompassing both essential oils and herbal extracts, such as capsaicin, ginger and Traditional Chinese Medicinal formulations. Unlike previous studies that focused solely on isolated interventions, the present study examined the collective impact of these botanical treatments, investigating their effectiveness when applied topically, integrated with massage or administered orally. Moreover, it considered key factors that may influence therapeutic outcomes, including treatment duration and mode of application, offering a more nuanced understanding of the mechanisms underlying botanical interventions in pain relief and functional improvement. By addressing these

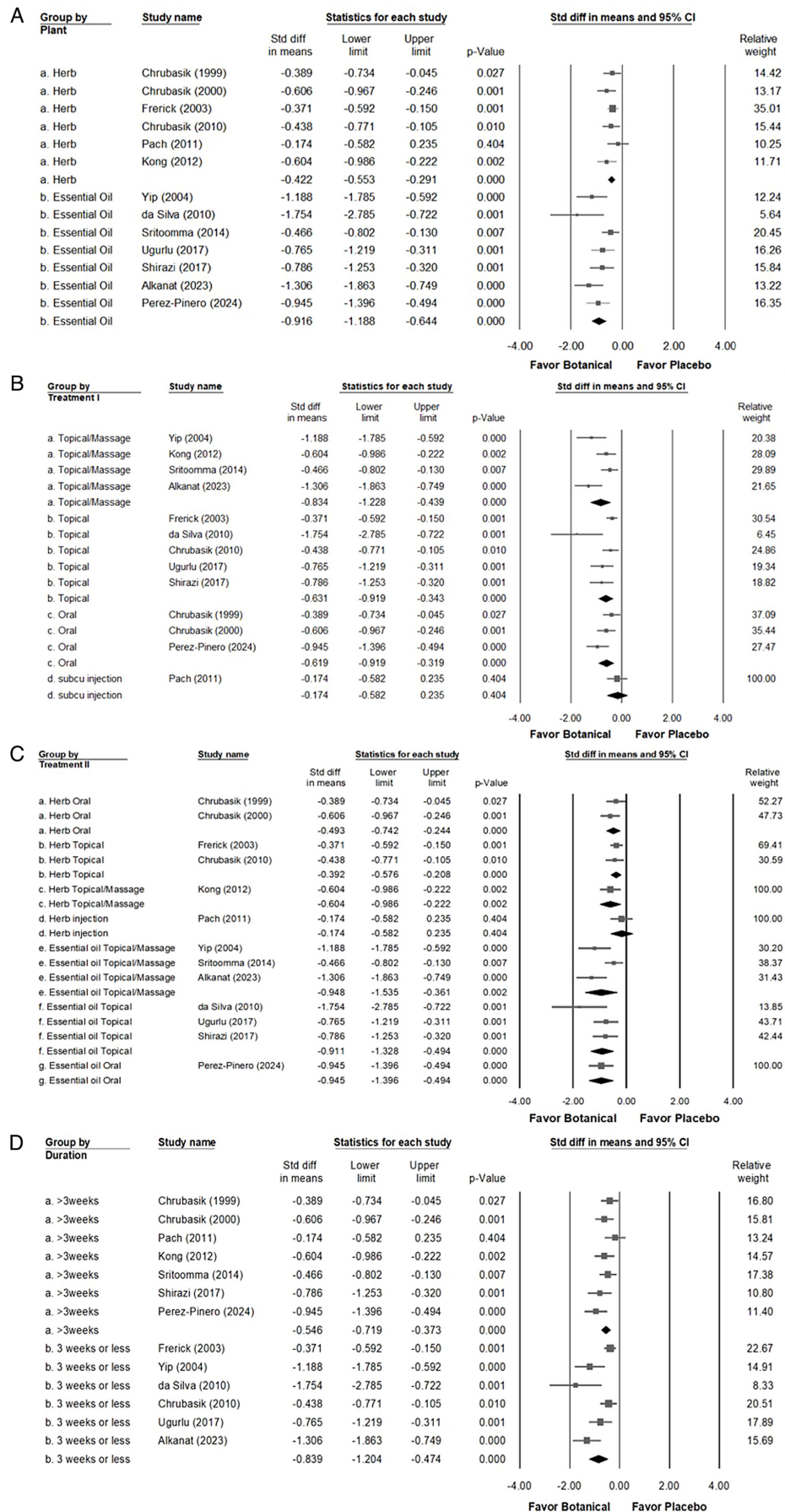
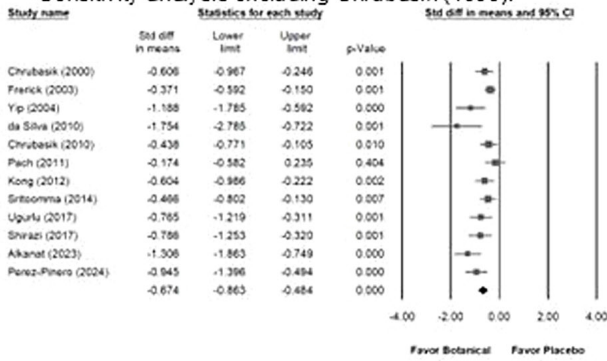
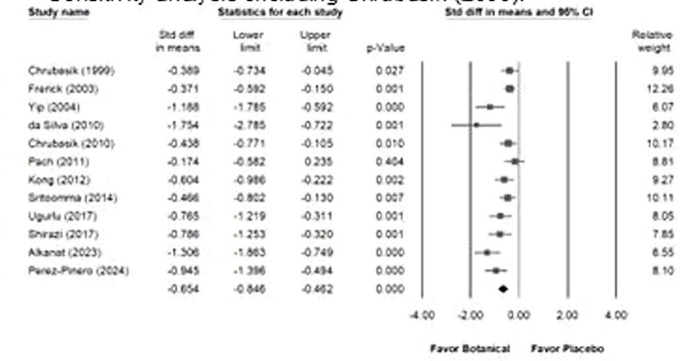


