“全谷物食品的营养与健康”特约专栏文章之一

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青稞：一种潜在的辅助降血糖食品资源

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摘　要：近年来，糖尿病对人类健康的威胁日趋严重，对糖尿病的治疗和康复引起了公众很大关注，饮食控制作为管理血糖的一项重要手段，因其几乎无副作用而备受青睐。青稞营养成分丰富，包括多酚、β-葡聚糖等生物活性成分，体内外实验结果充分证明了其具有多种健康益处，尤其在控制血糖上升水平方面表现出极高的效率。虽然对青稞的降糖机制的研究逐年增加，但主要集中在单一成分对血糖的影响，尚缺少系统阐释青稞整体参与血糖管理途径的报道。因此梳理了以近三年为主的研究文献，从营养组成和活性成分（多酚、β-葡聚糖等）两个角度总结了青稞的降糖作用，并对青稞降糖食品的加工利用情况进行了系统阐述，以期为进一步深入挖掘青稞降糖机理和开发青稞功能食品提供一些理论参考。

关键词：青稞；营养组成；多酚；β-葡聚糖；降血糖

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Highland Barley: A Potential Auxiliary Hypoglycemic Food Resource

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Abstract: In recent years, the threat of diabetes to human health is getting worse and worse, and the treatment and rehabilitation of diabetes have drawn great public attention. As an important vehicle of managing blood sugar, diet control is favored because of few side effects. Highland barley is rich in nutrients, including polyphenol, β-glucan, and other bioactive ingredients. Moreover, the experimental results in vivo and in vitro have fully proved that it has various health benefits, especially in reducing the rising level of blood glucose. Although the researches on the hypoglycemic mechanism of highland barley have increased year by year, they mainly focused on the impact of a single component on blood glucose, and there is still a lack of comments systematically explaining the overall involvement of highland barley in glycemic management. Therefore, with the research literature mainly of the recent three years reviewed, this paper summarized the hypoglycemic effect of highland barley from the perspectives of nutritional composition and bioactive components (polyphenol, β-glucan, etc.), and analyzed the utilization of highland barley

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hypoglycemic food, in order to provide some theoretical references for further exploring the hypoglycemic mechanism of highland barley and developing highland barley functional food.

Key words: highland barley; nutritional composition; polyphenol; β-glucan; hypoglycemia

近年来，人们生活水平日益提高，糖尿病和肥胖症等代谢疾病对人类的健康挑战加剧，根据国际糖尿病联合会报告，到 2019 年，糖尿病已导致 420 万人死亡，全球大约有 4.63 亿成年人（20~79 岁）患有糖尿病，预计到 2045 年将增加至 7 亿人。饮食控制是预防Ⅱ型糖尿病发生和延缓病情发展的重要手段。种植于高寒地区的青稞由于富含蛋白、多酚、维生素和膳食纤维等可以调节血糖的活性成分受到了极大的关注，研究人员尝试以青稞保障血糖健康[1]。

青稞（*Hordeum vulgare L. var. nudum Hook. f*），是一种禾本科小麦属变种，因其收获时颖片和颖果分离，也被称为无壳大麦、元麦或裸大麦[2]。最近的数据显示，我国青稞的种植面积已超过 27 km^2，青藏高原是青稞的主要产地，种植面积超过 25 km^2，产量超过 110 万 t，西藏和青海的青稞产量约占总产量的 90%[3-4]。青稞具有高蛋白、高膳食纤维、高维生素以及低糖、低脂肪的优点，适合用于开发糖尿病等特殊人群食用的功能性食品。尽管已经有一些关于青稞控制血糖和血脂的研究[5-6]，但相比于对大麦、燕麦和藜麦等传统杂粮与血糖的相关性的大量论述[7-10]，目前系统解释青稞参与血糖管理机制的评论仍较少，因此，本文基于青稞营养成分和活性物质总结了目前对青稞辅助降血糖机理及应用的研究。

