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黄精活性成分提取工艺研究进展

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摘要: 黄精是传统的食药同源物质, 富含多糖、皂苷、黄酮等多种营养与功效成分, 具有增强免疫功能、抗疲劳、调节血糖、调节肠道菌群等功效。随着大健康产品需求的增长, 黄精提取物常应用于中成药和保健食品的配伍。讨论了黄精活性成分提取工艺, 并从生产实际和科学研究 2 个方面进行了小结与展望。总结提取方法发现: 目前对于黄精中主要活性成分的提取, 尤其是工业化生产过程中, 大多仍采用传统的回流提取法, 虽成本低但损耗多、效率低。重点介绍了超声波协同酶提取等新方法在多糖、皂苷类成分提取中的优势, 新方法的得率可达传统方法的 1.5~3.3 倍。指出黄精中特有的小极性高异黄酮现有提取方法的不足。建议根据目标物的性质组合或开发出针对性的提取技术, 改良的提取工艺可提高黄精活性成分的得率。参 96

关键词: 黄精; 多糖; 皂苷; 高异黄酮; 提取方法

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Research progress on extraction technology of active components from polygonati rhizoma

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Abstract: Polygonati rhizoma, a substance that serves both as food and medicine, is rich in nutritional and functional components such as polysaccharides, saponins, and flavonoids. It has the effects of enhancing immune function, anti-fatigue, regulating blood sugar and regulating gut microbiota. With the increasing demand for healthy products, polygonati rhizoma extracts are commonly used in the combination of traditional Chinese patent medicines and health foods. The extraction process of active components from polygonati rhizoma is discussed, and a summary and outlook are provided from both the perspective of production practice and scientific research. The summary of extraction methods reveals that for the extraction of the main active components of polygonati rhizoma, the traditional reflux extraction method is still widely used in the industrial production process, which has high loss and low efficiency in spite of its low cost. This paper highlights the advantages of new methods such as ultrasonic-assisted enzymatic extraction in the extraction of polysaccharides and saponins. The yield of the new methods can be 1.5 to 3.3 times that of the traditional methods. It points out the shortcomings of the existing extraction methods for the unique small polar high isoflavones in polygonati

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rhizoma and suggests that targeted extraction techniques should be developed based on the properties of the target substances. The improved extraction process can increase the yield of active component. [Ch, 96 ref.]

Key words: polygonati rhizoma; polysaccharides; saponins; homoisoflavonoids; extraction methods

黄精 (polygonati rhizoma) 为植物鸡头黄精 *Polygonatum sibiricum*、滇黄精 *P. kingianum* 或多花黄精 *P. cyrtonema* 的干燥根茎, 具有补气养阴、健脾益肾、润肺等功效^[1]。现代药理学研究表明: 黄精还具有增强免疫功能、抗疲劳、调节血糖、调节肠道菌群、抗炎、抗肿瘤等多种生物学活性, 主要功效成分为非淀粉多糖, 如果聚糖等。此外, 还有甾体皂苷、黄酮等丰富的小分子化合物^[2-3], 其中多糖为主要活性成分。多糖被广泛应用于食品、饮品、保健食品和药品^[4], 《中国药典》将其作为评价黄精质量标准的指标。黄精多糖可包裹淀粉颗粒、延缓能量释放, 适合与主粮配伍制成黄精面条、饼干等食品^[5], 黄精单品还可与其他中药配伍发酵生产酒品, 能提升酒的口感和营养功效价值^[6]。黄精甘美易食, 制黄精中果糖质量分数高达 38%^[7], 可以代替蔗糖应用于运动食品和乳制品^[8]。黄精提取物黄酮和皂苷常被用于生产精华液护肤品, 具有抗氧化、保湿和修复肌肤的功效。在提取过程中, 富集营养功效成分, 去除口感和溶解性不佳的细胞壁等成分, 对精加工产品的生产至关重要。传统提取方法大多存在热敏性成分的不可逆损失、能量转化效率低下、环境负荷超标的问题, 因此探索保持黄精风味活性的绿色高效提取方式至关重要。当前, 低温酶提、超声波辅助提取等绿色节能高效技术正被逐渐应用。本文对黄精中不同理化性质的目标成分的制备工艺进行了综述, 以期满足不同应用和要求, 为丰富黄精产品种类、提升黄精产品附加值提供参考, 进一步促进黄精产业的发展。

1 黄精多糖提取工艺

1.1 热水回流提取法

热水回流提取法是植物多糖最常用的制备方法, 也是目前基于质量控制要求下工业化提取黄精多糖的主要技术。回流提取与索氏提取法^[9]的工作机理相同, 但热水回流提取法受热时间较短, 节省时间、损失较少, 是目前最常使用的方法^[10-11]。影响得率的主要因素有提取装置、提取时间、物料比、提取温度及提取次数。水提温度为 80 ℃、物料比为 1:20(质量比) 时, 得率较高, 最高可达 27%^[12-27]。物料比与时间两因素交互作用对多糖得率影响极显著。值得注意的是, 沸水的提取效果并不佳^[19], 这与《中国药典》中规定提取方法对温度的要求不同, 说明太高的温度不利于黄精多糖的提取, 可能是因为生黄精中主要的多糖是分子结构中有分枝的果聚糖, 具有易降解的特性^[28]。

1.2 碱液浸泡提取法

碱液浸泡提取法有利于某些含酸性基团多糖的提取, 可使细胞壁裂开以释放多糖。采用多因子多水平正交试验法碱提黄精多糖, 显示提取条件对多糖得率影响大小的顺序依次为药材粒度、碱液浓度、物料比。赵瑞萌等^[29]的研究结果表明: 黄精粉末颗粒度 60 目、碱液质量分数为 3%、物料比为 1:15 时, 得率可达 11.88%。碱性条件下糖苷键易水解使多糖失去生物活性, 因此提取结束后需快速将提取液 pH 调节至中性, 或将糖残基还原成糖醇, 尽可能阻止糖苷键降解。虽碱液浸泡提取比较繁琐, 但会增强提取出的多糖的某些活性。

1.3 酶辅助浸提法

酶辅助浸提法就是在适宜的环境下, 选取不同活性或品种的酶提高提取效率的方法。常用的酶类型有纤维素酶、淀粉酶、木瓜蛋白酶等, 酶的类型、浓度、反应时间、反应温度、pH 和药材粉碎的粒度大小均可影响提取效率^[30]。提取黄精多糖可用不同比例的纤维素酶和木瓜蛋白酶制备复合酶, 得率可达 20.00% 以上^[31-34], 为单一酶得率的 1.92~2.16 倍^[35]。利用正交试验优化酶解时间和料液比因素发现两者对得率的影响显著^[34]。纤维素酶用于破坏细胞壁, 木瓜蛋白酶则分离蛋白多糖中的蛋白^[36], 并将糖释放出来, 提升多糖得率。

1.4 超声波辅助提取法

超声波辅助提取法的主要运作原理是通过空化效应进行震动扰动, 产生真空气泡并膨胀爆裂, 促使

真空气泡裂解释放细胞内的多糖，有助于细胞内活性物质的渗出^[37]，使多糖等活性成分渗出并稳定地溶解在溶剂中。通过响应面法优化超声提取滇黄精多糖提取工艺参数，当提取时间为 30 min 时得率较高^[38-42]。酶辅助超声波提取可提高得率^[43-46]。陶涛等^[44]研究指出：纤维素酶与底物质量比为 1% 时，得率可达 39.36%；还可以选用木瓜蛋白酶和纤维素酶超声辅助提取^[46]，实现双重破坏，黄精多糖得率可达 25.63%。

1.5 微波提取法

微波提取法通过实现热能的均匀传递，有效促进多糖成分的释放和溶解。与传统方法相比，微波提取法不仅保持了提取物的性质^[47]，而且消耗时间短，得率高。通过单因素和正交试验优化黄精多糖提取工艺^[48-52]，发现通过调整微波辐照功率这一关键因素，得率可达 10.00%~20.00%。有研究指出：采用黄精多糖与黄酮最佳综合提取工艺，在外加元素干预下，测得多糖质量分数为 186.35 mg·g⁻¹^[51]。使用超声-微波协同提取仪，调节合适的超声功率、微波功率与频率，在提取温度为 60 ℃、超声时间为 80 s 的条件下可获得较高的得率^[53]，因此可将微波与其他提取技术相结合，实现工艺优化。

1.6 其他提取法

一些新提取技术也在逐渐被开发应用，均具有较好的提取效果，如闪式提取技术运用负压渗滤、强力震荡的原理对中药成分进行快速破碎与剧烈搅拌，能在强化提取的同时缩短提取时间，避免破坏有效成分^[54]。陈艳等^[55]利用闪式提取器和特定的溶剂，在物料比为 1:18，提取时间为 40 s，电压为 50 V 时，黄精多糖得率可达 14.99%。

