

# 亚麻籽活性成分及预防肥胖功能研究进展

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**摘要:** 亚麻籽是世界十大油料作物之一, 在我国主要用来生产油脂。亚麻籽中含有  $\alpha$ -亚麻酸、木酚素、亚麻籽胶、亚麻籽蛋白等多种活性成分, 因而使其具有抗氧化、抗炎、降血糖、降血脂、预防肥胖和糖尿病等多方面的活性作用。本文对亚麻籽中的营养活性成分及其降脂、预防肥胖功能和作用机制研究进行综述, 以期对亚麻籽功能作用的研究和亚麻籽功能性产品的研发提供参考。

**关键词:** 亚麻籽; 活性成分; 肥胖; 降脂

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## Research progress on active ingredients of flaxseed and its function of preventing obesity

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**Abstract:** Flaxseed is one of the top ten oil crops in the world, which is mainly used to produce oil in China. Flaxseed contains  $\alpha$ -linolenic acid, lignans, flaxseed gum, flaxseed protein and other active components, thus giving it multiple biological activities such as antioxidant, anti-inflammatory, hypoglycemic, hypolipidemic, prevention of obesity and diabetes. This paper reviewed the nutritive and active ingredients in flaxseed. Besides, its effects of lipid-lowering and preventing obesity as well as their mechanisms were summarized, aiming to provide references for the research on the functions of flaxseed and development of its functional products.

**Key words:** flaxseed; active ingredients; obesity; hypoglycemia

肥胖 (obesity) 是由于能量摄入超过能量消耗, 导致体内脂肪过量积累的现象, 目前主要通过测量体重指数 (BMI) 进行判断<sup>[1,2]</sup>。进入 21 世纪以来, 随着经济发展和生活方式的改变, 肥胖发生率逐年上升<sup>[3]</sup>。肥胖本身是一种慢性疾病, 而且还会增加患高血压<sup>[4]</sup>、糖尿病<sup>[5]</sup>、动脉粥样硬化<sup>[6]</sup> 和心血管疾病<sup>[7,8]</sup> 等慢性疾病的风险, 已成为影响人们健康和生活质量的重要因素之一。目前热量限制结合运动的减肥方式对于人们来说难以长期坚持, 而长期服用减肥药物可能会产生毒副作用。因此一些功能食品例如亚麻籽在预防和治疗肥胖中的作用逐渐引起了人们的广泛关注。

亚麻 (*Linum usitatissimum* L.) 属于亚麻科亚麻属的一年生或多年生草本植物, 在我国各地皆有栽培。亚麻籽 (flaxseed, linseed) 是亚麻的成熟种子, 又称胡麻籽, 是世界十大油料作物之一<sup>[9]</sup>。我国亚麻籽年产量约为 47.47 万吨, 位居世界第二<sup>[10]</sup>。供人们食用的四种亚麻籽形式包括全亚麻籽, 亚麻籽粉, 亚麻籽油和部分脱脂的亚麻籽粉<sup>[11]</sup>。在我国, 亚麻籽主要用来生产油脂, 只有很少一部分被开发用作功能性食品、涂料、纤维和动物饲料等的生产<sup>[12]</sup>。《本草纲目》中记载, 亚麻籽具有生肌长肉、止痛、消痈肿、眩晕、便秘、补皮裂、解热毒、解食毒、解虫毒、杀诸虫蝼蚁等药用价值。最新研究表明, 亚麻籽及亚麻籽提取物可以有效抗氧化、抗炎、抗癌、降血脂、调节肠道菌群, 尤其对肥胖、糖尿病、心血管疾病等慢性疾病有一定的预防或缓解作用<sup>[13-17]</sup>。

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本文重点对亚麻籽中的营养活性成分及其降脂、预防肥胖功能和可能的作用机制进行综述,以期对进一步研究其预防肥胖作用和作用机制夯实基础。

