苦荞麦关键活性组分、营养功效及工业应用研究进展

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摘要：苦荞麦是一种药食同源性植物，在我国的种植面积和产量均居世界首位。作为一种重要的粮食作物，有望成为未来众多种植业的目标。苦荞中含有多种营养成分和生物活性成分，如多糖、蛋白质、硒、植物甾醇、黄酮、多酚等，他们在抗氧化、抗炎、抗癌、降血脂、抗糖尿病、保肝等方面发挥着重要作用，在食品、医药行业具有非常广阔的应用前景。近年来，苦荞麦已成为国内外学者的研究热点。然而，目前有关苦荞麦的活性成分和营养功效的研究缺乏系统的梳理。该文梳理了国内外相关文献，对苦荞麦的活性成分、营养功效及在食品中的应用现状进行了综述，旨在为苦荞麦的综合开发利用提供一定的理论基础。

关键词：苦荞麦；活性成分；营养功效；应用

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Research Progress on Key Active Components, Nutritional Efficacy, and Industrial Application of Tartary Buckwheat

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Abstract: Tartary buckwheat possesses both medicinal and nutritional value, serving diverse roles in culinary and therapeutic applications. China is the global leader in Tartary buckwheat cultivation, with the largest planting area and highest yield. As an important food crop, Tartary buckwheat presents strong potential for future agricultural development. Tartary buckwheat contains a variety of nutrients and bioactive ingredients, including polysaccharides, proteins, selenium, phytosterols, flavonoids and polyphenols. These compounds exhibit antioxidant, anti-inflammatory, anticancer, hypolipidemic, antidiabetic, and liver-protective effects, highlighting the potential of Tartary buckwheat highly promising for applications in the food and pharmaceutical industries. In recent years, Tartary buckwheat has emerged as a prominent subject of research at both national and international levels. However, systematic research on the bioactive components and nutritional benefits of Tartary buckwheat remains limited. This paper reviews relevant domestic and international literature, offering an overview of the active components, nutritional benefits, and current food applications of Tartary buckwheat, aiming is to provide a theoretical foundation for the comprehensive development and utilization of Tartary buckwheat.

Key words: Tartary buckwheat; bioactive ingredients; nutritional efficacy; application

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由于生物学特性和栽培地区不同[1]，荞麦分为两个栽培品种：苦荞麦（*F. tataricum*）和普通荞麦（*F. esculentum*）（见图1）。苦荞麦（Tartary Buckwheat, TB）为一年生草本植物，隶属于蓼科，是一种传统的药食两用植物[2]。苦荞麦和普通荞麦在形态特征上差异很大[1,3]。此外，普通荞麦是异花授粉植物，结实率低，产量低。因此，TB作为一种重要的粮食作物，有望成为未来众多种植业的目标。TB分布在亚洲、欧洲和美洲，我国苦荞栽培历史悠久，分布广泛[4]，80%的TB作物集中分布在云贵川高原、青藏高原、甘南、湖南武陵山区、湖北秦岭南麓[5]。种植面积和产量均居世界首位。TB在我国食用历史悠久，但因其苦味明显，适口性差，发展一直受到抑制。目前关于普通荞麦的研究较多，而关于苦荞的系统研究较少。因此，本文总结了目前苦荞的生物活性化合物，它们的相关生物活性以及在食品工业中应用。旨在为苦荞麦的综合开发利用提供一定的理论基础。

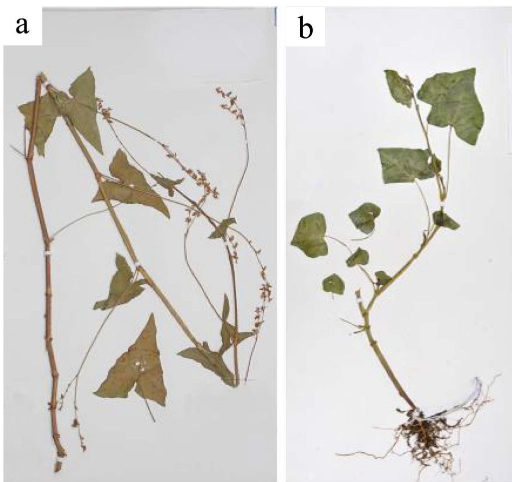


图1 苦荞麦（a）与普通荞麦（b）

Fig.1 *F. tataricum* (a) and *F. esculentum* (b)

1 苦荞麦的营养成分

TB不仅具有极好的营养和保健价值，而且还具有良好的治疗效果[6]。现代植物化学研究表明，从TB的种子、花、叶和根中分离和纯化了不同家族的生物活性化合物，如类黄酮，酚酸类、蒽醌类、生物活性多糖和生物活性蛋白质等[7-9]（见图2）。

1.1 碳水化合物

1.1.1 淀粉

TB种子的主要成分是淀粉，存在于胚乳细胞中，占总干重的70%以上。Zhu[10]总结了荞麦淀粉和TB淀粉的结构、性质及应用。其中直链淀粉含量为20%~28%，淀粉颗粒大多为多边形，大小为2~15 μm。颗粒具有A型多晶型，支链淀粉具有超长的单元链（Degree of Polymerization, DP＞100）。与普通荞麦的淀粉相比，TB中的淀粉具有较高的热稳定性和更紧密的双螺旋结构，且其中抗性淀粉含量高，抗性淀粉作为有膳食纤维特性的淀粉，能够降低结肠癌和肥胖的风险。21个苦荞基因型的抗性淀粉含量在13.1%~22.5%之间，高于18个基因型的普通荞麦[11]。此外，TB淀粉具有独特的糊化特性和理化特性，可作为再降解淀粉的适宜原料应用于食品加工[12]。

