7 Functional Associations Between Secondary Metabolic Traits and Gynecological Effects

7.1 Correlation between key active components and pharmacological efficacy

Chemical-pharmacological correlation studies consistently identify leonurine, stachydrine and trigonelline as core active alkaloids whose plasma exposure and tissue distribution parallel the traditional gynecological indications of *Leonurus japonicus* (Zhao et al., 2022). Network pharmacology and pharmacokinetic analyses show that these alkaloids act on targets involved in vascular regulation, inflammation and endocrine pathways, linking their presence in different plant parts to effects on menstrual disorders, postpartum recovery and blood-stasis syndromes (Wang et al., 2020).

At the single-compound level, leonurine displays pleiotropic cardiovascular, anti-oxidant and anti-inflammatory actions, furnishing mechanistic support for motherwort's use in conditions characterized by pelvic ischemia, pain and microvascular dysfunction (Li et al., 2019). Other secondary metabolites, including labdane diterpenoids and flavonoids, contribute anti-platelet, anti-inflammatory and hormone-modulating activities, suggesting that distinct metabolite classes collectively underpin the multi-target efficacy observed in obstetrical and gynecological practice (Xiao et al., 2017; Zhang et al., 2018).

7.2 Impact of metabolic variation on therapeutic stability

Comparative analyses of *L. japonicus* from different geographic origins reveal significant intergroup differences in active-ingredient profiles, despite relatively modest genetic divergence, indicating that environmental factors and cultivation conditions strongly influence secondary metabolite composition (Han et al., 2023). Such chemotypic variation implies that the content of key alkaloids or diterpenoids may fluctuate among accessions, potentially leading to inconsistent clinical responses when crude drugs are sourced without standardized quality control (Wang et al., 2023b).

A systematic Q-marker study further demonstrates that leonurine, stachydrine and trigonelline differ in stability during storage, with time-dependent declines that are substantial enough to affect pharmacologically effective doses if not controlled (Zhao et al., 2022). By establishing content limits and stability windows for these markers, the work directly links metabolic degradation dynamics to therapeutic reliability, providing a quantitative framework for ensuring consistent gynecological efficacy in commercial preparations (Wang et al., 2024).

7.3 Functional association studies based on metabolomics

Integrated metabolomics and network pharmacology applied to leonurine show that changes in circulating metabolites map to pathways in glycerophospholipid, linoleic acid, tryptophan and glutamate metabolism, which are central to oxidative stress, inflammation and energy homeostasis (Rong et al., 2022). Regulation of these metabolic networks aligns with leonurine's protective effects in cardiovascular and metabolic models, reinforcing the idea that modulation of systemic metabolism is a key route through which *L. japonicus* components support uterine and pelvic vascular health in gynecological disorders (Li et al., 2019).

In parallel, metabolomic and multivariate analyses of whole-plant extracts identify dozens of absorbed prototypes and biotransformation products whose patterns differ across plant parts, yet cluster with gynecologically relevant targets in network models (Zhao et al., 2022). These association studies suggest that specific metabolite signatures-rather than single compounds alone-correlate with anti-inflammatory, endocrine-modulating and pro-circulatory effects, pointing toward metabolomics-driven definition of chemotypes optimized for menstrual regulation, endometrial repair or estrogen-related conditions (Shi et al., 2024).

8 Case Study: Comparative Analysis of Metabolic Variation and Gynecological Efficacy of *Leonurus japonicus* from Different Origins

8.1 Comparative analysis of chemical composition among different geographical origins

Leonurus japonicus exhibits pronounced intraspecific chemical variation, reflecting both genetic divergence and environmental heterogeneity across its distribution range. Multi-locus barcoding combined with HPLC profiling has shown that accessions from different origins cluster into distinct genetic lineages, and these clades partially parallel differences in contents of key alkaloids such as leonurine and stachydrine (Figure 3) (Han et al., 2023).