## 1 亚麻籽中的营养和活性成分

### 1.1 亚麻籽中的营养成分

作为油料作物,亚麻籽含油率为 39.9% ~ 43.3%<sup>[18]</sup>。亚麻籽油中含 9% ~ 10% 的饱和脂肪酸、约 20% 的单不饱和脂肪酸和 70% 以上的多不饱和脂肪酸<sup>[19]</sup>。亚麻籽油的脂肪酸组成中, $\alpha$ -亚麻酸是主要的脂肪酸,含量为 39.00% ~ 60.42%,其次是油酸(13.44% ~ 19.39%)、亚油酸(12.25% ~ 13.44%)、棕榈酸(4.9% ~ 8%)和硬脂酸(2.24% ~ 4.59%)<sup>[20]</sup>。亚麻籽中还含有蛋白质(20% ~ 25%)、纤维素(23% ~ 29%)、多糖、维生素 A、维生素 E、矿物质等多种营养成分<sup>[21]</sup>。亚麻籽中丰富的营养成分使其具有较高的营养价值。

### 1.2 亚麻籽中的活性成分

研究表明,亚麻籽中含有丰富的  $\alpha$ -亚麻酸、植物雌激素木酚素、亚麻籽胶(膳食纤维)、亚麻籽蛋白等多种活性成分<sup>[22,23]</sup>。亚麻籽中的主要活性成分及其功能作用总结于表 1。

#### 1.2.1 $\alpha$ -亚麻酸

亚麻籽油中的  $\alpha$ -亚麻酸含量在 50% 左右<sup>[24]</sup>, $\alpha$ -亚麻酸是人体必需多不饱和脂肪酸之一,是二十二碳六烯酸(DHA)和二十碳五烯酸(EPA)的前体物质<sup>[25,26]</sup>。大量研究已经证明膳食中补充  $\alpha$ -亚麻酸对人们的身体健康有着不容忽视的作用<sup>[27,28]</sup>。在大鼠孕期给予补充亚麻籽  $\alpha$ -亚麻酸,其后代血压显著降低<sup>[29,30]</sup>;给予肥胖大鼠亚麻籽  $\alpha$ -亚麻酸处理,其平均动脉血压(MAP)降低了 6%,总外周阻力(TPR)降低了 25%<sup>[31]</sup>;另有研究表明饮食中  $\alpha$ -亚麻酸的摄入与血压血脂之间存在显著的反比关系<sup>[32-34]</sup>;亚麻籽中的  $\alpha$ -亚麻酸可促进膳食脂质的摄取,同时降低脂肪组织中脂肪酸的生物合成<sup>[35]</sup>;膳食  $\alpha$ -亚麻酸补充剂可有效预防肝脂肪变性<sup>[36]</sup>;  $\alpha$ -亚

麻酸还能够通过抗炎和抗增殖机制促进亚麻籽的抗动脉粥样硬化作用<sup>[37]</sup>,并具有降压和肾脏保护作用<sup>[38]</sup>。

#### 1.2.2 木酚素

木酚素又叫开环异落叶松酚二葡萄糖苷,是与人体雌激素十分相似的植物雌激素。亚麻籽木酚素主要分布在亚麻籽皮上<sup>[39]</sup>,相对含量达到 2.2%。亚麻籽中的木酚素主要有癸二异胡香脂树脂二糖苷(SDG)(294 ~ 700 mg/100 g)、罗汉松脂酚(0.55 mg/100 g)、落叶松树脂醇(3.04 mg/100 g)和松脂醇(3.32 mg/100 g)<sup>[40]</sup>。木酚素在预防和治疗癌症<sup>[41,42]</sup>、降血脂<sup>[43]</sup>、降低心血管疾病风险<sup>[44]</sup>等方面均显示出积极作用。木酚素经肠道菌群代谢后,其产物对于预防癌症、心血管疾病、骨质疏松症和更年期症状等慢性疾病具有显著作用<sup>[45]</sup>。木酚素还具有降低血浆 TC、LDL-C 和 TC/HDL-C 水平<sup>[46,47]</sup>,促进急性髓性白血病癌细胞 DNA 片段化和凋亡<sup>[48]</sup>,以及抗 DOCA 盐性高血压的作用<sup>[49]</sup>。

#### 1.2.3 亚麻籽胶(亚麻籽纤维)

亚麻籽胶是一种水溶性膳食纤维,含量在 10% ~ 15%,主要是由中性和酸性多糖构成<sup>[50]</sup>。中性多糖主要以阿拉伯糖、葡萄糖和木糖等组成,酸性多糖主要以鼠李糖和半乳糖醛酸等组成。亚麻籽胶具有降胆固醇并增加脂肪排泄<sup>[51]</sup>、降低动脉粥样硬化和心血管疾病的风险<sup>[52]</sup>、降低 II 型糖尿病患者体内血糖和胆固醇浓度的作用<sup>[53]</sup>。