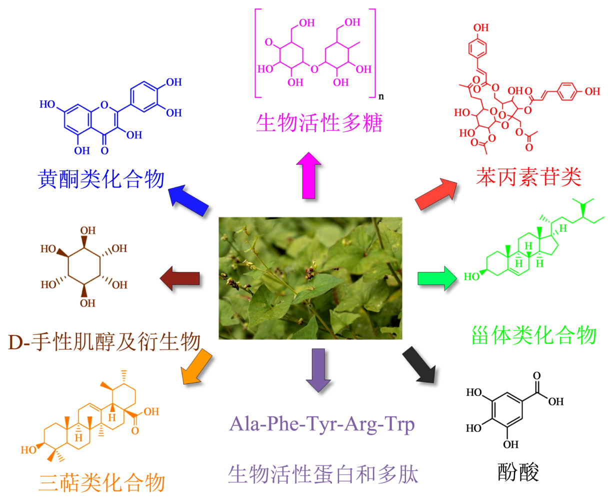


图2 从苦荞麦中分离的一些代表性生物活性化合物及化学结构

Fig.2 The basic skeletons of some representative bioactive compounds isolated from Tartary buckwheat

1.1.2 D-手性肌醇

D-手性肌醇（D-Chiro-Inositol, DCI）分子式为$C_6H_{12}O_6$，是肌醇的一种同分异构体，参与胰岛素信号转导通路。因此，DCI具有降低人体血压、葡萄糖浓度、血浆甘油三酯等功能。采用高效液相色谱-蒸发光散射检测法测定TB中DCI的含量[13]，发现种子中DCI含量为0.23~18 mg/g。因此，普通荞麦中DCI的水平与TB中相似[14]。在普通荞麦中，DCI以半乳糖基衍生物的形式存在[15]。由此可以推测TB中或许也具有类似特征。

1.1.3 生物活性多糖

TB中多糖可以被肠道微生物群利用，表现出明显的体外α-D-葡萄糖苷酶抑制活性和体内抗糖尿病活性[16,17]。荞麦多糖的提取率为7.23%~25.16%[8]。Wang等[16]使用尺寸排阻色谱法（Size-Exclusion Chromatography, SEC）从TB种子中分离并纯化了平均分子量为26 kDa的非淀粉多糖，发现其组成性单糖亚基为半乳糖、阿拉伯糖、木糖和葡萄糖，摩尔比分

别为 0.7:1.0:6.3:74.2。Wu 等[17]从 TB 麸皮中获得平均分子量为 19.6 kDa 的中性多糖，发现其在糖尿病小鼠中发挥了出色的降血糖和降血脂作用。

1.2 生物活性蛋白质

TB 中富含优质蛋白质，蛋白质占比为 8%~19%，其含量高于大米、小麦、玉米和高粱。普通荞麦和 TB 的蛋白质含量、氨基酸组成相似[18]（见表 1）。苦荞麦粗蛋白（Tartary Buckwheat Protein, TBP）是通过碱提取和等电沉淀从苦荞麦中获得的产品，在胆固醇喂养的大鼠中表现出对高胆固醇血症的抑制作用[19]。TBP 的蛋白质含量为 45.8%，氨基酸组成为 Asp、Thr、Ser、Glu、Gly、Ala、Cys、Val、Met、Ile、Leu、Tyr、Phe、Lys、His、Arg、Pro、Trp，并具有较高的 Lys、Glu、Gly、Arg 含量。Fag t2 是 TB 种子中的一种 16 kDa 蛋白过敏原。Chen 等[20]通过克隆 Fag t2 基因表明 Fag t2 基因属于 2S 白蛋白家族，在胚胎中表达最多。它能抵抗加热和胃蛋白酶消化。Fag t3 是在荞麦种子中鉴定的另一种过敏原。它类似于豆类 11S 储存蛋白[21]。通过热处理和美拉德反应，可使 Fag t3 蛋白糖基化，从而降低其致敏性[22]。

表 1 普通荞麦与苦荞麦氨基酸含量差异（g/kg）

Table 1 Differences in amino acid content between *F. esculentum* and *F. tataricum* (g/kg)

氨基酸	普通荞麦	苦荞麦
Asp	12.74±1.3	12.08±1.2
Thr	5.54±1.6	4.87±0.8
Ser	5.64±0.8	5.56±1.2
Glu	25.79±2.5	24.12±2.4
Gly	6.32±3.1	6.60±2.8
Ala	11.14±0.6	10.37±1.3
Val	9.24±0.9	8.64±1.7
Met	3.35±1.1	3.47±1.0
Ile	7.01±1.2	6.08±0.5
Leu	11.34±2.9	9.51±0.5
Tyr	7.85±2.1	7.25±3.0
Phe	8.81±2.8	9.26±2.4
Lys	10.37±2.4	8.73±0.0
His	5.49±1.5	4.62±0.5
Arg	13.11±0.9	13.49±1.4
Pro	5.92±0.9	4.74±1.4
E	61.15	55.19
T	149.66	140.12
E/T	0.41	0.39