微生物提取法是近年来发展起来的另一种多糖提取技术。该技术提取条件温和，可尽可能维持多糖结构稳定。有研究发现：该方法提取的黄精多糖质量分数达 33.11%^[56]。但是，微生物提取法需要选择特殊的细菌，故操作过程中易被其他细菌污染。

减压内部沸腾提取技术需要在专有的提取罐中进行，利用真空减压原理降低罐内压力实现物料的低温沸腾，从而实现高效提取。此技术可有效避免活性成分受热分解问题^[57]，尤其适用于黄精多糖中一些不稳定、热敏性成分的提取。杨军宣等^[58]通过单因素分析与正交试验，确定减压内部沸腾法提取黄精多糖的最佳工艺为体积分数为 60% 乙醇解析 30 min，多糖得率高达 11.15%。相较于传统方法，该方法乙醇用量减少，提取时间缩短，得率提升。

超高压提取作为非热提取技术，具有低温、低杂质、低萃取剂用量、工艺简便的特点，适用于天然化合物提取^[59]。在黄精多糖提取中，超高压技术展现出广阔的应用前景，特别是在黄精食品加工与食品添加剂领域，某些产品就是采用 255 MPa 的超高压技术提取黄精多糖而制成^[60]。有研究应用超高压技术提取滇黄精多糖，得率可达 19.57%，为后续结构特性研究与分离纯化奠定了基础^[61]。动态超高压微射流技术融合高压射流、撞击流及传统高压均质技术优势，使得总多糖得率升高。该方法还可用于其他活性成分的提取^[39]。

除新型提取技术外，新型提取介质如离子液体亦受瞩目。离子液体由离子构成，具备强溶解力、低挥发性、高热稳定性及较强的微波吸收与热转换能力^[62]，常与超声、微波相互协同来提取黄精多糖。此外，可切换极性溶剂的提取方法具环境友好、选择性高、污染少的优点，广泛适用于多种化合物的高效低能耗提取。以多花黄精多糖质量分数为指标，采用离子液体于 47 ℃ 下超声提取 20 min，得率高达 12.31%^[63]。CHEN 等^[64]采用不同胺基和水基的二氧化碳触发可切换亲水性溶剂对黄精多糖进行超声辅助提取，通过调节二氧化碳的泵入实现溶剂亲水性的转变，从而高效提取黄精多糖，虽测得指标为总多糖，但得率较高；还可利用超声辅助萃取-深共晶溶剂组合萃取，相较单一采用低共熔溶剂萃取的方法，得率明显提高^[65]。

这些新的提取方法从物理、生物方面强化了提取强度，从而提高了得率。闪式提取法、减压内部沸腾提取法和超高压提取法属于物理强化，既能快速制备又不易破坏热敏性成分。提取液体为离子液体或者加入一些化学成分使提取溶剂性质发生变化从而提升得率，同样不易破坏黄精多糖活性。微生物提取法重点在于加入了特殊的菌种辅助提取，提升得率的同时最大程度地保护了黄精多糖的结构，但存在提取物被污染的可能。另外，电场提取法、真空提取法、发酵醇沉淀提取法等也被用于黄精多糖的提取^[66]。

未来研究可进一步探索这些方法的适用性,并尝试与其他新型提取技术进行创新组合,以期在黄精多糖提取领域取得更多突破。

2 黄精皂苷提取工艺

2.1 浸渍提取法

由于加热耗时长,浸渍提取法提取黄精皂苷一般采用乙醇为提取液。为提高得率,可辅以机械振荡器或磁力搅拌器^[67]。王冬梅等^[68]探究黄精根中甾体皂苷生物抗菌活性,用乙醇浸泡至提取液近完全脱色,正丁醇相产物即为总甾体皂苷,优化方法后得率可达3.87%。浸渍法所需实验仪器少,但活性产物的提取宜在温度变化不大的环境下进行,过长时间浸渍可能导致皂苷水解,增加杂质,且皂苷溶出速度慢,故需要结合超声、微波等技术协同提取。

2.2 回流和索氏提取法

回流法的提取量较稳定,通过加热溶剂循环利用,适用于热稳定性较好的皂苷类成分,还可通过调节提取液的体积分数(如80%乙醇)平衡提取效率与杂质干扰。热回流法常用于黄精皂苷的大批量提取。多次提取过程中发现提取第2次且物料比为1:15时皂苷得率最高^[69],也有研究在优化提取工艺后用乙醇回流提取1h,得率可达3.01%^[70]。

由于提取次数较多、时间较长,上述2种传统方法的皂苷总得率相对较高,但耗时耗力,且选择性低,易引入或溶出多糖、蛋白及鞣质等杂质,增加后续纯化难度。温度也会对皂苷活性与结构产生影响。除了结合其他方法进行提取外,还可以基于不同类型黄精皂苷热稳定性差异,采用梯度升温策略(如从50℃升温到70℃分段提取),兼顾效率与活性成分的保留。

2.3 超声辅助提取法

超声辅助提取法是提取黄精皂苷最常用的方法,且平均得率最高。通过单因素和正交试验发现^[71-72]:提取液体积浓度与黄精皂苷得率极显著相关。在多数研究中,选择体积分数为80%乙醇作为提取溶剂较多^[73-77],其中最佳工艺采用体积分数为85%乙醇,水温为70℃,超声功率为300W,pH为5^[44]。在乙醇提取完成后,大部分实验会采用正丁醇萃取,但有些实验也会直接采用正丁醇作为提取溶剂^[78]。超声辅助提取法的提取水量较稳定,所需温度较低,故提取效率高且操作也较为简便,还可节省能源,是提取黄精皂苷的常用方法^[79]。然而,在使用超声技术时,需要控制超声时间和功率,以防止皂苷成分的损失。

2.4 微波辅助提取法

微波是一种非离子型电磁波。因微波辅助提取法提取时间短,溶液用量小以及其独特的加热提取机制,在药材有效成分萃取中逐渐得到广泛应用^[80-81]。在黄精皂苷提取时,黄精需在适宜温度下干燥后,用适宜体积分数的乙醇为提取剂,经微波处理后再进行溶剂萃取。采用390W微波功率间歇提取总皂苷,得率可达2.50%以上^[82]。尽管提取时间较超声辅助提取法短(微波法3min,超声法15min),但超声辅助提取法所需温度低^[83],且能提取更多黄精皂苷^[70]。

2.5 酶提取法

酶的反应条件比较温和,通过破坏细胞壁组织,可有效提高皂苷的得率^[44]。在植物皂苷提取中应用较多的酶是纤维素酶。有研究比较了用不同酶提取黄精甾体皂苷的效果,最后选择采用复合酶^[84]。也有实验在用纤维素酶辅助提取黄精皂苷后,还运用了冷等静压机,讨论了压力大小与施压时间对得率的影响^[85],发现运用320MPa施压5.3min可提高得率。多种提取方法相结合进行提取也可提升得率,例如酶提取法协同超声辅助提取,得率也可达12.00%^[86],超声过程料液比对提取结果影响极显著。总体而言,酶辅助提取法为提取黄精皂苷的最佳方法之一,专一性强且得率高。酶提取法处理时间较长,酶活性会因环境变化而改变,需要严格控制环境条件,同时要结合多种物理强化技术^[85-86],进一步促进黄精皂苷资源的高值化开发。

2.6 闪式提取法

闪式提取法亦称组织破碎提取法,具体原理可见本文1.6节。闪式提取法提取速度快,一次提取仅需几秒至几分钟时间,故称为闪式^[87]。应用闪式提取时,采用电压为100V,物料比为1:20,提取时间

为 40 s 的提取条件，黄精皂苷得率可达 3.50%^[88]。该提取工艺简单有效，很适合在各产业推广。然而，由于黄精富含糖类，闪式提取后，可能会出现黏度增加和乳化等问题，故需要通过离心处理或加装振动筛处理进行过滤。

3 黄精黄酮提取工艺

3.1 溶剂提取法

鉴于黄酮类物质中多含极性大的苷类结构，常选用乙醇等溶液作为提取溶剂，有利于提高得率，而对于极性较小的苷元，大多采用乙酸乙酯等进行萃取。因黄精黄酮中高异黄酮的母体结构比普通异黄酮多 1 个碳原子，故溶解性很小，多存在于石油醚-乙酸乙酯洗脱组分中。

WANG 等^[89]采用醇提法结合热回流技术提取多花黄精黄酮类化合物，结果显示：使用体积分数为 80% 乙醇在 70 ℃ 下提取 1 h 并重复提取 2 次，能有效提高黄酮得率。徐胜等^[90]发现：回流提取能得到更多且更完全的黄酮单体，考虑到取得最大得率并保证药材质量，最终选择对黄精中黄酮进行回流提取，且最佳提取模型中的黄精黄酮最大得率为 0.06%^[90]。