Figure 3. Forest plot that delineates the subgroup analyses of botanical extracts on CLBP. (A) The impact of different types of plant extracts. (B) Treatment methods I, (C) treatment methods II and (D) effects of treatment duration. The reduction in pain scale scores following the intervention is indicated by the square, which represents the standardized mean difference shifting to the left. The horizontal line extending through the square denotes the 95% CI, while the diamond symbol reflects the overall pooled effect size. Subcu, subcutaneous.

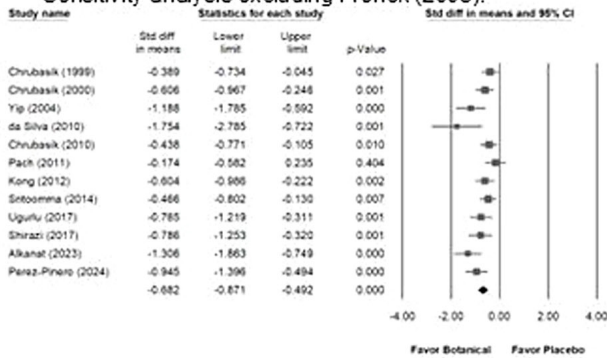
A Sensitivity analysis excluding Chrubasik (1999).



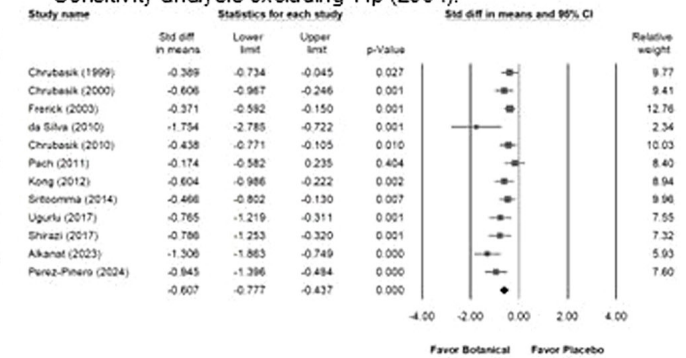
B Sensitivity analysis excluding Chrubasik (2000).