注：E 为必需氨基酸总量，T 为总氨基酸含量，E/T 为必需氨基酸占总氨基酸的比例。

1.3 矿物质及维生素

TB 是许多矿物质的良好来源。Ikeda 等[23]研究了日本 TB 和三种中国 TB 中八种必需矿物质的含量。钙含量相对较低，其他 7 种矿物质占每日推荐食物摄入量的 10%~80%。此外，TB 富含天然有机硒，这是其他谷物相对缺乏的（见表 2）。硒能在人体内形成“金属—硒—蛋白质复合物”，有助于排除有毒元素，调节人体免疫功能。TB 还富含三价铬；铬在体内形成的“葡萄糖耐量因子”可以增强胰岛素功能，改善葡萄糖耐受量。TB 中含有多种维生素，其中芦丁（VP）是苦荞麦特有的其它谷类作物所不含有的成分[24]。TB 籽粒中 B 族维生素的含量约为 0.78 mg/100 g，富含维生素 B1、B2 和 B6[23]。苦荞麦中重要的生物活性物质还包括一些脂溶性维生素，特别是维生素 E。TB 籽粒中维生素 E 含量为 2.0~5.8 mg/kg，平均值为 9.5 mg/kg[25]。

表 2 普通荞麦与苦荞麦营养成分的比较

Table 2 Comparison of nutritional components between *F. esculentum* and *F. tataricum*

营养成分	*F. esculentum*	*F. tataricum*
热量/kJ	1 354.00	1 276.80
脂肪/g	2.30	2.70
蛋白质/g	9.30	9.70
碳水化合物/g	66.50	60.20
膳食纤维/g	6.50	5.80
钙/mg	47.00	39.00
镁/mg	258.00	94.00
铁/mg	6.20	4.40
锰/mg	2.04	1.31
锌/mg	3.62	2.02
铜/mg	0.56	0.89
钾/mg	401.00	320.00
钠/mg	4.70	2.30
硒/μg	2.45	5.57
磷/mg	297.00	244.00
VC/mg	0	0
VE/mg	4.40	1.73
VA/μg	3.00	0
胆固醇/mg	0	0
胡萝卜素/μg	2.40	2.30
核黄素/mg	0.16	0.21
尼克酸/mg	2.20	1.50
VB1/mg	0.28	0.32

注：每 100 克食物中所占营养成分的比例。

1.4 脂类物质

荞麦的脂类主要集中在胚中，其脂肪含量在1%~5%之间与普通荞麦相近[26]。TB中的脂肪酸包括棕榈酸、亚油酸、油酸、硬脂酸、二十碳烯酸和花生酸[27]。其中油酸和亚油酸是主要脂肪酸，TB是不饱和脂肪酸的来源。

TB中含有大量的植物甾醇，并且可以达到整个种子的96 mg/100 g[28]。TB中含量最高的是β-谷甾醇，其次是菜油甾醇。Yang等[11]比较了TB与大米和小麦的植物甾醇组成，发现在TB中总植物甾醇含量明显高于其他两组，为74 mg/100 g。Guo等[29]从TB麦麸皮中分离得到胡萝卜甾醇。

1.5 多酚类化合物

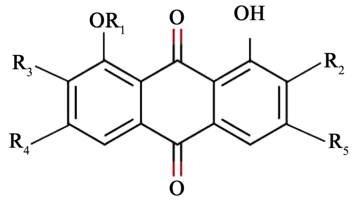
多酚是苦荞中研究最多的植物化学物质，具有多种亚型，并表现出与它们所含羟基分子的数量和位置一样广泛的生物活性。多酚具有抗氧化、抗炎、抗菌、抗糖尿病、抗衰老、抗肿瘤、抗癌和细胞毒活性[30-33]。由于这些作用，多酚可以降低慢性疾病的风险并改变疾病的治疗方法[34,35]。它们还被证明对心血管健康和认知功能有积极影响，可以预防神经退行性疾病[36]。

1.5.1 蒽醌类化合物

蒽醌类化合物具有抗菌、保肝、抗癌等生物学功能[37,38]。从TB种子中鉴定出6种不同类型的蒽醌类化合物，包括橙黄决明素、芦荟大黄素、大黄酸、大黄素、大黄酚和大黄素甲醚[34]（见图3）。Peng等[37]使用高效液相色谱联合光电二极管阵列检测（High Performance Liquid Chromatography with Diode Array Detector, HPLC-DAD）鉴定了TB种子和食品中的大黄素。4个TB基因型的大黄素含量范围为1.72~2.71 mg/kg。Wu等[38]采用选择性加速溶剂萃取（甲醇/丙酮（50:50，*V/V*）作为溶剂，硅胶作为吸附剂）结合超高效液相色谱联合光电二极管阵列检[31]测（Ultrahigh-Performance Liquid Chromatography with Diode Array Detector, UPLC-DAD）技术，同时测定6种蒽醌。通过研究发现，这些蒽醌类化合物可能以糖苷的形式存在于种子中，并在随后的制备过程中水解。

