

药用昆虫及其活性成分应用的研究进展*

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摘要 昆虫资源丰富, 历史悠久, 且作用多样, 具有食用、药用和工业价值。近年来, 因药用昆虫发挥治疗作用的特异性、活性成分的复杂性以及资源的丰富性使得药用昆虫成为研究热点。药用昆虫种类繁多, 具有多种入药形式, 其活性成分丰富, 呈现多样的药理价值和作用。测序技术的发展进一步推动了药用昆虫领域的研究, 使药用昆虫的功效得以更深入阐释, 同时也创造了发掘新药功效的可能。本文在总结我国药用昆虫的种类、药用昆虫虫药制剂作用和功效的基础上, 深入分析并归纳总结了药用昆虫氨基酸、蛋白质、脂肪类、生物碱、多糖、甾类物质、黄酮类和萜类等活性成分在抗肿瘤、抗菌消炎、治疗心血管疾病、降血脂、保护胃肠道和抗溃疡等方面的药理作用机制及其在临床上的应用研究进展, 为未来药用昆虫的研究提供了参考。

关键词 药用昆虫; 入药形式; 活性成分; 药理作用; 临床应用

Progress in research on medicinal insects

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Abstract Insects are a source of abundant edible, medicinal and industrial, resources. In recent years, medicinal insects have become the focus of considerable research due to their therapeutic effects, the complex nature of their active compounds, and the abundance of available insect resources. Medicinal insects encompass a wide variety of species and possess a rich assortment of active ingredients with a range of pharmacological benefits and effects. The advent of sequencing technology has greatly facilitated research on medicinal insects, enabling more comprehensive exploration of their potential medicinal value. This review summarizes medicinal insect species in China, the medicinal products derived from these, and provides a comprehensive analysis of the amino acids, proteins, lipids, alkaloids, polysaccharides, steroids, flavonoids, terpenoids, and other active ingredients found in medicinal insects. The pharmacological effects of insect-derived medicinal products, including anti-cancer, antibacterial, anti-inflammatory, cardiovascular disease treatment, blood lipid reduction, gastrointestinal tract protection and anti-ulcer effects, are summarized and progress in research on the clinical applications of these are discussed.

Key words medicinal insects; medication form; active ingredients; pharmacologic action; clinical application

1 药用昆虫概述

1.1 昆虫资源

昆虫是节肢动物门昆虫纲 Insecta 物种的总称, 繁衍能力极强、有翅能飞、体型小、经历变

态发育且适应力强, 故而已成为世界上最繁盛的动物类群之一。基于大量基因数据建立的昆虫进化树显示, 昆虫纲包括鞘翅目、鳞翅目、直翅目、蜚蠊目、半翅目和膜翅目等 29 个目 (Misof *et al.*, 2014) (图 1)。全球预计昆虫总数约 550 万种, 已知昆虫总数约 101.4 万种 (Stork, 2018)。昆

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虫蛋白质和脂肪含量高, 一直以来被用作食品、医药和化学原料, 作为饲料具有丰富的营养成分, 具备巨大的饲料开发潜力(刘佳妮等, 2017)。药用昆虫具有强大的药用功效, 与人类健康息息相关(Mozhui *et al.*, 2021)。由于昆虫繁殖速度快、数量众多, 它们具有广阔的开发和利用前景,

其开发和利用可分为四类, 包括工业用途、食用药用、法医调查应用以及具有生态重要性的昆虫(Lokeshwari and Shantibala, 2010)。昆虫的虫体本身、昆虫产物(分泌物、排泄物和内含物等), 甚至是昆虫体内的微生物, 都是人类可利用的药用资源(胡萃和张传溪, 1995)。