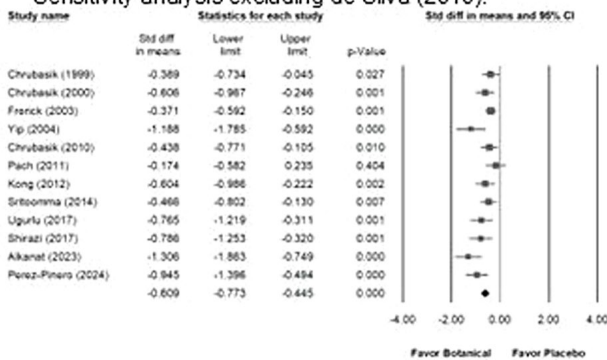
C Sensitivity analysis excluding Frerick (2003).



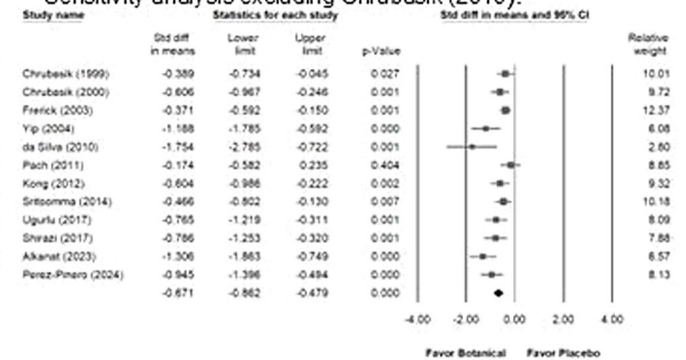
D Sensitivity analysis excluding Yip (2004).



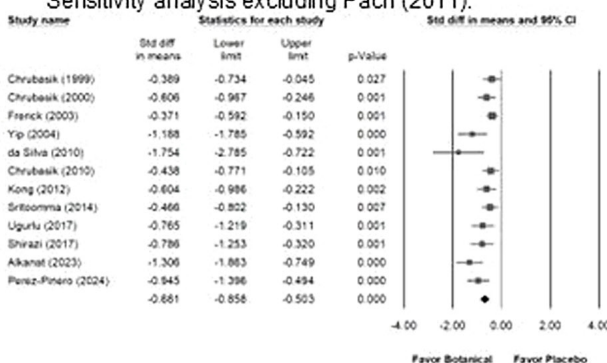
E Sensitivity analysis excluding de Silva (2010).



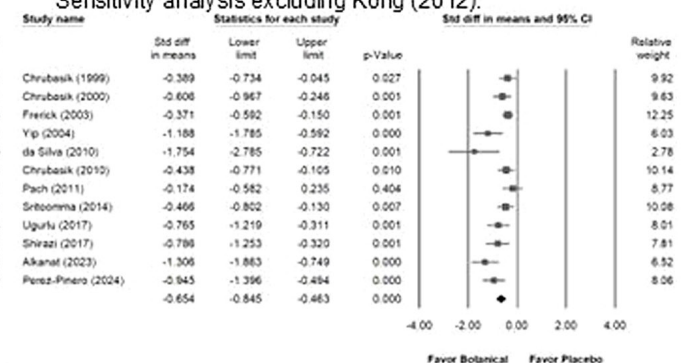
F Sensitivity analysis excluding Chrubasik (2010).



G Sensitivity analysis excluding Pach (2011).