#### 1.2.4 亚麻籽蛋白

亚麻籽蛋白<sup>[54]</sup>含量在 15% ~ 30%,是一种优质蛋白,可用于生产高蛋白食品。亚麻籽蛋白富含多种氨基酸,其中谷氨酸和精氨酸含量较高,赖氨酸含量较低。亚麻籽蛋白可显著阻止肝损伤血浆标志物升高,降低脂质过氧化,减轻抗氧化酶的变化,从而改善乙醇诱导的肝毒性<sup>[55]</sup>。此外,亚麻籽蛋白及其水解产物具有清除羟基自由基活性,从而具有抗氧化能力<sup>[56,57]</sup>。

表 1 亚麻籽中的主要活性成分及其功能作用

Table 1 Main active ingredients in flaxseed and their effects

活性成分 Active ingredient	功能作用 Effect	参考文献 Ref.
$\alpha$ -亚麻酸	降压和肾脏保护作用	38
	降低大鼠及其子代血压血脂	29,30,32-34
	降低平均动脉血压、总外周阻力	31

续表 1 (Continued Tab. 1)

活性成分 Active ingredient	功能作用 Effect	参考文献 Ref.
木酚素	降低脂肪组织中脂肪酸的生物合成	35
	预防肝脂肪变性	36
	预防和治疗癌症	41, 42
	降低 TC、LDL-C 和 TC/HDL-C 水平	43, 46-48
	降低心血管疾病风险	44
亚麻籽纤维	预防癌症、心血管疾病、骨质疏松症和更年期症状等慢性疾病	45
	降血压	49
	降低胆固醇并增加脂质排泄	51, 58, 59
亚麻籽蛋白	降低动脉粥样硬化和心血管疾病的风险	52
	降低 II 型糖尿病患者体内血糖和胆固醇	53
	预防乙醇诱导的肝毒性	55
	抗高血压	57
	抗氧化	56, 60

## 2 亚麻籽预防肥胖功能研究

Hadi 等<sup>[61]</sup>检索了 PubMed、Scopus、Web of Science 和谷歌学者数据库 1900 年 1 月至 2019 年 5 月之间的出版物,通过随机对照试验的元分析,以确定补充亚麻籽对血脂的潜在影响。分析结果显示,补充亚麻籽及其制品(10.0 ~ 60.0 g/d)显著降低总胆固醇(TC)、甘油三酯(TG)和低密度脂蛋白胆固醇(LDL-C)的浓度,而对高密度脂蛋白胆固醇(HDL-C)的浓度影响不显著。

此外,有研究发现在哺乳期给母鼠饲喂 25% 的亚麻籽饲料,母鼠断奶时血清中 17 $\beta$ -雌二醇(E2)和瘦素水平较高,乳汁中 TC 较低,E2 和瘦素水平较高。仔鼠 21 天时体重(BM)、体脂肪(BFM)、内脏脂肪(VFM)、TC 和甘油三酯(TG)水平较低,血清中瘦素和 E2 水平较高,而且后代表现出青春发育延迟;150 天时,子代 BFM、VFM、TC、TG、E2 升高,子宫相对体重降低,孕酮降低<sup>[62]</sup>。哺乳期补充亚麻籽会影响子代成年期的脂质、脂肪组织和性功能<sup>[63]</sup>;脱脂亚麻籽粉和亚麻籽油的组合可显著降低大鼠血清中胆固醇水平。亚麻籽可相对降低高胆固醇饮食兔子体内的 TC 和 LDL-C 水平<sup>[64]</sup>,并减轻高脂饮食诱导的脂肪积累,以及诱导脂联素在小鼠体内的表达<sup>[65,66]</sup>。

临床研究表明亚麻籽可降低外周动脉疾病患者体内的总胆固醇和 LDL 胆固醇含量,并与降胆固醇药物结合使用时具有降低 LDL 胆固醇的附加功

能<sup>[67]</sup>。研究者发现代谢综合征患者补充亚麻籽油 7 周后,腰围明显下降,血清中 TC、TG、LDL-C 和空腹血糖浓度也显著降低<sup>[68]</sup>。补充亚麻籽可使血浆总量和 LDL-胆固醇含量降低,并增加脂肪排泄<sup>[51,58,59]</sup>。亚麻籽还可降低绝经后妇女的血清 LDL-胆固醇和脂蛋白浓度<sup>[69]</sup>,降低高胆固醇血症受试者的血浆胆固醇和葡萄糖浓度<sup>[46]</sup>。