1.5.2 酚酸类化合物

酚酸及其衍生物广泛分布于植物中，在TB中检测到的酚酸类化合物（$C_{16}H_{22}O_5$）为羟基苯甲酸和羟基肉桂酸[7,39]。通过超高效液相色谱-电喷雾质谱（Ultrahigh-Performance Liquid Chromatography with Electrospray Ionization Mass Spectrometry, UPLC-ESI-MS）在TB中鉴定了没食子酸、4-羟基苯甲酸、对羟基苯甲酸、香草酸、原儿茶酸、丁香酸、水杨酸、对香豆酸、邻香豆酸、咖啡酸、阿魏酸和绿原酸[40]。与VP一样，TB的酚酸含量受加工方法的影响，经发酵处理后，胡萝卜酸、阿魏酸和4-羟基苯甲酸的浓度显著提高[41]，而热辅助烘焙和微波烹饪后，水杨酸、胡萝卜酸、绿原酸、原儿茶酸和没食子酸的含量显著降低[40]。



（1）橙黄决明素 (Aurantio-obstusin)$R_1=R_4=CH_3,R_2=OCH_3,R_3=R_5=OH$

（2）芦荟大黄素 (Aloe-emodin) $R_1=R_2=R_3=R_4=H,R_5=CH_2OH$

（3）大黄酸 (Rhein) $R_1=R_2=R_3=R_4=H,R_5=COOH$

（4）大黄素 (Emodin)$R_1=R_2=R_3=H,R_4=CH_3,R_5=OH$

（5）大黄酚 (Chrysophanol)$R_1=R_2=R_3=R_5=H,R_4=CH_3$

（6）大黄素甲醚 (Physcion)$R_1=R_2=R_3=H,R_4=CH_3,R_5=OCH_3$

图3 苦荞麦中6种蒽醌类化合物的化学结构

Fig.3 Chemical structure of 6 anthraquinones in Tartary buckwheat

1.6 黄酮类化合物

TB中的黄酮类化合物（$C_{15}H_{10}O_2$）因其含量丰富、成分独特、生物活性强等特点，近年来引起了人们的广泛关注。Qin等[26]采用$AlCl_3$比色法比较了21个苦荞品种和18个普通荞麦品种的总黄酮含量，研究表明TB粉中总黄酮含量平均是普通荞麦粉的10倍左右。黄酮类化合物是植物和膳食中多酚类次级代谢产物中最主要的一类。TB种子中黄酮类化合物的含量约为40 mg/g，而其叶、茎和花中黄酮类化合物的含量约为100 mg/g[7]。如表3所示，目前已通过高效液相色谱（High-Performance Liquid Chromatography, HPLC）、高效液相色谱-质谱法（High-Performance Liquid Chromatography-Mass Spectrometer, HPLC-MS）、超高效液相色谱-质谱法（Ultra-Performance Liquid Chromatography-Mass Spectrometry, UPLC-MS）等多种检测方法对TB中不同的黄酮类化合物进行了鉴定，通过UPLC-ESI-MS和核磁共振（Nuclear Magnetic Resonance Spectra, NMR），将它们分类为黄酮醇、黄酮、异黄酮、黄烷酮、黄烷醇、花青素、荞麦苷、原花青素、和黄酮木酯素[7]。在TB中检测到了几种黄酮醇，如VP、山萘酚和槲皮素衍生物[5,42-45]。结果表明，从TB中分离鉴定的黄酮类化合物中，VP含量最高，占总酚的90%[46]。大量的流行病学证据表明，类黄酮是炎性细胞因子的活性抑制剂、炎症相关途径的调节剂、一氧化氮（Nitric Oxide, NO）和ROS累积的还原剂[47]。

染料木黄酮可减轻肥胖相关的胰腺 β 细胞炎症和氧化应激[48]。从新鲜水果和蔬菜中大量摄入黄酮类化合物可以防止氧化，炎症和慢性疾病。通过饮食干预试验表明，食用富含类黄酮的食物可以通过调节胰腺 β 细胞、肝细胞和脂肪细胞的功能来防止 II 型糖尿病的胰岛素抵抗[49]。特定的膳食黄酮类化合物对人体健康有积极的影响，但其潜在的机制还需进一步研究。

表 3 不同研究人员用于检测苦荞麦中存在的黄酮类化合物的方法

Table 3 Methods used by different researchers to detect flavonoids in Tartary buckwheat

成分	检测方法	参考文献
异槲皮素、槲皮素和槲皮素	HPLC	[50-52]
金丝桃甙和槲皮素	HPLC-ESI-MS and HPLC-UV	[53]
	UPLC-ESI-MS/MS	[45]
	HPLC-MS	[54]
	RP-UHPLC-ESI-MS	[55]
	UPLC-ESI-MS/MS	[45]
	HPLC	[52]
原花青素 B2	RP-UHPLC-ESI-MS	[55]
	HPLC-MS	[54]
	HPLC	[52]
木犀草素	RP-UHPLC-ESI-MS	[55]
山奈酚	RP-UHPLC-ESI-MS	[55]
	UPLC-ESI-MS/MS	[45]
	HPLC	[50]
儿茶酚	RP-UHPLC-ESI-MS	[55]
儿茶素和表儿茶素	HPLC-PAD and LIT-FTICR-MS	[39]
异牡荆素和牡荆素	RP-UHPLC-ESI-MS	[55]
	UPLC-ESI-MS/MS	[45]
	HPLC	[52]
异荭草甙、异杜荆黄素、荭草素和杜荆黄素	HPLC	[52]
	HPLC-ESI-MS，HPLC-UV	[53]
	UPLC-ESI-MS/MS	[45]
	HPLC-MS	[54]