H Sensitivity analysis excluding Kong (2012).



continue

Figure 4. Continued.

aspects, the present study advanced the body of evidence supporting non-pharmacological strategies for pain management. It highlighted the potential of botanical therapies not only as adjuncts to conventional treatments but also as

effective standalone interventions with minimal adverse effects. These findings reinforce the growing shift toward integrative and personalized approaches in chronic pain management, underscoring the need for further research to

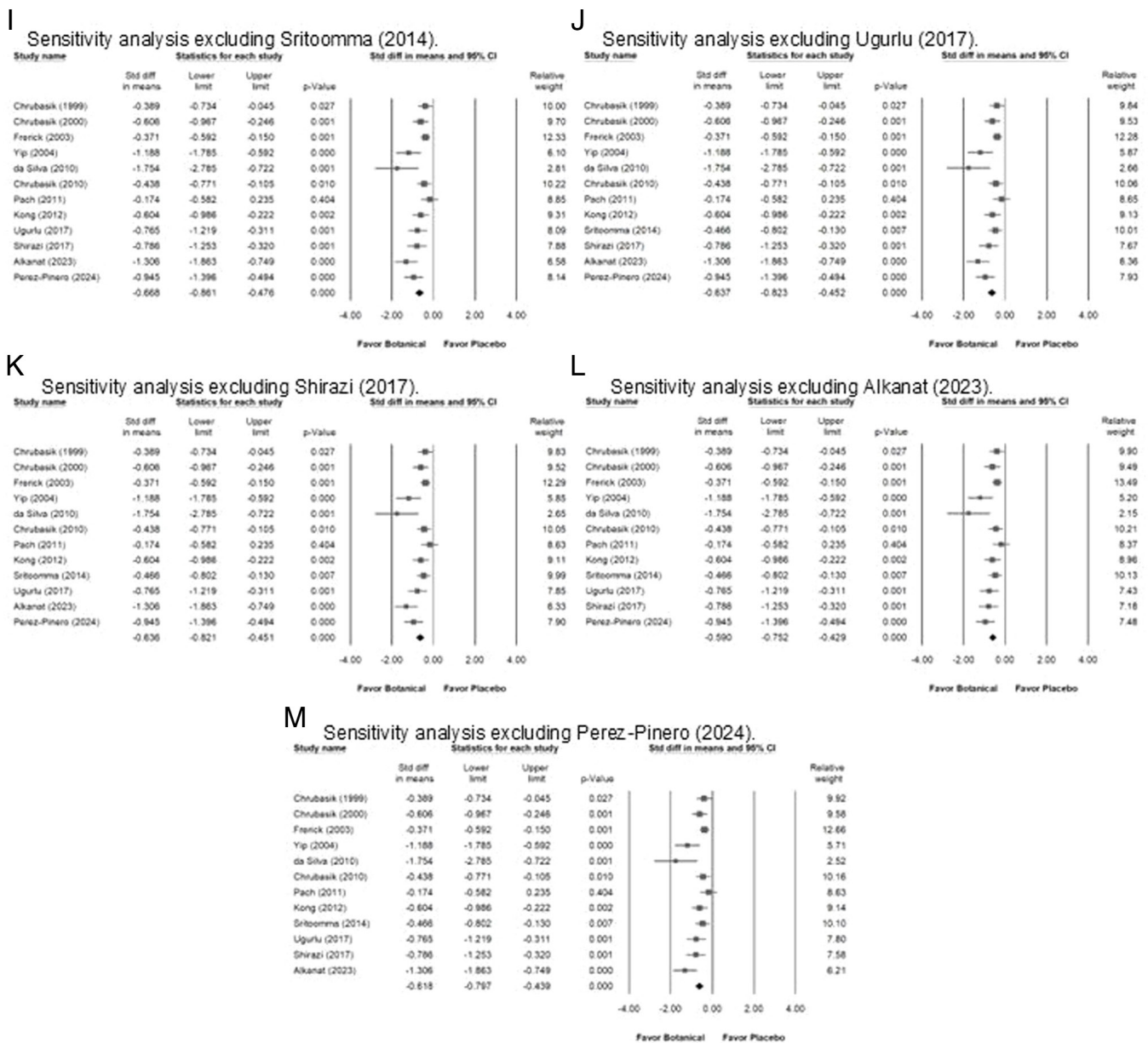


Figure 4. Forest plots depicting the sensitivity analysis using the one-study removal method, where each of the thirteen included studies was sequentially excluded. Exclusion of the study by (A) Chrubasik (1999), (B) Chrubasik (2000), (C) Frerick (2003), (D) Yip (2004), (E) de Silva (2010), (F) Chrubasik (2010), (G) Pach (2011), (H) Kong (2012), (I) Sritoomma (2014), (J) Ugurlu (2017), (K) Shirazi (2017), (L) Alkanat (2023) and (M) Perez-Pinero (2024). The overall random-effect estimate remained consistent, confirming that the study's conclusions are not influenced by the inclusion or exclusion of any single study.

elucidate the long-term efficacy and optimal application of botanical extracts for musculoskeletal disorders.