1 青稞辅助降血糖机理

1.1 营养成分

青稞的蛋白含量在 12.85%~14.51%之间，显著高于大麦[11-12]。青稞蛋白是一种高质量蛋白，根据周等[13]的研究，12 种黑青稞的总必需氨基酸含量平均值为 319.90 mg/g，接近 WHO/FAO 推荐值（360 mg/g），其中 Z526，Z533 和 Z523 三个品种的必需氨基酸总量均高于此推荐值。此外，青稞蛋白经过酶解得到衍生肽可以使其营养价值最大化。二肽基肽酶Ⅳ（DPP-Ⅳ）的抑制剂最近被确定为潜在的抗糖尿病药物，有助于增加葡萄糖调节激素的释放，间接刺激胰岛素的分泌[14]。Wang 等[15]通过水解青稞白蛋白和谷蛋白得到对 DPP-Ⅳ具有抑制作用的活性肽，体外试验得到的 IC 50 分别为 8.15 mg/mL 和 1.83 mg/mL，证明了青稞蛋白具有潜在的降血糖作用。青稞粗脂肪含量约为 1.18%~3.09%，平均值为 2.13%，低于玉米、高粱和燕麦[11,16-17]。青稞富含亚油酸（14.52%~50.79%）、油酸（10.32%~15.61%）、棕榈酸（9.61%~24.58%）和亚麻酸（2.95%~19.04%）等对人类健康有益的不饱和脂肪酸[17]。动物试验结果显示，摄入青稞麸皮油可显著降低高血脂小鼠甘油三酯（TG）、总胆固醇（TC）、动态动脉僵硬指数（AASI）、高密度脂蛋白胆固醇与低密度脂蛋白胆固醇比值指数（HDL-C/TC），显示出青稞脂肪酸作为降血糖保健食品的潜力[18]。同时，青稞富含多种维生素和矿物质，含量较高的有维生素 B、C、E 以及铜、锌、铁、硒和镁等元素[19-20]，这些营养素在青稞辅助降血糖功能中起着不可或缺的作用。虽然维生素和矿物质是谷物中的微量营养素，但它们可以改变肠道菌群的组成，改善肠道屏障功能，参与细胞葡萄糖转运和葡萄糖代谢的内分泌控制，包括胰岛素和甲状腺素[21]。

淀粉是影响谷物及其制品餐后血糖的主要因素，也是青稞最主要的营养组分，青稞淀粉含量在 58%~67%之间，与基因型和环境因素相关[22]。青稞淀粉包含两种碳水化合物聚合物，一种是 α-D-葡萄糖以 α-1, 4 糖苷键连接聚合并呈线性排布的直链淀粉，另一种是葡萄糖单位通过 α-1, 4 糖苷键构成主链再通过 α-1, 6 糖苷键连接分支结构的支链淀粉[23]。淀粉酶对淀粉的消化率高度依赖于底物的分子结构，直链淀粉、支链淀粉的结构在酶-底物复合物的形成和酶催化中起重要作用，直/支比例显著影响淀粉的整体消化率[24]。直链淀粉含量高能够有效抵抗消化酶的消化，并产生较低的血糖反应[25]。这可能与支链淀粉拥有更多分支结构，更容易被淀粉酶接近并提供更多的结合位点有关[26]。根据文献报道，青稞淀粉具有

较高的直/支比，约有 25%~30%的直链淀粉，高于普通大米（0%~25%）和小麦（25%）这意味青稞淀粉更难被消化分解[27-29]。此外，淀粉颗粒大小也是影响淀粉消化性的关键因素，淀粉颗粒大小与消化酶的有效利用面积有关，淀粉颗粒大与消化率低正相关[30]。Li 等[31]发现相比于从蜡质玉米中分离出的淀粉颗粒（2~20 mm），从蜡质青稞分离出的淀粉颗粒尺寸更大(2~30 mm)，更大的淀粉颗粒使其消化率更低。青稞淀粉也表现出特殊的糊化特性，与其他谷物相比，青稞淀粉具有更高的糊化温度，更好的回生和糊化能力，淀粉糊表现出剪切稀化的非牛顿流体特性[32]。在青稞淀粉的体外胃肠消化模型中也证明了青稞淀粉不易消化，根据 Moza 等[33]的研究，青稞淀粉的预测血糖生成指数（predict glycemic Index，pGI）在 38.4~47.5 之间，低于 55，适宜糖尿病及肥胖等特殊人群食用。