注：HPLC（高效液相色谱）；HPLC-ESI-MS（高效液相色谱－电喷雾－质谱）；HPLC-UV（高效液相色谱－紫外）；UPLC-ESI-MS/MS（超高效液相色谱－电喷雾－质谱联用）；HPLC-MS（高效液相色谱－质谱法）；RP-UPLC-ESI-MS（反相超高效液相色谱－电喷雾－质谱）；HPLC-PAD（高效液相色谱与光电二极管阵列检测器）；LIT-FTICR-MS（线性离子阱结合傅里叶变换离子回旋共振质谱）。

1.7　其它生物活性成分

采用 HPLC-PDA 技术首次鉴定了 TB 中的生物碱：N-反式阿魏酰酪胺[5]。该生物碱具有神经保护作用[56]。TB 根是传统中药的一部分，用于治疗慢性疾病，如风湿性疾病和癌症。通过 HPLC 技术鉴定了来自 TB 根中的 8 种苯丙素苷[57]。其中，苦荞麦苷（Tatarisides A-G）和二苷（Diboside A）是从 TB 根中分离得到的苦荞特有的成分[39,44]。

2　苦荞的生物活性

大量体外和体内研究证明，上述生物活性化合物是促进健康的主要原因，例如抗氧化、降血脂、抗菌、抗癌、抗炎等（如表 4）。

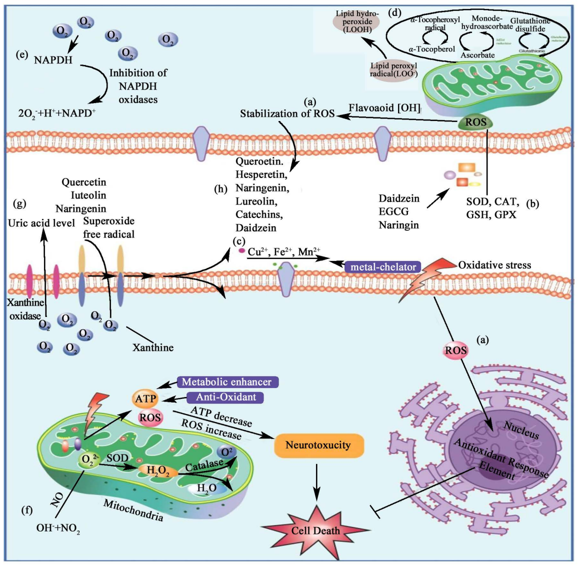


图 4 黄酮类化合物体外抗氧化作用机制的研究

Fig.4 Mechanisms of flavonoid antioxidant activity *in vitro*

2.1　抗氧化活性

许多研究表明，TB 及其产物由于含有多种生物活性成分，如多酚和肽类，在体外和体内都表现出强大的抗氧化活性[8,9,58]。抗氧化机制如图 4 所示[59]，主要包括以下几点：（a）直接清除活性氧；（b）抗氧化酶的激活；（c）金属螯合活性的活化；（d）增加 α- 生育酚自由基水平；（e）抑制 NAPDH 氧化酶；（f）减轻氧化应激引起的 NO；（g）增加尿酸水平；（h）提高低分子量抗氧化剂的抗氧化性能。一般来说，较高的多酚含量与体外抗氧化活性呈正相关，此外，不同的食品加工技术可能会显著影响 TB 及其产品的抗氧化活性[39]。例如，与 80% 丙酮和乙酸乙酯提取物相比，在 70% 乙醇提取物中观察到更高的抗氧化活性[41]。此外，与热水提取、超声辅助提取和超声辅助亚临界水提取等

其他方法相比，单一亚临界水提取法更有利于从 TB 中提取抗氧化化合物[60]。同时，适当的烘焙、酿造、煮沸、蒸制、高压灭菌、发酵和发芽等预处理，能够提高总多酚含量，从而提高抗氧化活性[40,61,62]。此外，在 TB 面包制备的面团形成和发酵阶段，类黄酮糖苷（VP 和山奈酚-3-芸香糖苷）转化为糖苷配基（槲皮素和山奈酚）的过程中抗氧化活性增加[63]。在 TB 的副产物，如麸皮、外壳、叶子和花中同样具有相关的抗氧化活性，因此可作为天然抗氧化剂的来源[53,64-66]。除了多酚，TB 衍生肽也表现出显著的抗氧化活性。从 TB 白蛋白中提取的新抗氧化肽通过改善 GSH/GSSG 的比值，对脂质过氧化和还原力表现出较强的抑制作用[67]。