采用碱提法也可提取黄酮，且提取溶剂的选择因植物成分而异。黄精黄酮的最佳提取溶剂可沿此方向探究。黄精中的黄酮含量相对较低，且含有高达 39 种的高异黄酮成分，这些成分的极性极小。目前尚缺乏针对黄精中高异黄酮这一特殊物质的专门提取方法。

黄精中黄酮类化合物的提取大多采用醇提方式。水提法是针对水溶性黄酮含量较高的植物的提取方法，虽然操作简单且无有机溶剂残留，但黄酮类活性化合物的得率低，且易带入水溶性杂质。醇提法中醇的浓度大小通常依据黄酮在植物中的存在形式而定，黄精中的黄酮常用体积分数为 50%~80% 的醇溶液溶解并回流提取。碱提法则是考虑到黄酮类化合物所含基团大多呈酸性，易溶于碱液，但碱液浓度过大也易破坏母核，所以仍需结合后续结果探究合适的提取条件。

3.2 超声波提取法

超声波提取法被广泛用于黄酮类物质的提取过程，其技术应用原理类似于黄精多糖的提取原理。在超声波的辅助作用下，从黄精中提取黄酮类化合物时，可引入低共熔溶剂 (deep eutectic solvents, DES) 作为环保型提取介质，建立绿色超声辅助提取植物黄酮类化合物的方法^[91]。通过正交试验设计，部分研究确定了最佳超声提取条件^[92-93]，发现提取时间以 30 min 为较优选择。一些研究通过响应面法对超声提取黄精根茎及叶片中黄酮、总黄酮的方法进行优化，发现在 50 ℃、450 W 功率条件下用体积分数为 80% 乙醇超声提取得率较高^[94-95]。

超声波提取法是最常用的提取黄精黄酮的方法，提取过程穿透力强，可使黄酮类物质短时间内持续溶解于提取溶剂中，同时传热效应使提取温度恒定，一定程度上提高了黄酮类物质的提取效率^[96]，但是若超声时间过长，黄精中黄酮类化合物的得率会降低，一般不宜超过 1 h。多项研究表明：影响因素显著性排序为物料比、提取温度及乙醇体积分数，正交试验的极差高低依次为 0.56、0.09、0.08^[93]。超声波提取法选择性强，有显著提升黄精黄酮得率的效果。除了优化超声参数，与黄精多糖提取中采用提取介质提升得率的策略相似，可将超声波技术与绿色提取介质，如低共熔溶剂或离子溶剂相结合；还可设置适宜的功率与频率，例如低频更利于细胞破碎，高频 (>100 kHz) 适合精细控制能量输入，促进黄精黄酮成分溶出。

3.3 微波提取法

微波提取法可引起黄酮类物质分子间热效应，使温度急速升高，同时避免传统直接加热对黄酮类物质的损耗。探究微波辅助法提取黄精总黄酮的最佳工艺，大多运用单因素和正交试验相结合的方法。有研究发现：只需微波加热提取 80 s，黄酮类化合物得率就有所提升^[83]。总的来说，微波提取法表现出高效、节时和节能等优点^[85]。探究微波辅助提取黄精黄酮类物质方法时，也可加入一些离子液体，充分发挥耗时短、产率高及环境友好等优点。

近年来被广泛应用于天然产物中黄酮提取工艺的还有超临界流体萃取方法。该技术利用低温条件以更好地保留提取物的活性，同时在萃取过程中能有效分离溶剂与提取物，从而获得对人体和环境均友好的天然成分。该方法的主要优势在于大部分提取溶剂具有高挥发性，废物量极少，对黄酮类化合物的提

取率较高。在提取极性小又难以萃取的黄精黄酮,尤其是高异黄酮时,该方法可作为一种研究思路与方向。但该方法仍存在一些局限性,例如需要维持溶质和溶剂之间的平衡,运行和维护成本较高等。

4 总结和展望

黄精作为药食同源中药材,具有毒副作用小、临床应用广泛的特点,展现出显著的开发潜力。黄精的活性成分如多糖、皂苷和黄酮,具有调节血糖、增强免疫力、益生元、抗疲劳等多重药理作用。黄精多糖提取已有深入研究,超声波协同酶提等方法可显著提升得率,低温处理既可保护多糖结构,又保证酶活性,是绿色环保的高效提取手段,且得率为一般提取方法的1.5~3.3倍,未来黄精多糖类提取时还可继续优化工艺以保证分子结构的完整性。对于皂苷提取,酶提法因其高得率成为当前最优选择,闪式提取法等新型技术也展现出高效、低成本的潜力,但仍需构建起提取效率与能耗成本的最优平衡点。针对黄酮提取,鉴于黄精中高异黄酮较低且极性小,未来研究可探索新型物理场辅助提取技术,以提高黄酮得率并保留其生物活性。此外,开发专属的液质联用方法,准确测定黄精高异黄酮含量,并实现低含量成分的高效提取是重要的研究方向。综上所述,选择黄精活性成分的适宜提取方法时,应探索多种技术的协同应用,充分考虑提取目的、环境条件及经济成本,并结合分子机制、绿色技术等对成分结构及生物活性的影响,控制原料标准化,实现提取工艺与产品功能的精准对接。

5 参考文献

- [1] 国家药典委员会. 中华人民共和国药典:一部[M]. 北京:中国医药科技出版社,2020:319-320. Chinese Pharmacopoeia Commission. *Pharmacopoeia of People's Republic of China, Volume I* [M]. Beijing: China Medical Science and Technology Press, 2020: 319-320.
- [2] CHAI Yangyang, LUO Jiayuan, BAO Yihong. Effects of *Polygonatum sibiricum* saponin on hyperglycemia, gut microbiota composition and metabolic profiles in type 2 diabetes mice[J]. *Biomedicine & Pharmacotherapy*, 2021, **143**: 112155. DOI: [10.1016/j.biopha.2021.112155](https://doi.org/10.1016/j.biopha.2021.112155).
- [3] YELITHAO K, SURAYOT U, PARK W, *et al.* Effect of sulfation and partial hydrolysis of polysaccharides from *Polygonatum sibiricum* on immune-enhancement[J]. *International Journal of Biological Macromolecules*, 2019, **122**: 10-18. DOI: [10.1016/j.ijbiomac.2018.10.119](https://doi.org/10.1016/j.ijbiomac.2018.10.119).
- [4] 斯金平, 裘雨虹, 孙云娟, 等. 新兴林粮——黄精产业发展战略研究[J]. *中国工程科学*, 2024, **26**(2): 113-120. SI Jinping, QIU Yuhong, SUN Yunjuan, *et al.* Development strategy of Huangjing industry[J]. *Strategic Study of CAE*, 2024, **26**(2): 113-120. DOI: [10.15302/J-SSCAE-2023.07.035](https://doi.org/10.15302/J-SSCAE-2023.07.035).
- [5] XIONG Siqing, TAO Pengcheng, YU Yuanguo, *et al.* Effect of *Polygonatum cyrtonema* Hua polysaccharides on gluten structure, *in vitro* digestion and shelf-life of fresh wet noodle[J]. *International Journal of Biological Macromolecules*, 2024, **279**(Pt 4): 135475. DOI: [10.1016/j.ijbiomac.2024.135475](https://doi.org/10.1016/j.ijbiomac.2024.135475).
- [6] WANG Jingjing, ZHANG Wangwei, GUAN Zijing, *et al.* Effect of fermentation methods on the quality and *in vitro* antioxidant properties of *Lycium barbarum* and *Polygonatum cyrtonema* compound wine[J]. *Food Chemistry*, 2023, **409**: 135277. DOI: [10.1016/j.foodchem.2022.135277](https://doi.org/10.1016/j.foodchem.2022.135277).
- [7] 郑晓倩, 金传山, 张亚中, 等. 黄精九蒸九晒炮制过程中糖类成分动态变化[J]. *中成药*, 2020, **42**(7): 1837-1841. ZHENG Xiaqian, JIN Chuanshan, ZHANG Yazhong, *et al.* Dynamic changes of saccharides from *Polygonatum cyrtonema* during "Nine-Steam-Nine-Bask" processing[J]. *Chinese Traditional Patent Medicine*, 2020, **42**(7): 1837-1841. DOI: [10.3969/j.issn.1001-1528.2020.07.031](https://doi.org/10.3969/j.issn.1001-1528.2020.07.031).
- [8] CHEN Donghong, SI Dun, LIU Jingjing, *et al.* Huangjing is not only a good medicine but also an affordable healthy diet[J]. *Science China Life Sciences*, 2024, **67**(11): 2520-2522. DOI: [10.1007/s11427-024-2713-1](https://doi.org/10.1007/s11427-024-2713-1).
- [9] 喻祖文, 张旺凡. 多倍体黄精中多糖和皂苷的提取及含量测定[J]. *中国现代中药*, 2011, **13**(5): 20-22. YU Zuwen, ZHANG Wangfan. The extraction and determination of polyploid main active ingredients of *Polygonatum*[J]. *Modern Chinese Medicine*, 2011, **13**(5): 20-22. DOI: [10.3969/j.issn.1673-4890.2011.05.007](https://doi.org/10.3969/j.issn.1673-4890.2011.05.007).
- [10] LIU Dan, TANG Wei, HAN Chao, *et al.* Advances in *Polygonatum sibiricum* polysaccharides: extraction, purification, structure, biosynthesis, and bioactivity[J]. *Frontiers in Nutrition*, 2022, **9**: 1074671. DOI: [10.3389/fnut.2022.1074671](https://doi.org/10.3389/fnut.2022.1074671).
- [11] 黄竹珺, 李茜, 陈丹, 等. 云南地区滇黄精中黄精多糖的提取及其含量的测定[J]. *生物化工*, 2021, **7**(4): 107-109.