The inclusion of 13 RCTs involving 1,739 patients provided a statistically robust dataset for analysis. The use of a random-effects model accounted for inter-study variability and the results demonstrated consistent and clinically significant findings. Heterogeneity was moderate and was addressed through subgroup and sensitivity analyses, confirming the reliability of the primary outcomes. The sample size used was sufficient for detecting meaningful differences, as reflected by the significant reductions in pain scores and improvements in functional outcomes observed across various intervention methods.

Various botanical extracts, such as capsaicin, have demonstrated significant reductions in pain scores, likely

due to their analgesic and anti-inflammatory properties (14). The anti-inflammatory and analgesic mechanisms underlying the effects of botanical extracts have a crucial role in their therapeutic potential for CLBP. Essential oils, such as lavender, exert their analgesic effects by modulating neurotransmitters, such as glutamate, which are key to pain perception pathways (31). Capsaicin, a bioactive compound, acts through transient receptor potential cation channel subfamily V member 1 activation, leading to the depletion of pro-inflammatory neuropeptides, such as substance P and calcitonin gene-related peptide, ultimately reducing nociceptive signaling (45). The active compounds of ginger, including 6-gingerol and 6-shogaol, inhibit pro-inflammatory cytokines (such as TNF- α and IL-6) and suppress NF- κ B activation, mitigating inflammation and oxidative stress (46). These