2.2　抗炎活性

炎症是一种常见的生物学过程，是组织损伤，微生物病原体和化学刺激的一种防御反应，存在于癌症，阿尔兹海默病，肥胖症和糖尿病的发病初期阶段[68]。已有研究表明 TB 及其活性成分具有显著的抗炎活性[7,39,58]。Hwang 等[69]研究表明，从 TB 分离的山奈酚-3-O-β-芸香糖苷对脂多糖（Lipopolysaccharide, LPS）诱导的 RAW 264.7 巨噬细胞具有抗炎作用。该化合物通过核因子 κB（Nuclear Factor Kappa-B, NF-κB）和丝裂原活化蛋白激酶（Mitogen-Activated Protein Kinase, MAPK）途径抑制 LPS 诱导的 RAW 264.7 细胞中 NO、白细胞介素（Interleukin-6, IL-6）和肿瘤坏死因子 A（Tumor Necrosis Factor A, TNF-α）的产生，并抑制环氧化酶-2（Cyclooxygenase-2, COX-2）和诱导型一氧化氮合酶（Inducible Nitric Oxide Synthase, iNOS）的表达。TB 也通过 NF-κB 和 MAPK 途径促进了对 LPS 诱导的 RAW 264.7 细胞的抗炎作用[70]。

2.3　降血脂活性

高脂血症是一种与甘油三酯（Triglycerides, TG）、总胆固醇（Total Cholesterol, TC）、低密度脂蛋白（Low-Density Lipoproteins, LDL）水平升高和高密度脂蛋白（High-Density Lipoproteins, HDL）水平降低有关的代谢性疾病[58]。Wang 等[71]研究 TB 乙醇提取物（TB Ethanol Extract, TBEE）的抗氧化活性及其对高脂饮食诱导的高血脂大鼠血脂谱的影响。结果表明，TBEE 可显著降低血清和肝脏中的 TG 和 TC 水平，上调血清谷胱甘肽过氧化酶（Glutathione Peroxidase, GSH-Px）活性，并下调血清丙二醛（Malondialdehyde, MDA）水平、血浆致动脉粥样硬化指数（Atherogenic Index of Plasma, AIP）和致动脉粥样硬化指数（Atherogenic Index, AI）。谢琳琳等[72]通过建立高脂血症大鼠模型，用荞麦槲皮素对大鼠进行灌胃治疗，并测定各组大鼠的血清、肝脏脂质水平等，结果表明荞麦槲皮素能显著调节高脂膳食大鼠的血脂异常，改善脂质堆积。此外，从 TB 中分离的生物活性蛋白可预防高脂饮食喂养小鼠中与肠道微生物群变化相关的血脂异常，降低血液 TC 和 TG 水平，并降低 TNF-α 和 IL-6 水平[73]。

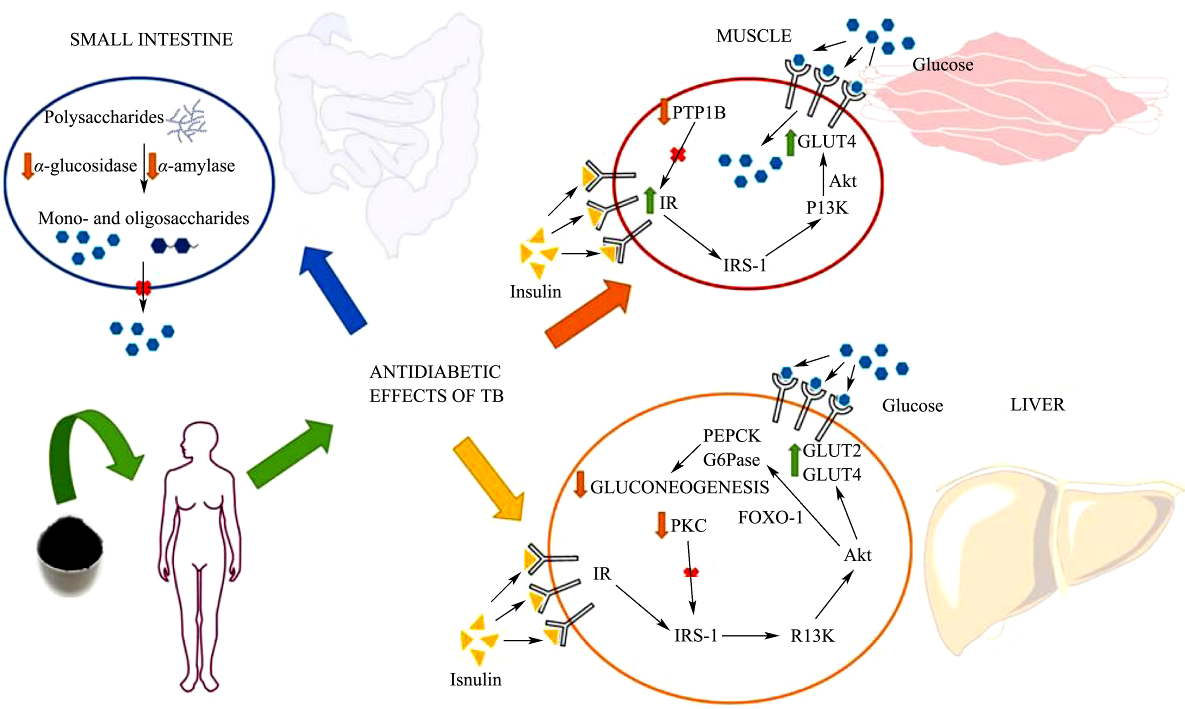


图 5 苦荞麦及其活性成分的降糖机制

Fig.5 The antidiabetic mechanisms of Tartary buckwheat and its bioactive components