- HUANG Zhujun, LI Qian, CHEN Dan, *et al.* Content determination of *Polygonatum polysaccharides* in *Polygonatum kingianum* in Yunnan Province[J]. *Biological Chemical Engineering*, 2021, 7(4): 107–109. DOI: 10.3969/j.issn.2096-0387.2021.04.026.
- [12] 郭未艳, 孙秋燕, 徐晓红, 等. 滇黄精多糖提取的工艺组合及其优化[J]. 时珍国医国药, 2013, 24(6): 1391–1393. GUO Weiyan, SUN Qiuyan, XU Xiaohong, *et al.* The extraction technology of polysaccharide from *Polygonatum kingianum* Coll. et Hemsl and its optimization[J]. *Journal of Li-shizhen Traditional Chinese Medicine*, 2013, 24(6): 1391–1393. DOI: CNKI:SUN:SZGY.0.2013-06-045.
- [13] 杨圣贤, 杨正明, 陈奕军, 等. 黄精“九蒸九制”炮制过程中多糖及皂苷的含量变化[J]. 湖南师范大学学报(医学版), 2015, 12(5): 141–144. YANG Shengxian, YANG Zhengming, CHEN Yijun, *et al.* Study on the polysaccharides and saponins constituents of *Polygonatum sibiricum* Red. in “Nine-Steam-Nine-Bask” processing[J]. *Journal of Hunan Normal University (Medical Sciences)*, 2015, 12(5): 141–144. DOI: CNKI:SUN:HNYG.0.2015-05-052.
- [14] 李智敏, 石瑶, 赵纯希, 等. 滇黄精多糖的提取工艺及其抗氧化活性研究[J]. 云南民族大学学报(自然科学版), 2020, 29(6): 535–540. LI Zhimin, SHI Yao, ZHAO Chunxi, *et al.* A study of the extraction and antioxidation activity of polysaccharide from *Polygonatum kingianum*[J]. *Journal of Yunnan Minzu University (Natural Sciences Edition)*, 2020, 29(6): 535–540. DOI: 10.3969/j.issn.1672-8513.2020.06.002.
- [15] 陈钢, 陈红兰, 苏伟, 等. 响应面分析法优化黄精多糖提取工艺参数[J]. 食品科学, 2007, 28(7): 198–201. CHEN Gang, CHEN Honglan, SU Wei, *et al.* Optimization of extraction technique of polyonatic sibiricum polysaccharides by response surface analysis[J]. *Food Science*, 2007, 28(7): 198–201. DOI: 10.3321/j.issn:1002-6630.2007.07.044.
- [16] 肖坤敏, 马佳钰, 王军民, 等. 滇黄精多糖提取工艺及其抗氧化活性研究[J]. 西南林业大学学报(自然科学), 2022, 42(4): 147–154. XIAO Kunmin, MA Jiayu, WANG Junmin, *et al.* Extraction process and antioxidant activity of polysaccharides from *Polygonatum kingianum*[J]. *Journal of Southwest Forestry University (Natural Sciences)*, 2022, 42(4): 147–154. DOI: 10.11929/j.swfu.202103016.
- [17] LIU Ji, LI Tianyu, CHEN Haiyun, *et al.* Structural characterization and osteogenic activity *in vitro* of novel polysaccharides from the rhizome of *Polygonatum sibiricum*[J]. *Food & Function*, 2021, 12(14): 6626–6636. DOI: 10.1039/D1FO00938A.
- [18] WANG Shiqiang, LI Gang, ZHANG Xinfei, *et al.* Structural characterization and antioxidant activity of *Polygonatum sibiricum* polysaccharides[J]. *Carbohydrate Polymers*, 2022, 291: 119524. DOI: 10.1016/j.carbpol.2022.119524.
- [19] ZHAO Ping, LI Xia, WANG Ying, *et al.* Characterisation and saccharide mapping of polysaccharides from four common *Polygonatum* spp.[J]. *Carbohydrate Polymers*, 2020, 233: 115836. DOI: 10.1016/j.carbpol.2020.115836.
- [20] YELITHAO K, SURAYOT U, LEE J, *et al.* RAW_{264.7} cell activating glucomannans extracted from rhizome of *Polygonatum sibiricum*[J]. *Preventive Nutrition and Food Science*, 2016, 21(3): 245–254. DOI: 10.3746/pnf.2016.21.3.245.
- [21] 王毅, 穆麒麟, 田小海, 等. 正交法优化黄精多糖的提取工艺[J]. 湖北农业科学, 2020, 59(15): 114–117. WANG Yi, MU Qilin, TIAN Xiaohai, *et al.* Optimization of extraction technology of polysaccharide in *Polygonatum sibiricum* by orthogonal method[J]. *Hubei Agricultural Sciences*, 2020, 59(15): 114–117. DOI: 10.14088/j.cnki.issn0439-8114.2020.15.022.
- [22] 李惠, 李立祥, 陶涛, 等. 黄精中水浸出物、多糖和皂苷综合提取工艺优化[J]. 食品与发酵工业, 2011, 37(10): 223–226. LI Hui, LI Lixiang, TAO Tao, *et al.* Optimization of technology for synthetic extraction of water extracts, polysaccharides and saponin from *Polygonatum (Polygonatum cy-rtonema Hua)*[J]. *Food and Fermentation Industries*, 2011, 37(10): 223–226. DOI: 10.13995/j.cnki.11-1802/ts.2011.10.014.
- [23] 王笑月, 刘效兰, 薛燕, 等. 黄精及其复配植物多糖提取工艺优化及人体保湿评价[J]. 食品工业科技, 2018, 39(5): 221–225. WANG Xiaoyue, LIU Xiaolan, XUE Yan, *et al.* Optimization of process extraction for polysaccharides of *Polygonatum* and its prescription and evaluation of moisture retention capacity of human body[J]. *Science and Technology of Food Industry*, 2018, 39(5): 221–225. DOI: 10.13386/j.issn1002-0306.2018.05.042.
- [24] JIANG Qunguang, LÜ Yunxia, DAI Weidong, *et al.* Extraction and bioactivity of *Polygonatum* polysaccharides[J]. *International Journal of Biological Macromolecules*, 2013, 54: 131–135. DOI: 10.1016/j.ijbiomac.2012.12.010.
- [25] SHEN Qianru, LIAN Lian, YU Hongyan, *et al.* Extraction optimization of polysaccharides from rhizoma polygonati by response surface methodology and content determination[J]. *Medicinal Plant*, 2020, 11(6): 62–66.
- [26] 楚冬海, 张振秋. 响应面分析法优化黄精多糖提取工艺及含量测定[J]. 辽宁中医杂志, 2020, 47(2): 162–165. CHU Donghai, ZHANG Zhenqiu. Optimization of polysaccharide extraction from polygonati rhizoma by response surface methodology and its content determination[J]. *Liaoning Journal of Traditional Chinese Medicine*, 2020, 47(2): 162–165. DOI: 10.13192/j.issn.1000-1719.2020.02.050.