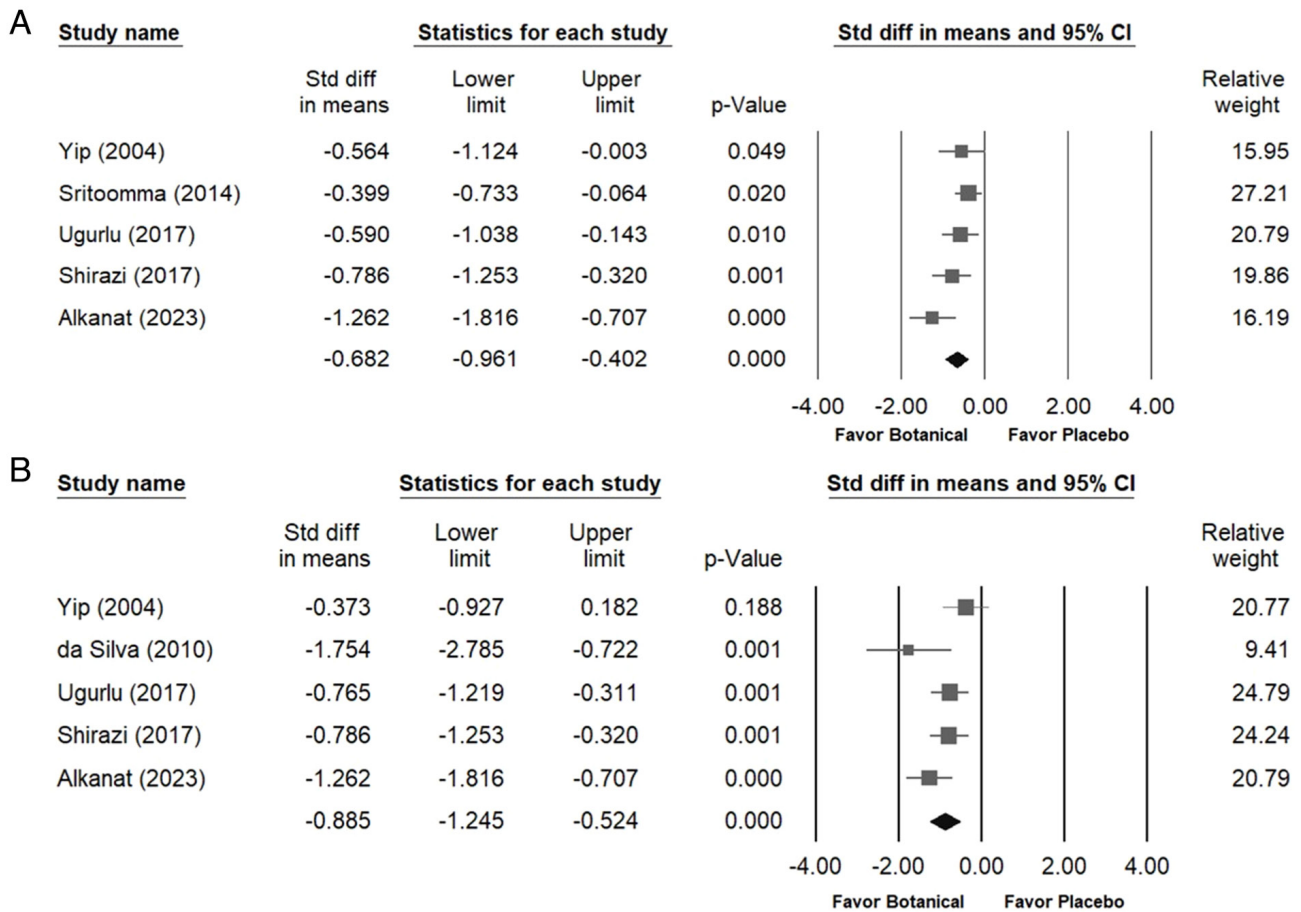


Figure 5. Forest plot that delineates the effects of botanical extract on lumbar flexion and walking time. (A) Impact of botanical extracts on lumbar flexion. The heterogeneity among the 5 included RCTs is reported as $I^2=45.428\%$; $P=0.119$. (B) Impact of botanical extracts on walking time. The heterogeneity among the 5 included studies is reported as $I^2=50.733\%$; $P=0.087$. The horizontal line through the square illustrates the 95% confidence interval, while the diamond symbol summarizes the overall effect size.

mechanisms not only highlight the biological plausibility of botanical interventions but also provide a strong foundation for exploring their long-term benefits in pain management. The application methods, including topical, with massage or oral, offer flexibility in treatment plans to suit individual patient needs and preferences. This is supported by research from Frerick *et al* (7) and Mason *et al* (15,16), which emphasized the minimal systemic side effects and localized action of topical agents such as capsaicin. Additionally, the findings of the present study aligned with those of Kroenke *et al* (47), who advocate for a stepped-care approach to chronic pain management that includes topical analgesics, particularly when other treatments are ineffective. This strategy not only addresses pain but also minimizes the negative side effects associated with systemic medications. Furthermore, incorporating aromatic ginger oil into massage therapy has demonstrated significant potential, augmenting the efficacy of conventional massage techniques in alleviating pain and enhancing functional outcomes in patients with CLBP (36). This observation is consistent with prior research on the analgesic and anti-inflammatory effects of ginger, which have been shown to be beneficial for various musculoskeletal disorders, including knee osteoarthritis, neck pain, non-specific lower back pain and pregnancy-related lower back pain (15,16,47).

In the present study, the administration route analysis further substantiated the effectiveness of botanical extracts, with all application modes showing significant benefits compared with the placebo. This is particularly relevant for clinical practice, where the customization of treatment based on patient-specific factors is crucial for optimizing therapeutic outcomes. The findings from the subgroup analyses in the present study also emphasized the importance of considering individual differences in response to treatment, which can guide more personalized and effective management strategies for CLBP. Additionally, the results of the present study suggested that combining botanical treatments with manual therapies can amplify their benefits. This synergistic effect not only reduces pain but also addresses the underlying inflammatory processes, contributing to a holistic treatment strategy that aligns with both patient needs and the complexities of CLBP. The present study demonstrated a trend indicating a greater efficacy of essential oils compared with Chinese herbs, which may be attributed to the potent and pleasant aromas of essential oils. A study has shown that essential oils can significantly improve pain and functionality in musculoskeletal conditions, aligning with these findings (10). Additionally, the integration of essential oils into massage therapy has been shown to enhance therapeutic outcomes by increasing local blood flow and providing both thermal and aromatherapy benefits (12).