表 4 苦荞的生物活性及作用机制

Table 4 Bioactive of Tartary buckwheat and their mechanisms

生物活性	作用机制	参考文献
抗氧化	清除自由基活性	[80]
	提高总抗氧化能力	[81]
	GSH/GSSG 比值升高	[67]
	减少 ROS	[82]
	提高 SOD，CAT 和 GSH-Px 活性	[81]
	抑制脂质过氧化	[67]
抗炎	减少 TNF-α、IL-6、NF-κB 和 NO	[69,70]
	抑制 iNOS、COX-2 和 MCP-1	[69,83]
降血脂	降低血清 TC、TG、LDL 和 MDA 水平	[71,84]
	降低肝脏 TC 和 TG 水平	[58,71]
	降低致动脉粥样硬化指数	[71]
	升高血清 HDL 水平	[84]
	增强肠道微生物菌群	[73]
抗癌	对肝 HepG 2、结肠 Caco-2、乳腺 Bcap 37、MCF-1 和 MDA-MB-231、胃 MGC 80-3、肺 A549 和 H460 以及白血病 THP-1 癌细胞系的细胞毒性	[60,65,75,76,85-88]
抗糖尿病	降低血清葡萄糖水平	[78,89]
	降低胰岛素水平	[90]
	增强葡萄糖摄取和耐受能力	[17,91]
	抑制氧化应激	[92]
抗肥胖	减轻体重	[93]
	减少体脂百分比	[94]
	抑制氧化应激和脂肪组织炎症	[95]
保肝	降低血清 AST、ALT、ALP、LDH 和 CRP 水平	[96]
	降低 ROS、TBARS、MDA、TC、TG、LDL 水平	[97]
	TNF-α、IL-1β 和 IL-6 降低	[96]
	增强 GSH、GSH—Px、CAT、GR、GST 和 SOD 活性	[96]
其他生物活性	抗菌活性	[66]
	预防心血管功能障碍	[39]
	抗高血压活性	[98,99]
	DNA 结构预防	[100]
	降低胆固醇	[11,19,101,102]

2.4 抗癌活性

大量体内和体外研究发现 TB 提取物具有抗癌活性[39,44,58]。最近研究表明，TB 多酚对人肝癌细胞[60]和人结肠癌 Caco-2 细胞[74]具有细胞毒性。此外，还研究了 TB 及其生物活性化合物的抗癌作用和可能的分子机制，表明 TB 酚类化合物通过 p38/MAPK 通路诱导细胞凋亡以及细胞周期从 G1 期停滞至 S 期，以剂量依赖性方式对人乳腺癌 MDA-MB-231 细胞具有抗癌活性[75]。Zhou 等[76]通过促进凋亡蛋白的介导表达，发现 TB 黄酮类化合物对人胃癌 MGC 80-3 细胞表现出显著的抗癌活性。

2.5 抗糖尿病活性

糖尿病是一种以高血糖为特征的代谢性疾病，是现代社会主要的健康问题之一。苦荞及其活性成分的抗糖尿病作用主要作用于小肠、肌肉和肝脏[77]（见图 5）：（1）在小肠中，TB 及其生物活性成分抑制 α-葡萄糖苷酶和 α-淀粉酶的活性，并抑制膳食多糖分解为易于吸收的寡糖和单糖，从而降低餐后血糖

水平。(2)在肌肉中，TB及其生物活性成分通过下调PTP 1B的表达和上调PI3 K的表达来改善胰岛素抵抗。(3)在肝脏中，TB及其生物活性成分通过激活GLUT 2和GLUT 4的表达来促进葡萄糖摄取，并通过抑制PEPCK和G6-ERK的表达来下调肝细胞生成。PTP 1B，蛋白酪氨酸磷酸酶1B；IR，胰岛素受体；IRS-1，胰岛素受体底物-1；PI3 K，磷酸肌醇-3-激酶；Akt，蛋白激酶B；GLUT，葡萄糖转运蛋白；FOXO1，叉头盒蛋白O1；PEPCK，磷酸烯醇丙酮酸羧激酶；G6 β，葡萄糖-6-磷酸。Lee等[78]在高糖诱导的FL83B肝细胞和喂食富含果糖饮食（FRD）的小鼠中系统评价了乙醇提取物、芦丁和槲皮素的抗糖尿病活性。结果表明，给予乙醇提取物和芦丁可显著降低FRD诱导小鼠的血清葡萄糖和胰岛素水平，改善胰岛素敏感性，降低肝脏和血清TC、TG和LDL水平，并增加肝脏中过氧化氢酶（Catalase, CAT）、谷胱甘肽还原酶（Glutathione Reductase, GR）、超氧化物歧化酶（Superoxide Dismutase, SOD）和GSH-Px活性。除了黄酮类化合物外，TB衍生的DCI也具有优异的抗糖尿病活性。口服富含DCI的苦荞提取物（Tartary Buckwheat Extract, TBE）可降低Ⅱ型糖尿病KK-A^y小鼠的血糖、C肽、胰高血糖素、TG和尿素氮，从而增强葡萄糖耐量和胰岛素敏感性[79]。TB的生物活性及作用机制总结如表4所示。