- [27] 王月茹, 谢伟, 胡丽平, 等. 星点设计-效应面法多指标优选陕产黄精提取工艺[J]. *陕西中医*, 2017, **38**(3): 396–397. WANG Yueru, XIE Wei, HU Liping, *et al.* Optimization of extraction process of *Polygonatum sibiricum* from Shaanxi by central composite design-response surface methodology[J]. *Shaanxi Journal of Traditional Chinese Medicine*, 2017, **38**(3): 396–397. DOI: [10.3969/j.issn.1000-7369.2017.03.056](https://doi.org/10.3969/j.issn.1000-7369.2017.03.056).
- [28] SI Dun, LIU Jingjing, SHI Yan, *et al.* Huangjing fructan: a kind of novel active carbohydrate with energy-supply function[J]. *Trends in Food Science & Technology*, 2025, **162**: 105097. DOI: [10.1016/j.tifs.2025.105097](https://doi.org/10.1016/j.tifs.2025.105097).
- [29] 赵瑞萌, 孙庭阁, 张玲. 碱法提取黄精多糖及提取工艺流程的优化[J]. *泰山医学院学报*, 2010, **31**(1): 45–47. ZHAO Ruimeng, SUN Tingge, ZHANG Ling. Extracting polysaccharides from polygonatum with alkaline and optimizing of the extracting flow-sheet[J]. *Journal of Taishan Medical College*, 2010, **31**(1): 45–47. DOI: [10.3969/j.issn.1004-7115.2010.01.014](https://doi.org/10.3969/j.issn.1004-7115.2010.01.014).
- [30] MARIĆ M, GRASSINO A N, ZHU Z Z, *et al.* An overview of the traditional and innovative approaches for pectin extraction from plant food wastes and by-products: Ultrasound-, microwaves-, and enzyme-assisted extraction[J]. *Trends in Food Science & Technology*, 2018, **76**: 28–37. DOI: [10.1016/j.tifs.2018.03.022](https://doi.org/10.1016/j.tifs.2018.03.022).
- [31] 刘常青, 宋力飞, 黄伟明, 等. 一种富含黄精多糖及多种活性成分的黄精提取物制备方法: CN113786453A[P]. 2021-12-14. LIU Changqing, SONG Lifei, HUANG Weiming, *et al.* Preparation Method of *Polygonatum sibiricum* Extract Rich in *Polygonatum sibiricum* Polysaccharide and Various Active Ingredients: CN113786453A[P]. 2021-12-14.
- [32] 苑璐, 冷凯良, 周余航, 等. 复合酶解法优化黄精多糖提取工艺[J]. *食品与生物技术学报*, 2017, **36**(9): 996–1001. YUAN Lu, LENG Kailiang, ZHOU Yuhang, *et al.* Optimization of multi-enzymatic extraction process of polysaccharide from ploygonatum sibiricum[J]. *Journal of Food Science and Biotechnology*, 2017, **36**(9): 996–1001. DOI: [10.3969/j.issn.1673-1689.2017.09.016](https://doi.org/10.3969/j.issn.1673-1689.2017.09.016).
- [33] 张梓原, 徐伟, 王鑫, 等. 黄精多糖的提取工艺对比研究[J]. *包装工程*, 2020, **41**(9): 51–58. ZHANG Ziyuan, XU Wei, WANG Xin, *et al.* Comparative study on extraction technologies of polysaccharides from rhizoma *Polygonatum*[J]. *Packaging Engineering*, 2020, **41**(9): 51–58. DOI: [10.19554/j.cnki.1001-3563.2020.09.008](https://doi.org/10.19554/j.cnki.1001-3563.2020.09.008).
- [34] 古丽扎旦姆·达吾提, 刘晓风, 杨家珺, 等. 黄精多糖酶辅助法提取工艺优化及活性分析研究[J]. *中国酿造*, 2024, **43**(6): 245–251. Gulizhadanmu Dawuti, LIU Xiaofeng, YANG Jiajun, *et al.* Optimization of enzyme assisted extraction process and activity analysis of *Polygonatum sibiricum* polysaccharide[J]. *China Brewing*, 2024, **43**(6): 245–251. DOI: [10.11882/j.issn.0254-5071.2024.06.038](https://doi.org/10.11882/j.issn.0254-5071.2024.06.038).
- [35] 杨德, 薛淑静, 黄蕾, 等. Box-Behnken 设计优化黄精多糖酶法提取工艺[J]. *湖北农业科学*, 2017, **56**(16): 3121–3124. YANG De, XUE Shujing, HUANG Lei, *et al.* Optimization of enzymatic extraction of polysaccharide from ploygonatum by box-behnken design and response surface methodology[J]. *Hubei Agricultural Sciences*, 2017, **56**(16): 3121–3124. DOI: [10.14088/j.cnki.issn0439-8114.2017.16.031](https://doi.org/10.14088/j.cnki.issn0439-8114.2017.16.031).
- [36] 胡庆娟, 吴光杰, 牛庆川, 等. 响应面试验优化木瓜蛋白酶法脱马齿苋多糖蛋白工艺[J]. *食品科学*, 2018, **39**(20): 246–252. HU Qingjuan, WU Guangjie, NIU Qingchuan, *et al.* Optimization of papain-catalyzed deproteinization of polysaccharide from *Portulaca oleracea* L. by response surface methodology[J]. *Food Science*, 2018, **39**(20): 246–252. DOI: [10.7506/spkx1002-6630-201820036](https://doi.org/10.7506/spkx1002-6630-201820036).
- [37] 周燕芳, 丁利君. 超声波辅助提取艾叶黄酮的工艺研究[J]. *食品与机械*, 2006, **22**(4): 39–41. ZHOU Yanfang, DING Lijun. Research on the extraction of flavone from *Artemisia argyi* with ultrasonic wave cooperated method[J]. *Food and Machinery*, 2006, **22**(4): 39–41. DOI: [10.3969/j.issn.1003-5788.2006.04.011](https://doi.org/10.3969/j.issn.1003-5788.2006.04.011).
- [38] 雍潘. 多花黄精的多糖提取、纯化、结构解析及活性研究[D]. 成都: 西南民族大学, 2019. YONG Pan. *Isolation, Purification, Structural Characterization and Biological Activity of Polysaccharides from Polygonatum Cyrtonema Hua*[D]. Chengdu: Southwest Minzu University, 2019.
- [39] 董琪, 李娜, 刘露, 等. 超声波辅助提取黄精多糖工艺优化及抗氧化活性研究[J]. *安徽科技学院学报*, 2021, **35**(5): 83–88. DONG Qi, LI Na, LIU Lu, *et al.* Extraction optimization of ultrasonic-assisted and antioxidant activity of polysaccharides from *Polygonatum sibiricum*[J]. *Journal of Anhui Science and Technology University*, 2021, **35**(5): 83–88. DOI: [10.19608/j.cnki.1673-8772.2017.0982](https://doi.org/10.19608/j.cnki.1673-8772.2017.0982).
- [40] 吴英详. 炮制工艺对黄精有效成分及指纹图谱的影响[D]. 福州: 福建农林大学, 2013. WU Yingxiang. *The Effect of the Effective Components and the Fingerprint of Polygonatum Sibiricum by Different Processing Technology*[D]. Fuzhou: Fujian Agriculture and Forestry University, 2013.
- [41] 贾宇涵. 黄精口服液产品研发及品质鉴定[D]. 泰安: 山东农业大学, 2019. JIA Yuhan. *Product Development and Quality*