This dual action likely contributes to the superior pain relief observed with essential oils in the present study.

In the present meta-analysis, 1 RCT explored the use of subcutaneous injections of botanical extracts for CLBP but found no significant difference in pain reduction or functional improvement compared with the control group. This contrasts with the overall study findings, where topical and oral applications showed more consistent efficacy. The route of administration may explain this discrepancy; subcutaneous injections may not achieve the localized anti-inflammatory and analgesic effects observed with topical treatments, which interact more directly with sensory receptors (48,49). Additionally, the small sample size and the potential variability in the bioavailability of the botanical extract may have affected the results. While subcutaneous administration may warrant further study, current evidence supports the superiority of topical and oral botanical treatments for managing CLBP.

Despite the promising findings, several limitations of the present meta-analysis should be acknowledged. First, although some analyses, such as the duration of botanical extract use, showed low heterogeneity, others exhibited significant variability. For instance, the heterogeneity for the use of essential oils in topical application combined with massage and for durations <3 weeks was notably high, indicating that the results may be influenced by differences in study populations, methodologies or massage techniques. Second, Egger's regression analysis indicated significant publication bias, suggesting that the effects of botanical extracts on CLBP may be overestimated due to the selective publication of positive results. Additionally, there were inconsistencies in the blinding methods among the included studies. Only 9/13 studies utilized a double-blind approach, while others employed single-blind, assessor-blind or unspecified methods. This lack of uniformity in the study design could impact the reliability of the findings. Furthermore, 4 studies demonstrated significant quality issues and there were moderate concerns about the risk of bias across five distinct areas, which raises questions regarding the robustness of the conclusions drawn from these studies. A total of 4 studies had unclear outcome measurements, which could affect the interpretation of the results. The accurate and consistent measurement of outcomes is crucial for reliable meta-analysis conclusions. Moreover, the meta-analysis included 13 RCTs, which may limit the generalizability of the findings. More high-quality, large-scale RCTs are required to strengthen the evidence for the use of botanical extracts in treating CLBP. Additionally, the studies included in the present analysis did not provide long-term follow-up data, limiting the understanding of the sustained effects of botanical extracts on CLBP. In addition, to assess publication bias, the present study utilized Egger's regression test and visually inspected funnel plots. While it can be acknowledged that additional methods, such as the trim-and-fill method, could provide further adjustments for small-study effects, they were not employed in the present analysis. This is an area that should be addressed in future research to enhance the robustness of these findings. Moreover, the specific types and formulations of botanical extracts varied across studies. This variability makes it challenging to draw definitive conclusions about the most effective type or preparation of botanical extract for CLBP. The comparative evaluation

of essential oils, capsaicin and ginger could not be performed in the present study due to the limited number of head-to-head RCTs directly comparing these interventions. Additionally, the included studies exhibited considerable variability in terms of study design, intervention protocols, dosages and outcome measures, which limited the feasibility of conducting a reliable indirect comparison. A network meta-analysis requires a more interconnected dataset with sufficient overlap between studies, which was not available in the present study. However, this meta-analysis offers distinct advantages by incorporating both essential oils and herbal extract-based therapies, providing a more comprehensive evaluation of botanical interventions for CLBP management. By assessing different administration routes and treatment durations, the present study offered practical insights into personalized treatment strategies. Additionally, these findings highlighted the potential benefits of combining botanical treatments with manual therapies, such as massage, which may further enhance therapeutic outcomes. Future research should aim to address these limitations by standardizing botanical extract formulations, conducting larger and higher-quality RCTs with long-term follow-up data and further investigating the mechanisms underlying botanical interventions. Exploring the potential interactions between botanical treatments and manual therapies may also contribute to the development of more effective and integrative approaches for CLBP management.