1.2 活性成分

在青稞独特的营养组分之外，青稞还富含降糖效果显著的活性成分，主要是青稞多酚和青稞 β-葡聚糖。青稞多酚含量在 336.31~453.94 mg/kg 之间，高于玉米、小麦、大米和燕麦[3]。青稞多酚含量与品种，种植条件以及加工工艺均有关，一般来说，黑青稞的多酚含量要高于其他颜色青稞[34]。青稞酚酸以结合形式和游离形式存在，游离酚是生物可利用的形式，而结合酚在人类胃肠道中不能被消化吸收，直接进入结肠，并在结肠中被微生物发酵从而发挥有益的生物活性[35-36]。在青稞酚类物质中检出阿魏酸、草酸、绿原酸、（+）-儿茶素、对香豆素酸和原儿茶酸等酚酸，单体酚中阿魏酸含量最高[37-40]。之前的研究发现，青稞中丰富的阿魏酸使其对血脂和血糖有显著的调节作用[41-42]。青稞多酚具有较高的抗氧化活性，Ge 等[43]在白、黄、蓝和黑色青稞中共鉴定出 156 种酚类物质，酚类物质是全谷物青稞抗氧化能力的重要贡献者，有色青稞提取的多酚表现出更好的抗氧化活性。青稞多酚可通过清除 DPPH+等自由基的方式实现抗氧化[44]，细胞试验证明了青稞多酚提取物可以提高 HepG2 细胞的抗氧化活性[45]，而氧化应激被认为与Ⅱ型糖尿病的发病机制密切相关，提高抗氧化活性对减轻糖尿病并发症有一定的帮助作用[46]。食物中的淀粉主要在人体小肠中消化分解，α-淀粉酶和 α-葡萄糖苷酶是小肠中将多糖分解为葡萄糖的两种重要的酶，淀粉酶将淀粉水解为寡糖，α-葡萄糖苷酶将寡糖水解为葡萄糖，葡萄糖从小肠进入血液，引起血糖上升[47-48]。体外试验发现，青稞多酚对 α-淀粉酶和 α-糖苷酶均有一定的抑制作用，相比于游离酚，结合酚的抑制作用更强[49]。此外，细胞和小鼠试验也证明了青稞多酚可以通过调节 IRS-1，PI3K 和 AKT 等信号通路提高糖原的合成速率，降低糖原分解速率，从而起到调节血糖的作用，不过这种调节作用依赖于青稞多酚的摄入量[49-50]。

另一方面，青稞是一种潜在的优质 β-葡聚糖资源，在麦类作物中 β-葡聚糖含量最高，西藏青稞平均 β-葡聚糖含量为 5.25%[51-52]。β-葡聚糖是一种葡萄糖通过 β-1, 3 或 β-1, 4 糖苷键以非随机和非重复方式组成的线性多糖分子，作为膳食纤维的一种，在人体内不会被水解[53]。对于 β-葡聚糖辅助降血糖的机制有多种解释，目前认可度最高的是它的增稠作用。食物经过口腔的咀嚼和胃的蠕动成为食糜后进入小肠，β-葡聚糖能够增加食糜的粘度，延缓食糜从胃进入小肠的速度[54]。同时，食糜的粘度增大，减缓了消化酶向底物淀粉的扩散速率。β-葡聚糖也可以使粘度增加的内容物在淀粉颗粒表面形成一层凝胶，阻碍了消化酶和淀粉的接触，进而减缓淀粉的消化速度[55]。类似青稞多酚，β-葡聚糖也被证明能够抑制 α-淀粉酶、α-葡萄糖苷酶和转化酶的活性[5]。此外，高脂饮食喂养的大鼠在摄入青稞 β-葡聚糖后，胰岛素抵抗、动脉硬化、血清葡萄糖和血脂等症状均有所改善[56]，这表明了青稞 β-葡聚糖也可以通过降低胰岛素抵抗参与血糖管理。一直以来，青稞 β-葡聚糖的增稠作用被认为是其能够辅助降血糖的主要原因，然而，最近的研究发现增加粘度可能不是 β-葡聚糖的主要作用机制[57]。Xie 等[58]的实验证明，单独的青稞 β-葡聚糖不能增加提纯的青稞淀粉的粘度并降低体外淀粉消化率，只有完整的青稞细胞壁，β-葡聚糖才能发挥降血糖活性，但在某些特殊情况下，青稞 β-葡聚糖能够和淀粉、蛋白质形成复合物，这种复合物能够将淀粉包裹其中，阻碍消化。张等[59]研究燕麦 β-葡聚

糖对燕麦淀粉消化特性的影响也得到了相似的结论，淀粉、蛋白质和 β-葡聚糖可能共同形成了一种聚合结构，这种物理或化学的空间结构降低了淀粉和消化酶的接触度，延缓了淀粉的消化。虽然两种对于青稞 β-葡聚糖降低淀粉消化率机制的解释不一致，但其阻碍淀粉消化的作用仍是毋庸置疑的。值得说明的是，青稞蛋白、脂肪和 β-葡聚糖对青稞淀粉的消化率的降低作用可能存在协同作用，去除多种内源性非淀粉组分比去除单一组分对淀粉消化率的提高更为显著[60]。