- Identification of Polygonatum Oral Liquid*[D]. Tai'an: Shandong Agricultural University, 2019.
- [42] 杜泽飞, 陶爱恩, 夏从龙, 等. 正交试验优选滇黄精中多糖超声提取工艺研究[J]. *海峡药学*, 2019, **31**(9): 52–54. DU Zefei, TAO Aien, XIA Conglong, *et al.* Optimization of ultrasonic extraction of polysaccharide from *Polygonatum kingianum* by orthogonal array design[J]. *Strait Pharmaceutical Journal*, 2019, **31**(9): 52–54. DOI: [10.3969/j.issn.1006-3765.2019.09.016](https://doi.org/10.3969/j.issn.1006-3765.2019.09.016).
- [43] 王莹, 李锋涛, 黄美子, 等. 黄精多糖提取工艺优化及其抗氧化活性研究[J]. *畜牧与兽医*, 2021, **53**(12): 53–59. WANG Ying, LI Fengtao, HUANG Meizi, *et al.* Optimizing the extraction technology and determining the antioxidant activity of *Polygonatum sibiricum* polysaccharides[J]. *Animal Husbandry & Veterinary Medicine*, 2021, **53**(12): 53–59.
- [44] 陶涛, 李立祥, 张芳, 等. 超声波协同纤维素酶对黄精多糖和皂苷的提取研究[J]. *食品工业科技*, 2012, **33**(9): 271–275. TAO Tao, LI Lixiang, ZHANG Fang, *et al.* Study on the extraction of polysaccharides and sibiricoside from polygonatum(*Polygonatum cyrtonema* Hua) with cellulase enzyme under ultrasonic wave[J]. *Science & Technology of Food Industry*, 2012, **33**(9): 271–275. DOI: [10.13386/j.issn1002-0306.2012.09.036](https://doi.org/10.13386/j.issn1002-0306.2012.09.036).
- [45] 赵志君, 任婧. 超声波协同纤维素酶提取黄精多糖的工艺优化研究[J]. *农产品加工*, 2019(13): 41–44. ZHAO Zhijun, REN Jing. Study on the extraction of polysaccharides from *Polygonatum* with cellulase enzyme under ultrasonic wave[J]. *Farm Products Processing*, 2019(13): 41–44. DOI: [10.16693/j.cnki.1671-9646\(X\).2019.07.011](https://doi.org/10.16693/j.cnki.1671-9646(X).2019.07.011).
- [46] 刘日斌, 张宇鹏, 马崇坚, 等. 超声波辅助酶法优化黄精多糖提取工艺的研究[J]. *食品研究与开发*, 2021, **42**(7): 141–146. LIU Ribin, ZHANG Yupeng, MA Chongjian, *et al.* Ultrasonic-assisted enzymatic optimization of extraction process of polysaccharides from *Polygonatum sibiricum*[J]. *Food Research and Development*, 2021, **42**(7): 141–146. DOI: [10.12161/j.issn.1005-6521.2021.07.022](https://doi.org/10.12161/j.issn.1005-6521.2021.07.022).
- [47] BALAVIGNESWARAN C K, SUJIN JEBA KUMAR T, MOSES PACKIARAJ R, *et al.* Anti-oxidant activity of polysaccharides extracted from *Isocrysis galbana* using RSM optimized conditions[J]. *International Journal of Biological Macromolecules*, 2013, **60**: 100–108. DOI: [10.1016/j.ijbiomac.2013.05.014](https://doi.org/10.1016/j.ijbiomac.2013.05.014).
- [48] 鲁敬荣, 郑泽宝. 微波技术用于泰山黄精多糖的提取[J]. *食品科技*, 2006, **31**(8): 124–127. LU Jingrong, ZHENG Zebao. Polysaccharides extraction in *Polygonatum sibiricum* red of mount Tai by microwave technique[J]. *Food Science and Technology*, 2006, **31**(8): 124–127. DOI: [10.3969/j.issn.1005-9989.2006.08.037](https://doi.org/10.3969/j.issn.1005-9989.2006.08.037).
- [49] 李翔, 梁忠厚, 张先文, 等. 多花黄精多糖提取条件优化及其抗氧化能力评价[J]. *中国调味品*, 2025, **50**(1): 222–226. LI Xiang, LIANG Zhonghou, ZHANG Xianwen, *et al.* Optimization of extraction conditions of polysaccharides from *Polygonatum cyrtonema* and evaluation of their antioxidant capacity[J]. *China Condiment*, 2025, **50**(1): 222–226. DOI: [10.3969/j.issn.1000-9973.2025.01.034](https://doi.org/10.3969/j.issn.1000-9973.2025.01.034).
- [50] 李志涛, 孙金旭, 朱会霞, 等. 黄精多糖的提取及其抑菌性研究[J]. *食品研究与开发*, 2017, **38**(15): 36–38. LI Zhitao, SUN Jinxu, ZHU Huixia, *et al.* Extracting of *Polygonatum* polysaccharides and its antimicrobial activity[J]. *Food Research and Development*, 2017, **38**(15): 36–38. DOI: [10.3969/j.issn.1005-6521.2017.15.008](https://doi.org/10.3969/j.issn.1005-6521.2017.15.008).
- [51] 滕树锐, 廖璐婧, 武芸, 等. 黄精多糖与黄酮综合提取工艺优化及硒肥对其含量的影响[J]. *湖北农业科学*, 2017, **56**(23): 4572–4576. TENG Shurui, LIAO Lujing, WU Yun, *et al.* Optimization of extraction technology of polysaccharides and flavonoids from *Polygonatum sibiricum* and effects of selenium fertilizer on its content[J]. *Hubei Agricultural Sciences*, 2017, **56**(23): 4572–4576. DOI: [10.14088/j.cnhi.issn0439-8114.2017.23.039](https://doi.org/10.14088/j.cnhi.issn0439-8114.2017.23.039).
- [52] ZHANG Hui, CAI Xiuting, TIAN Qinghua, *et al.* Microwave-assisted degradation of polysaccharide from *Polygonatum sibiricum* and antioxidant activity[J]. *Journal of Food Science*, 2019, **84**(4): 754–761. DOI: [10.1111/1750-3841.14449](https://doi.org/10.1111/1750-3841.14449).
- [53] 周桃英, 陈年友, 陈中建, 等. 超声波-微波协同法提取黄精多糖工艺研究[J]. *江苏农业科学*, 2013, **41**(6): 231–233. ZHOU Taoying, CHEN Nianyou, CHEN Zhongjian, *et al.* Study on extraction technology of *Polygonatum* polysaccharide by ultrasonic-microwave synergistic method[J]. *Jiangsu Agricultural Sciences*, 2013, **41**(6): 231–233. DOI: [10.3969/j.issn.1002-1302.2013.06.085](https://doi.org/10.3969/j.issn.1002-1302.2013.06.085).
- [54] 康才洁, 张琪婧, 蒋晓敏, 等. 树莓干果多酚的闪式提取及抗氧化、降血糖活性[J]. *食品科技*, 2025, **50**(1): 197–205. KANG Caijie, ZHANG Qijing, JIANG Xiaomin, *et al.* Flash extraction, antioxidant and hypoglycemic activities of polyphenols from dried raspberries[J]. *Food Science and Technology*, 2025, **50**(1): 197–205. DOI: [10.13684/j.cnki.spkj.2025.01.022](https://doi.org/10.13684/j.cnki.spkj.2025.01.022).
- [55] 陈艳, 王杰, 李慧, 等. 黄精多糖的闪式提取及对乳酸菌发酵特性的影响[J]. *食品工业*, 2017, **38**(6): 161–166. CHEN Yan, WANG Jie, LI Hui, *et al.* Extraction of polysaccharide from *Polygonatum* and its effects on fermentation characteristics of lactic acid bacteria[J]. *The Food Industry*, 2017, **38**(6): 161–166.