2.6 其他生物活性

除了上述药用价值外，TB及其衍生化合物还具有其他药用保健价值[77]。Jin等[103]研究了TBE在雄性昆明小鼠游泳实验中的抗疲劳特性。结果表明，TBE具有抗疲劳特性，延长了小鼠的游动时间，有效抑制了血乳酸的增加，降低了血尿素氮水平，提高了小鼠的组织糖原含量以及SOD和GSH-Px的活性。因此，TB中的抗氧化剂有助于清除导致疲劳的自由基。通过体外测定和动力学研究发现，存在于TB中的提取物和纯化合物（例如，槲皮素、异槲皮素和芦丁）对包括α-淀粉酶[104]在内的α-葡糖苷酶[105]和胰脂肪酶[106]等消化酶显示出抑制活性。此外，TB衍生的D-荞麦碱可以通过降低餐后肝脏果糖水平来对抗蔗糖诱导的脂肪变性和高血压，能有效预防代谢综合征风险[99]。

3 苦荞麦的工业应用

近年来，随着人们对TB生物活性作用认识的提高，以及现代食品加工技术和设备的迅速发展，TB产品的种类更加丰富和多样化。中国国家市场监督管理总局[11]批准了几种与TB相关的健康食品。在不同的健康食品中，主要由TB粉或TBE构成健康组合配方，其形式多样，包括TB胶囊、TB醋、TB片剂和TB茶。其中，TB茶由于其独特的麦芽香味以及对健康的益处在全球范围内越来越受欢迎[74]。根据原料的不同，一般可分为三种类型：全植物茶、全麸皮茶和全胚茶。据估计，中国有30多家知名企业生产TB茶，年产值超过25亿元人民币。从表5中可知[77]，普通人群最受欢迎的产品形式为TB胶囊。大量研究证明，约88.6%的TB健康食品能够降低血糖、血脂、血压水平、改善胃肠道功能以及防止辐射危害[2,7,39]。TB及其产品在美国、加拿大和欧洲很受欢迎[58]，其面条、面包、饼干和茶在中国、日本、韩国、印度、尼泊尔和加拿大[58]等国家被广泛消费。TB中含有丰富的营养成分以及功能因子，经常食用能强身健体、改善体质，因此在食品加工与新产品开发方面具有很大的发展潜力。目前，我国趋向于对TB籽粒的研究，TB的应用局限于茶叶和TB粉的形式，造成了TB副产品资源的浪费，建议借鉴其它植物叶的应用优势，深入研究TB各部位的功能，对其功能性成分进行探索，加强其活性成分的提取分离，充分发挥TB丰富的营养优势，开发出更多、更有效的功能性食品。此外，为了确保健康食品的有效性和安全性，应尽快制定和完善TB食品的质量控制标准，关注TB过敏原、重金属和霉菌毒素污染，并开发特定的食品加工技术，尽量减少TB产品中的过敏原含量。

表5 中国国家市场监督管理局批准的与TB相关的健康食品，功效及适用人群

Table 5 TB related health food approved by the state administration for market regulation, efficacy and population

产品	主要成分	功效	适用人群
胶囊	TBE	GL、FL	HGFL
胶囊	TBE	GL	HGL
胶囊	TBF	GL	HGL
胶囊	TBF	GL、FL	HGFL
胶囊	TBF	RHP	RE
胶囊	TBF	RHP	RE
片剂	TBE	GL	HGL
TB醋	TBS	FL	HLP
TB粉	TBF	WR	SO
TB粉	TBF	GL、FL	HGFL
TB茶	TBF	GL、FL	HGL
饼干	TBF	GL、FL	HGFL

注：TBE：苦荞提取物；TBF：苦荞粉；TBS：苦荞种子；GL：降血糖；FL：降血脂；RHP：防护辐射危害；WR：减重；HGFL：高血糖和高脂肪水平；HGL：高血糖水平；RE：辐射暴露；HLP：高脂血；SO：单纯性肥胖

4 结论与展望

TB 中丰富的黄酮类、酚酸类、三萜类、生物活性多糖、生物活性蛋白质等活性物质使其具有一系列生理功能，如抗氧化、降血脂、抗炎、抗糖尿病、抗高血压和抗癌等等。黄酮类化合物，如芦丁和槲皮素，是 TB 中的主要生物活性成分。然而，这些生物活性化合物在不同的食品加工方法中的变化还有待阐释，需要进一步的研究来提高 TB 在功能食品工业中的应用。TB 在世界上有很长的食用历史，但由于苦味和适口性差，其发展受到了抑制。制备没有苦味、富含黄酮类化合物的食品将是苦荞加工的潜在发展方向。因此，在今后 TB 产品的开发中，不仅要考虑到有益的保健作用，而且要减少或消除产品的苦味。在 TB 育种时，应注重培育可用于饮料、酸奶、化妆品、保健茶生产和对各种疾病疗效显著的优质品种，切实提高苦荞的经济价值，满足不同消费者的需求。大量体外和体内的流行病学研究表明，TB 中的生物活性成分具有多种促进健康的好处。然而，许多研究仅使用粗提物，有必要探索从 TB 中提取和分离生物活性物质的有效方法。尽管已有研究对 TB 及其生物活性化合物的潜在分子机制进行了研究，但潜在的分子靶点仍需进一步阐明，还需进行更多的研究以深入阐明 TB 的作用机制，使 TB 充分发挥其经济价值和社会效益。

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