2 青稞辅助降血糖食品的开发与加工

随着对青稞营养功能研究的深入和食品加工业的发展，对青稞食品的加工利用呈现多样化趋势，应用于特色食品、功能食品、酿酒和饮料多个领域，这些产品结合了传统藏区青稞的食用方式，不仅风味独特，口感好，对人体也有很好的保健滋补作用。围绕青稞在辅助降血糖领域显著优势开发的产品，则以面条、饼干和面包等面制品为主。青稞是一种富含蛋白、膳食纤维和多酚的健康谷物，但本身缺乏面筋蛋白，这将不利于在加工过程中形成强而有力的面筋网络[61]。因此，开发以青稞为基础的面制品关键在于如何通过配方或加工工艺增加青稞粉的比例，在提高青稞面制品营养价值的同时兼顾口感、风味和质构等感官品质。面条是许多亚洲国家的主食之一，已经食用了数千年[62]。Hong 等[63]通过向青稞和小麦复合面条中添加海藻酸钠，发现较高浓度的海藻酸钠（0.3%~0.5%）可以促进蛋白质–淀粉相互作用，有助于形成致密均匀结构，同时也能够改善面条的食用品质。Zhang 等[61]的研究则发现，向青稞面条中添加壳聚糖不仅能够显著抑制面条的体外淀粉消化率，降低血糖生成指数，还能够增强其抗菌、抗氧化活性和感官特性。中粮集团以黑青稞为主要原料，开发了一款青稞挂面，该款挂面添加西藏黑青稞粉超 70%，具备低 GI（46）、高蛋白（16.1%）、高膳食纤维（10.7%）、高 β-葡聚糖（3.5%）等创新点，充分利用了黑青稞的营养功能，实现了营养价值与感官品质的和谐统一。通过挤压青稞粉可以制作面条，青稞也可用于饼干和面包等烘焙产品的开发。Deng 等[64]比较了以23种青稞全粉为原料制作的饼干的营养和感官特性，发现以高直链淀粉青稞全粉制作的饼干品质更佳，表现在较高的蛋白质、β-葡聚糖含量和较低的 GI 值。此外，在青稞饼干制作的过程中，β-葡聚糖和阿拉伯木聚糖并不受影响，但花色苷会被降解[65]。类似地，对于青稞面包地风味、质地、纹理和体外消化率等品质也有相应的研究[66-67]。最近，将青稞全粉挤压膨化生产成冲调粉扩大了青稞在食品工业的应用，通过工艺参数的调整，生产的青稞冲调粉不仅体外消化率和人体餐后血糖反应低，并且结肠发酵得以增强，提高了其营养价值[68]。需要强调的是青稞加工的面条、面包或者饼干都是以全谷物青稞为原料的。美国国际谷物化学家协会（AACCI）定义全谷物应有完整的、磨碎的、破裂的或片状的颖果组成，其主要成分淀粉胚乳、胚芽和麸皮的存在比例应和其在完整的颖果中的相对比例相同[69]。谷物在碾磨过程中，麸皮和胚芽从淀粉胚乳中分离出来，淀粉胚乳被磨成淀粉，在谷物外部含量较高的营养素也会在精炼过程大量损失[70]。食用全谷物可降低患糖尿病的风险，也可能在体重管理中发挥积极作用[71-72]。一项荟萃分析表明，每天多吃两份全麦食品与Ⅱ型糖尿病风险降低 21%正相关[73]。在一项针对 11 名超重或肥胖高胰岛素血症个体的小型随机交叉试验中，受试者在消费 6 周的大麦、燕麦和玉米等全谷物后，提高了胰岛素的敏感性[74]。青稞麸皮富含多酚、花青素、黄酮和膳食纤维，以全谷物形式加工可以有效利用青稞的活性成分，提高其营养价值[75]。

3 结论与展望

青稞是藏区传统主食，也是一种高纤维、高蛋白的健康谷物，对人类健康有相当大的益处。正如体外和体内研究所证明的，区别于其他谷物，青稞在辅助降血糖领域有着巨大潜力，可作为功能性食品的重要成分，用于预防糖尿病。青稞全粉蛋白含量高，但面筋蛋白含量低，不易形成面筋，限制了青稞的应用。随着对青稞功能特性和营养结构的深入研究，通过配方和加工工艺的改进已经能够生产出营养价值和食用品质俱佳的创新产品。但在加工过程中应保持全谷物的形式，

碾磨或抛光会使青稞的营养价值降低。此外，青稞营养成分和生物活性的关系值得进一步研究，营养成分在加工过程中的变化也尚未明确，大部分青稞的实验室理论研究距离大规模工业化生产还有很长的路要走。尽管如此，依然可以认为青稞在人类健康领域尤其是降低Ⅱ型糖尿病风险具有广阔的应用前景，可进一步发展为可持续作物以增强人类健康。

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