- [56] 包智影, 张智, 杜亚飞, 等. 微生物法提取黄精多糖及体外降脂功能评价[J]. *中南林业科技大学学报*, 2021, **41**(5): 142–151. BAO Zhiying, ZHANG Zhi, DU Yafei, *et al.* Microbial fermentation technology of *Polygonatum sibiricum* polysaccharides and evaluation of lipid-lowering function *in vitro*[J]. *Journal of Central South University of Forestry & Technology*, 2021, **41**(5): 142–151. DOI: [10.14067/j.cnki.1673-923x.2021.05.016](https://doi.org/10.14067/j.cnki.1673-923x.2021.05.016).
- [57] 蔡锦源, 廖登未, 唐念, 等. 减压内部沸腾提取技术及其在有效成分提取中的应用[J]. *轻工科技*, 2016, **32**(11): 5–6. CAI Jinyuan, LIAO Dengwei, TANG Nian, *et al.* Vacuum internal boiling extraction technology and its application in the extraction of active ingredients[J]. *Light Industry Science and Technology*, 2016, **32**(11): 5–6.
- [58] 杨军宣, 张毅, 吕珊珊, 等. 减压内部沸腾法提取黄精多糖的工艺[J]. *中成药*, 2016, **38**(2): 460–463. YANG Junxuan, ZHANG Yi, LÜ Shanshan, *et al.* Extraction of *Polygonatum* polysaccharide by reduced pressure internal boiling method[J]. *Chinese Traditional Patent Medicine*, 2016, **38**(2): 460–463. DOI: [10.3969/j.issn.1001-1528.2016.02.052](https://doi.org/10.3969/j.issn.1001-1528.2016.02.052).
- [59] KARIMI N, JABBARI V, NAZEMI A, *et al.* Thymol, cardamom and *Lactobacillus plantarum* nanoparticles as a functional candy with high protection against *Streptococcus mutans* and tooth decay[J]. *Microbial Pathogenesis*, 2020, **148**: 104481. DOI: [10.1016/j.micpath.2020.104481](https://doi.org/10.1016/j.micpath.2020.104481).
- [60] 魏炜, 李彦伟, 刘凤霞, 等. 响应面法优化超高压提取黄精多糖工艺[J]. *精细化工*, 2019, **36**(5): 875–881. WEI Wei, LI Yanwei, LIU Fengxia, *et al.* Optimization of ultrahigh pressure extraction of polysaccharides from *Polygonatum cyrtonema* Hua by response surface methodology[J]. *Fine Chemicals*, 2019, **36**(5): 875–881. DOI: [10.13550/j.jxhg.20180756](https://doi.org/10.13550/j.jxhg.20180756).
- [61] 梁朋光, 孙健, 岳健, 等. 响应面优化滇黄精多糖提取及其结构与活性分析[J]. *南方农业学报*, 2021, **52**(12): 3434–3445. LIANG Pengguang, SUN Jian, YUE Jian, *et al.* Response surface optimization of extraction and structure and activity analysis of polysaccharides from *Polygonatum kingianum* Coll. et Hemsl[J]. *Journal of Southern Agriculture*, 2021, **52**(12): 3434–3445. DOI: [10.3969/j.issn.2095-1191.2021.12.028](https://doi.org/10.3969/j.issn.2095-1191.2021.12.028).
- [62] 潘思源, 田英姿, 韦士鹏. 微波辅助离子液体提取罗布麻叶总黄酮及其抗氧化活性研究[J]. *现代食品科技*, 2019, **35**(7): 182–190. PAN Siyuan, TIAN Yingzi, WEI Shipeng. Ionic liquid-based microwave-assisted extraction and antioxidant activity of total flavonoids from *Apocynum venetum* L. leaves[J]. *Modern Food Science and Technology*, 2019, **35**(7): 182–190. DOI: [10.13982/j.mfst.1673-9078.2019.7.025](https://doi.org/10.13982/j.mfst.1673-9078.2019.7.025).
- [63] 粟敏, 陈琳, 龙昱, 等. 离子液体-微波辅助提取多花黄精多糖工艺研究[J]. *中药材*, 2016, **39**(9): 2075–2077. SU Min, CHEN Lin, LONG Yu, *et al.* Study on ionic liquid-microwave-assisted extraction of *Polygonatum multiflorum* polysaccharide[J]. *Journal of Chinese Medicinal Materials*, 2016, **39**(9): 2075–2077. DOI: [10.13863/j.issn1001-4454.2016.09.036](https://doi.org/10.13863/j.issn1001-4454.2016.09.036).
- [64] CHEN Jincui, XU Yuan, TAN Zhijian. CO₂-triggered switchable hydrophilicity solvent as a recyclable extractant for ultrasonic-assisted extraction of *Polygonatum sibiricum* polysaccharides[J]. *Food Chemistry*, 2023, **402**: 134301. DOI: [10.1016/j.foodchem.2022.134301](https://doi.org/10.1016/j.foodchem.2022.134301).
- [65] SUN Chaoqun, WANG Guodong, SUN Jing, *et al.* A new method of extracting *Polygonatum sibiricum* polysaccharide with antioxidant function: ultrasound-assisted extraction-deep eutectic solvents method[J]. *Foods*, 2023, **12**(18): 3438. DOI: [10.3390/foods12183438](https://doi.org/10.3390/foods12183438).
- [66] LIU Yang, HUANG Gangliang. Extraction and derivatisation of active polysaccharides[J]. *Journal of Enzyme Inhibition and Medicinal Chemistry*, 2019, **34**(1): 1690–1696. DOI: [10.1080/14756366.2019.1660654](https://doi.org/10.1080/14756366.2019.1660654).
- [67] 王倩. 黄精炮制过程中甾体皂苷的变化研究[D]. 昆明: 昆明理工大学, 2017. WANG Qian. *Study on the Transformation of the Steroid Saponins in Processing of Rhizoma Polygonati*[D]. Kunming: Kunming University of Science and Technology, 2017.
- [68] 王冬梅, 张京芳, 李晓明, 等. 卷叶黄精根中甾体皂苷化学成分及其抗菌活性[J]. *林业科学*, 2007, **43**(8): 91–95. WANG Dongmei, ZHANG Jingfang, LI Xiaoming, *et al.* Steroid saponins of *Polygonatum cirrhifolium* root and their antiseptic activity[J]. *Scientia Silvae Sinicae*, 2007, **43**(8): 91–95. DOI: [10.3321/j.issn:1001-7488.2007.08.015](https://doi.org/10.3321/j.issn:1001-7488.2007.08.015).
- [69] 王易芬, 穆天慧, 陈纪军, 等. 滇黄精化学成分研究[J]. *中国中药杂志*, 2003, **28**(6): 524–527. WANG Yifen, MU Tianhui, CHEN Jijun, *et al.* Studies on chemical constituents from the root of *Polygonatum kingianum*[J]. *China Journal of Chinese Materia Medica*, 2003, **28**(6): 524–527. DOI: [10.3321/j.issn:1001-5302.2003.06.015](https://doi.org/10.3321/j.issn:1001-5302.2003.06.015).
- [70] 尤新军, 郭蕊, 王琳, 等. 黄精总皂苷超声提取工艺研究[J]. *西北林学院学报*, 2010, **25**(3): 163–166. YOU Xinjun, GUO Rui, WANG Lin, *et al.* Ultrasonic extraction process of saponins from *Polygonatum sibiricum*[J]. *Journal of Northwest Forestry University*, 2010, **25**(3): 163–166.
- [71] 张丽, 常青, 王艳, 等. 响应面法优化提取黄精茎秆中总多糖、总皂苷、总黄酮的工艺研究[J]. *中医药导报*, 2019,

- 25(8): 64–67. ZHANG Li, CHANG Qing, WANG Yan, *et al.* Optimization of extraction process of total polysaccharides, saponins and flavonoids in stem of Huangjing (*Polygonatum sibiricum*) by response surface method[J]. *Guiding Journal of Traditional Chinese Medicine and Pharmacy*, 2019, 25(8): 64–67. DOI: 10.13862/j.cnki.cn43-1446/r.2019.08.018.
- [72] 黄金月, 崔芙岩, 郑时嘉, 等. 响应面优化黄精根茎总皂苷、总黄酮提取方法及其在不同产地黄精成分含量比较中的应用[J]. *中医药学报*, 2021, 49(9): 56–61. HUANG Jinyue, CUI Fuyan, ZHENG Shijia, *et al.* Extraction process of total saponins and total flavonoids from polygonati rhizoma by response surface optimization and its application in contents comparison from polygonati rhizoma in different origin[J]. *Acta Chinese Medicine and Pharmacology*, 2021, 49(9): 56–61. DOI: 10.19664/j.cnki.1002-2392.210212.
- [73] 权利娜, 王露, 王嘉雯, 等. 多花黄精总皂苷的提取工艺及体外抗氧化研究[J]. *现代中医药*, 2022, 42(5): 47–51. QUAN Lina, WANG Lu, WANG Jiawen, *et al.* Study on extraction technology and *in vitro* antioxidant activity of total saponins from *Polygonatum multiflorum*[J]. *Modern Chinese Medicine*, 2022, 42(5): 47–51. DOI: 10.13424/j.cnki.mtcm.2022.05.008.
- [74] 黄祥元, 黄美容. 黄精提取物中总皂苷含量的测定[J]. *食品与机械*, 2012, 28(6): 106–108. HUANG Xiangyuan, HUANG Meirong. Content determination of total saponins in extracts of rhizoma polygonati[J]. *Food and Machinery*, 2012, 28(6): 106–108. DOI: 10.3969/j.issn.1003-5788.2012.06.026.
- [75] HE Sen, WANG Xifu, CHEN Jiaqiang, *et al.* Optimization of the ultrasonic-assisted extraction technology of steroidal saponins from *Polygonatum kingianum* Collett & Hemsl and evaluating its quality planted in different areas[J]. *Molecules*, 2022, 27(5): 1463. DOI: 10.3390/molecules27051463.
- [76] 罗毅. 黄精总皂苷与薯蓣皂苷的提取分离及抗肿瘤活性研究[D]. 哈尔滨: 哈尔滨商业大学, 2023. LUO Yi. *Stu Extraction, Separation and Antitumor Activity of Saponins of Rhizoma Polygonati and Dioscin* [D]. Harbin: Harbin University of Commerce, 2023.
- [77] 刘晨星, 曹艳, 夏其乐. 多花黄精根须皂苷的提取工艺及其抗氧化活性研究[J]. *浙江农业学报*, 2024, 36(5): 1144–1152. LIU Chenxing, CAO Yan, XIA Qile. Study on the extraction processing and antioxidant activities of saponins from *Polygonatum cyrtonema* Hua roots[J]. *Acta Agriculturae Zhejiangensis*, 2024, 36(5): 1144–1152. DOI: 10.3969/j.issn.1004-1524.20230718.
- [78] 戴万生, 毕露露, 邱斌, 等. 黄精总皂苷的提取和含量测定方法研究[J]. *云南中医中药杂志*, 2023, 44(2): 73–76. DAI Wansheng, BI Lulu, QIU Bin, *et al.* Study on extraction and content determination of total saponins from *Polygonatum*[J]. *Yunnan Journal of Traditional Chinese Medicine and Materia Medica*, 2023, 44(2): 73–76. DOI: 10.3969/j.issn.1007-2349.2023.02.017.
- [79] 陈志春, 李成伟, 陈莹, 等. 基于等高线生成算法的多花黄精中多糖、皂苷提取工艺优化研究[J]. *福建中医药*, 2024, 55(2): 57–64. CHEN Zhichun, LI Chengwei, CHEN Ying, *et al.* Optimization of extraction process for polysaccharides and saponins from *Polygonatum cyrtonema* based on contour generation algorithm[J]. *Fujian Journal of Traditional Chinese Medicine*, 2024, 55(2): 57–64. DOI: 10.13260/j.cnki.fjftcm.2024.02015.
- [80] ZHANG Huafeng, YANG Xiaohua, WANG Ying. Microwave assisted extraction of secondary metabolites from plants: current status and future directions[J]. *Trends in Food Science & Technology*, 2011, 22(12): 672–688. DOI: 10.1016/j.tifs.2011.07.003.
- [81] 朱璐, 董福, 冯叙桥, 等. 浸提法、超声波法和微波法提取紫薯花色苷的抗氧化性比较研究[J]. *食品科学*, 2015, 36(19): 83–88. ZHU Lu, DONG Fu, FENG Xuqiao, *et al.* Comparative antioxidant activities of anthocyanins extracted from purple sweet potato by organic solvent, ultrasonic-assisted and microwave-assisted extraction[J]. *Food Science*, 2015, 36(19): 83–88. DOI: 10.7506/spkx1002-6630-201519015.
- [82] 赵丽蓉, 罗汉, 相英龙, 等. Box-Benken 响应面法优化微波提取黄精总皂苷的条件[J]. *中国现代中药*, 2018, 20(8): 1010–1015. ZHAO Lirong, LUO Han, XIANG Yinglong, *et al.* Optimization of microwave extracting total saponins from rhizoma polygonati by box-benken response surface method[J]. *Modern Chinese Medicine*, 2018, 20(8): 1010–1015. DOI: 10.13313/j.issn.1673-4890.20180310001.
- [83] 李丽, 李羚, 丘贤, 等. 微波辅助黄精总黄酮提取工艺研究[J]. *保山学院学报*, 2014, 33(5): 39–42. LI Li, LI Ling, QIU Xian, *et al.* Study on extraction of total flavonoids from microwave assisted route[J]. *Journal of Baoshan University*, 2014, 33(5): 39–42. DOI: 10.3969/j.issn.1674-9340.2014.05.011.
- [84] 包瑞敏, 张智, 杜亚飞, 等. 黄精总皂苷提取工艺优化及其对 α -淀粉酶及 α -葡萄糖苷酶抑制活性[J]. *食品工业科技*, 2020, 41(16): 163–168. BAO Ruimin, ZHANG Zhi, DU Yafei, *et al.* Optimization of extraction technology of total saponin