总的来说,亚麻籽在动物和人体中均具有显著的降脂作用<sup>[43]</sup>。亚麻籽降脂功能主要体现在降低血脂和血糖浓度、减轻体重和减少脂肪积累等方面,并且能够通过影响母体从而减轻新生儿的肥胖症状。因此补充亚麻籽及其制品有助于预防肥胖,改善身体健康。

## 3 亚麻籽降脂的作用机制

亚麻籽发挥降脂、预防肥胖作用可能与其富含的亚麻酸、木酚素和多糖等相关——它们都有降低循环中脂质浓度的作用。

### 3.1 对脂质生成的影响

固醇调节元件结合蛋白(sterol regulatory element binding proteins, SREBPs)是脂质合成的转录因子<sup>[70]</sup>,包括 SREBP-1a、SREBP-1c 和 SREBP-2 三种亚型,它们对于内源性胆固醇、脂肪酸(FA)、三酰甘油和磷脂的合成非常重要。体外研究表明,用  $\alpha$ -亚麻酸处理可以显著抑制 SREBP-1a、SREBP-1c、SREBP-2、脂肪酸合成酶(FAS)、乙酰辅酶 A (ACC) 和硬脂酰辅酶 A (SCD) 的 mRNA 水平,下调参与 TC

和 TG 生物合成途径和脂质转运的脂质代谢相关基因 (SC5D、TM7SF2、CYP51、HMGCS1、SQLE、ACSL3、ABCA1、ACSS2) 的表达水平<sup>[71,72]</sup>。以上研究表明  $\alpha$ -亚麻酸可能通过抑制转录因子 SREBPs 的表达来抑制胆固醇和脂肪酸生物合成途径,从而减少脂质生成。此外,木酚素也可以通过激活 AMPK $\alpha$  通路,抑制 SREBPs 的表达,从而抑制脂肪的生成<sup>[73]</sup>。

### 3.2 对脂质代谢的影响

AMPK 是生物能量代谢调节的关键因子,它除了参与脂质生成,在脂肪酸代谢方面也起到重要调节作用<sup>[74]</sup>。研究表明亚麻籽多糖可以通过激活 AMPK 信号通路去除瘦素抗性,增加饱腹感,并促进脂质代谢<sup>[75]</sup>。 $\alpha$ -亚麻酸可以诱导线粒体和  $\beta$  氧化

有关基因 PGC1 $\alpha$ 、Nrf1、CPT1a、PPAR $\alpha$  和 ACOX1 的表达上调,促进脂质代谢,提高高胆固醇饮食诱导小鼠体内的脂质稳态<sup>[74,76]</sup>。此外, $\alpha$ -亚麻酸可通过促进胆固醇分解代谢和排泄,来实现降低体内的脂质浓度的作用<sup>[27]</sup>。Kang 等<sup>[77]</sup> 也发现,亚麻籽木酚素能够诱导白色脂肪组织褐变并激活 AMPK $\alpha$  通路,刺激线粒体生物发生/激活/裂变,从而预防肥胖的发生。

总之,亚麻籽及其活性成分主要通过激活 AMPK 信号通路,影响脂肪生成及代谢过程中关键酶的表达水平,实现降低脂肪堆积,从而达到预防肥胖的作用。其通过调控 AMPK 影响生成及代谢的作用机制总结于图 1。