Moreover, current research on botanical therapies for CLBP primarily focuses on their efficacy and safety in isolation, without direct comparisons to conventional pharmacological treatments. A Cochrane review has suggested that certain herbal medicines, such as devil's claw (*Harpagophytum procumbens*) and white willow bark (*Salix alba*), may offer greater pain relief when compared with a placebo, with adverse effects generally limited to mild and transient gastrointestinal discomfort or skin irritation (50). A systematic review indicated that NSAIDs and opioids provide short-term pain relief for non-specific CLBP but are associated with a higher incidence of adverse effects compared with a placebo. However, this review did not include direct comparisons with botanical therapies (51). Similarly, while some studies have explored the effectiveness of complementary therapies, such as acupuncture and herbal medicine, for chronic non-specific lower back pain, the evidence remains inconclusive, and direct comparisons with standard pharmacological treatments are lacking (42,52). Beyond their efficacy, concerns persist regarding the long-term safety and cost-effectiveness of botanical treatments. Regarding cost-effectiveness, research has shown that interdisciplinary rehabilitation, exercise, acupuncture, spinal manipulation and cognitive-behavioral therapy are cost-effective for sub-acute or chronic low back pain (50). However, there is insufficient evidence on the cost-effectiveness of botanical therapies compared with conventional pharmacological treatments (53). To address these limitations, future research should prioritize long-term safety assessments by conducting RCTs with extended follow-up periods, which will allow for a more thorough evaluation of delayed adverse effects. Economic evaluations comparing the direct costs, such as medication expenses and hospitalizations, with indirect costs, including productivity loss and quality of life impact, will

be essential for determining their real-world applicability. Standardization of botanical formulations should also be a key area of focus to ensure consistency in composition and therapeutic effects across studies, thereby improving the reproducibility and reliability of clinical outcomes. Another critical aspect that requires attention is the methodological rigor of clinical trials, particularly regarding blinding and placebo control. Many trials involving botanical therapies face challenges in maintaining blinding due to the distinct sensory characteristics of herbal preparations. Future studies should adopt more sophisticated blinding techniques, such as the use of indistinguishable placebo formulations, to minimize bias and strengthen the reliability of the evidence. By addressing these gaps, future investigations can provide more comprehensive insights into the clinical utility, safety, and economic viability of botanical therapies for CLBP. This will ultimately contribute to a stronger evidence base for their potential role in evidence-based treatment strategies.

In conclusion, the present meta-analysis highlighted the potential of botanical extracts as effective and safe alternatives for managing CLBP, providing pain relief and functional improvements with minimal adverse effects. To strengthen these findings, larger RCTs with standardized botanical formulations, consistent blinding methods and long-term follow-up are needed to confirm the sustained benefits of these interventions. Additionally, future research should investigate the cost-effectiveness of botanical therapies to support their role in reducing dependence on conventional pharmacological treatments. While the present study offered an overview of the individual effects of various botanical extracts, future network meta-analyses should provide a more robust framework for directly comparing their relative effectiveness. Such analyses could enable a comprehensive ranking of these interventions, offering valuable insights to guide clinical decision-making and addressing current gaps in the literature.

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Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

RYT was responsible for study conception, data curation, investigation (gathering and analyzing primary data, and conducting experiments), visualization of results as figures, and writing, reviewing and editing the manuscript. CCC was responsible for study conception and data curation. SYL was responsible for investigation (gathering and analyzing primary data, and conducting experiments) and visualization of results as figures. JYU assisted in identifying RCTs and abstract

screening. YH assisted in identifying RCTs and figure production. RYT and CCC confirm the authenticity of all the raw data. All authors read and approved the final version of the manuscript.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Use of artificial intelligence tools

During the preparation of this work, artificial intelligence tools were used to improve the readability and language of the manuscript or to generate images, and subsequently the authors revised and edited the content produced by the artificial intelligence tools as necessary, taking full responsibility for the ultimate content of the present manuscript.

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