- from *Polygonatum sibiricum* and its inhibitory activity to α -amylase and α -glucosidase[J]. *Science and Technology of Food Industry*, 2020, **41**(16): 163–168. DOI: [10.13386/j.issn1002-0306.2020.16.026](https://doi.org/10.13386/j.issn1002-0306.2020.16.026).
- [85] ZHOU Tiantian, WANG Guanyue, ZHEN Feng, *et al.* Study on efficient extraction of saponins from *Polygonatum sibiricum* by enzyme assisted cold isostatic pressing technology[J]. *Industrial Crops and Products*, 2024, **220**: 119163. DOI: [10.1016/j.indcrop.2024.119163](https://doi.org/10.1016/j.indcrop.2024.119163).
- [86] 谢冰宗, 李密, 董彩文, 等. 黄精皂苷与多糖超声辅助提取工艺优化及降血糖活性研究[J]. *食品与机械*, 2024, **40**(1): 158–166. XIE Bingzong, LI Mi, DONG Caiwen, *et al.* Study on the technology of ultrasonic assisted combined extraction of saponins and polysaccharides from *Polygonatum sibiricum* and its hypoglycemic activity[J]. *Food and Machinery*, 2024, **40**(1): 158–166. DOI: [10.13652/j.spjx.1003.5788.2023.80404](https://doi.org/10.13652/j.spjx.1003.5788.2023.80404).
- [87] 孟庆举, 刘晓谦, 杨华, 等. 闪式提取技术的研究进展[J]. *中国实验方剂学杂志*, 2013, **19**(19): 349–355. MENG Qingju, LIU Xiaoqian, YANG Hua, *et al.* Recent advances of smashing tissue extraction technology[J]. *Chinese Journal of Experimental Traditional Medical Formulae*, 2013, **19**(19): 349–355. DOI: [10.11653/syfx.2013190349](https://doi.org/10.11653/syfx.2013190349).
- [88] 崔婧, 范桂强, 庞红霞, 等. 正交法优化闪式提取黄精皂苷工艺研究[J]. *中国药师*, 2017, **20**(1): 53–55. CUI Jing, FAN Guiqiang, PANG Hongxia, *et al.* Optimization of flash extraction for *Polygonatum* saponin by orthogonal design[J]. *China Pharmacist*, 2017, **20**(1): 53–55. DOI: [10.3969/j.issn.1008-049X.2017.01.014](https://doi.org/10.3969/j.issn.1008-049X.2017.01.014).
- [89] WANG Yongqiang, GAO Yujie, DING Hui, *et al.* Subcritical ethanol extraction of flavonoids from *Moringa oleifera* leaf and evaluation of antioxidant activity[J]. *Food Chemistry*, 2017, **218**: 152–158. DOI: [10.1016/j.foodchem.2016.09.058](https://doi.org/10.1016/j.foodchem.2016.09.058).
- [90] 徐胜, 屈曾义, 毕健丽, 等. 基于 BP-ANN 优化提取 HPLC 特征图谱测定 3 种黄精辐照前后黄酮含量变化[J]. *食品工业科技*, 2021, **42**(5): 257–264. XU Sheng, QU Zengyi, BI Jianli, *et al.* Optimization of extraction by BP-ANN and determination of flavonoids in three varieties of polygonati rhizoma before and after irradiation by HPLC chromatographic fingerprint[J]. *Science and Technology of Food Industry*, 2021, **42**(5): 257–264. DOI: [10.13386/j.issn1002-0306.2020050171](https://doi.org/10.13386/j.issn1002-0306.2020050171).
- [91] ZHANG Hongli, HAO Feilong, YAO Zhifang, *et al.* Efficient extraction of flavonoids from *Polygonatum sibiricum* using a deep eutectic solvent as a green extraction solvent[J]. *Microchemical Journal*, 2022, **175**: 107168. DOI: [10.1016/j.microc.2021.107168](https://doi.org/10.1016/j.microc.2021.107168).
- [92] 陈毅坚, 石雪, 屈睿, 等. 滇黄精黄酮提取工艺及活性的初步研究[J]. *食品工业科技*, 2013, **34**(5): 222–225. CHEN Yijian, SHI Xue, QU Rui, *et al.* Study on extraction process of flavonoids from *Polygonatum kingianum* Coll. et Hemsl and antioxidative activities of flavonoids[J]. *Science and Technology of Food Industry*, 2013, **34**(5): 222–225.
- [93] 韦国兰, 吴超群, 胡秀虹, 等. 黄精总黄酮的提取工艺优化及抗氧化研究[J]. *广州化工*, 2023, **51**(13): 127–130. WEI Guolan, WU Chaoqun, HU Xiuhong, *et al.* Optimization of extraction process and antioxidant study on total flavonoids from *Polygonatum sibiricum*[J]. *GuangZhou Chemical Industry*, 2023, **51**(13): 127–130. DOI: [10.3969/j.issn.1001-9677.2023.13.035](https://doi.org/10.3969/j.issn.1001-9677.2023.13.035).
- [94] 陈鹏飞. 多花黄精叶黄酮提取纯化及其在抗氧化复合膜中的应用[D]. 重庆: 重庆工商大学, 2023. CHEN Pengfei. *Extraction and Purification of Flavonoids from Leaves of Polygonatum Cyrtonea and Its Application in Antioxidant Composite Membranes* [D]. Chongqing: Chongqing Technology and Business University, 2023.
- [95] 张佳鑫, 梁思琪, 肖强, 等. 黄精总黄酮提取工艺优化及抗氧化活性分析[J]. *湖北林业科技*, 2024, **53**(1): 37–44. ZHANG Jiaxin, LIANG Siqi, XIAO Qiang, *et al.* Extraction and antioxidant activity analysis of total flavonoids of *Polygonatum sibiricum*[J]. *Hubei Forestry Science and Technology*, 2024, **53**(1): 37–44. DOI: [10.3969/j.issn.1004-3020.2024.01.009](https://doi.org/10.3969/j.issn.1004-3020.2024.01.009).
- [96] HSU B Y, LIN S W, INBARAJ B S, *et al.* Simultaneous determination of phenolic acids and flavonoids in *Chenopodium formosanum* Koidz. (djulis) by HPLC-DAD-ESI-MS/MS[J]. *Journal of Pharmaceutical and Biomedical Analysis*, 2017, **132**: 109–116. DOI: [10.1016/j.jpba.2016.09.027](https://doi.org/10.1016/j.jpba.2016.09.027).