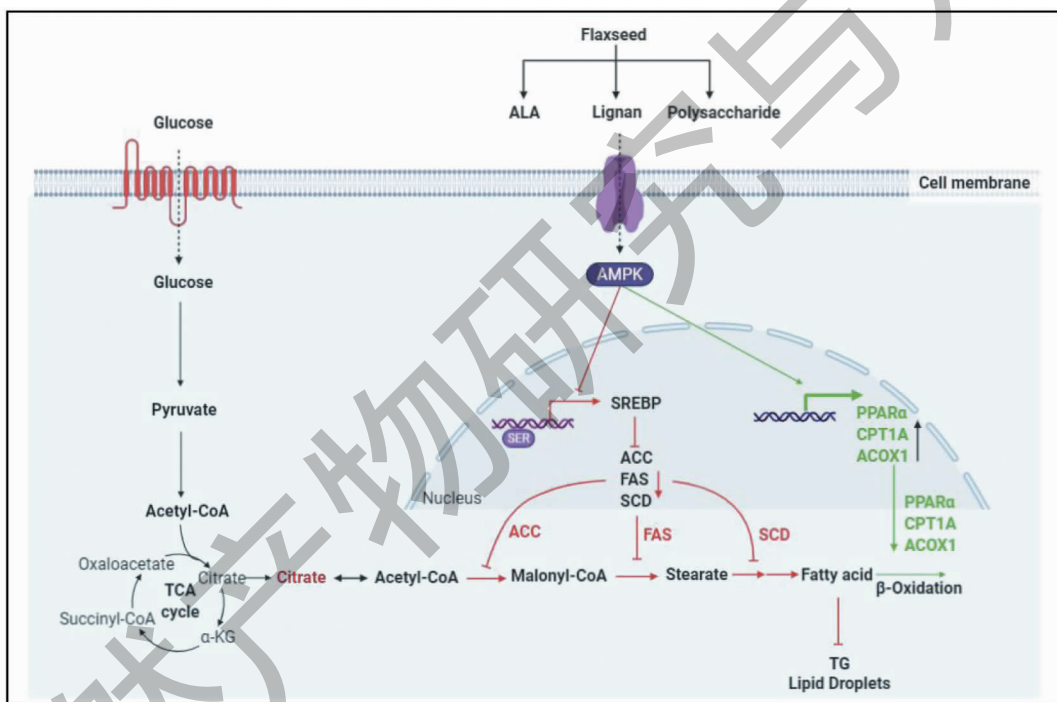


图 1 亚麻籽对脂质生成和代谢的影响

Fig. 1 Effects of flaxseed on the production and metabolism of lipid

### 3.3 对肠道菌群的影响

越来越多的研究表明,肥胖与肠道菌群失调有关<sup>[78]</sup>。饮食中补充全亚麻籽可以改善小鼠盲肠和粪便中的细菌生长和多样性<sup>[79]</sup>,并减轻肠道炎症<sup>[80]</sup>。单纯摄入亚麻籽油也可以改善肠道菌群,抑制肠道炎症,有助于代谢健康<sup>[81,82]</sup>。此外,亚麻籽纤维在肠道中经发酵后产生短链脂肪酸(SCFA),其可增加肠道菌群的丰度,促进有益菌属的增殖;同时,SCFA 通过增加结肠中肠内分泌细胞中短链脂肪酸受体 (GPR41) 的表达水平,从而促进宿主代谢并保护宿主

免于饮食引起的肥胖<sup>[83]</sup>。以上表明亚麻籽纤维主要通过提高机体能量消耗和减少体重增加,以及提高机体的葡萄糖耐受性两个方面来影响机体代谢。

综上所述,亚麻籽及其活性成分发挥预防肥胖功能主要通过以下两种作用机制:(1)通过调控 AMPK 信号通路,抑制脂质生成和促进脂质代谢;(2)通过增加肠道菌群丰度和促进有益菌属的增殖,促进机体能量消耗,从而预防肥胖发生。

## 4 总结与展望

近年来,我国居民肥胖和超重均呈逐年上升趋势

势,儿童肥胖率上升速度高于成年人。肥胖不仅给人们生活带来不便,更重要的是会引起多种慢性疾病的发生。对于肥胖的预防和治疗,健康饮食和适量锻炼是最有效的方式。近年来相关荟萃分析结果显示,饮食中添加适量的亚麻籽或其制品,能够有效降低血脂浓度,预防肥胖的发生。此外,母体孕期补充亚麻籽或其制品,母体和新生儿的血脂浓度和血糖浓度均明显降低。这可能是由于亚麻籽中的多种活性成分,通过调节脂质代谢、糖代谢、抗炎、调节肠道菌群等多种途径共同作用的结果。未来关于亚麻籽及其活性成分的降脂、预防肥胖功能及作用机制值得进一步深入探究。此外,聚焦中国人群特点,加大对亚麻籽健康减肥产品的研究与开发将对我国居民身体健康起到积极作用。

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