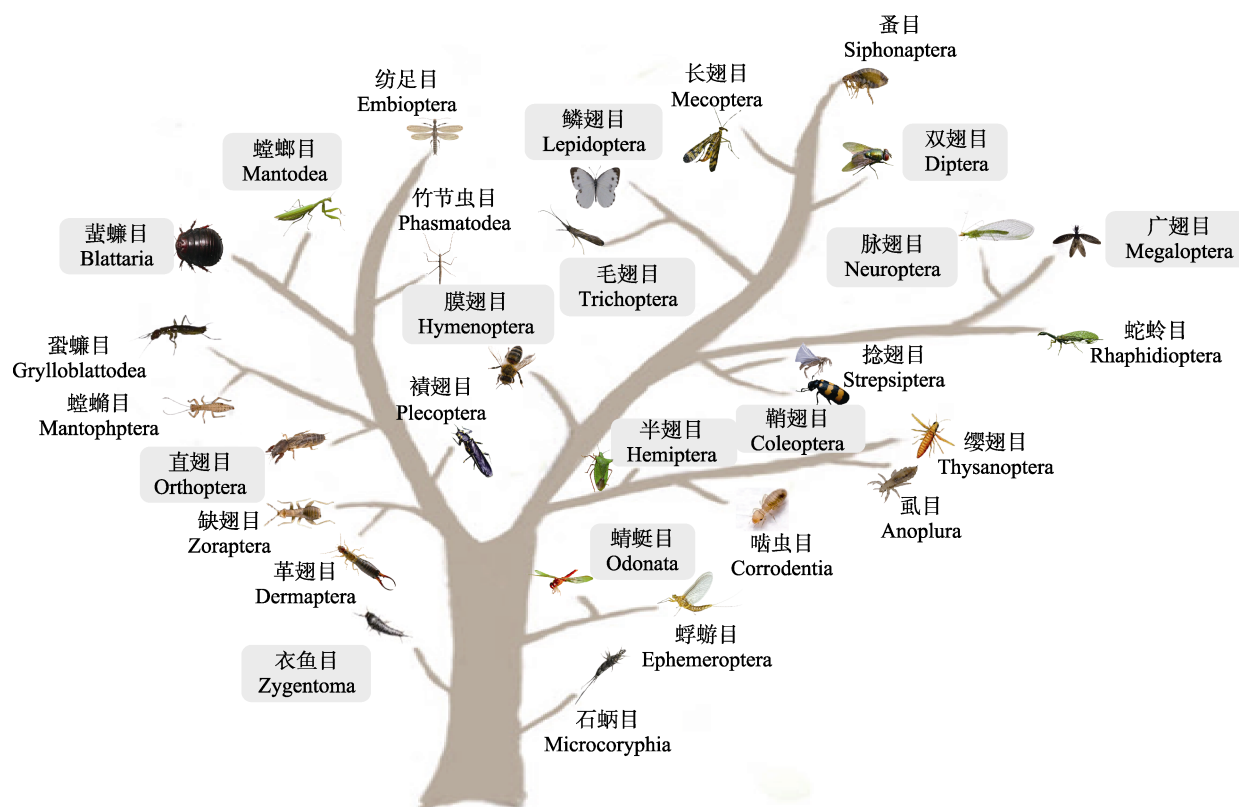


图1 昆虫进化系统昆虫纲 29 个目进化树(改自 Misof *et al.*, 2014)

Fig. 1 A total of 29 insect orders are graphically displayed according to the recently updated insect evolutionary system (adapted from Misof *et al.*, 2014)

灰色框代表已有记录的药用昆虫目。

The gray box represents the recorded orders of medicinal insects.

1.2 我国药用昆虫及其制剂

《中国药用动物志》(《中国药用动物志》协作组, 1983)对药用昆虫的定义是指虫体本身、局部或其产物(衍生物、分泌物和病理产物等), 可以用于治疗或辅助治疗疾病。全世界至少有 1 000 种昆虫被用于疾病的治疗(Meyer-Rochow, 2017)。我国是研究药用昆虫历史最悠久的国家, 早在西周时期《周礼》中就记载了药用昆虫:“五药, 草、木、虫、石、谷也”。西汉时期的《五

十二病方》、东汉的《神农本草经》和《伤寒杂病论》、南北朝的《名医别录》和《本草经集注》、唐代的《新修草本》、宋代的《本草衍义》、明代的《本草纲目》以及清代的《本草纲目拾遗》, 均记载了昆虫在中医领域中所起到的重要作用。近年来, 大量的文献报道了药用昆虫的活性成分、药理作用及其机制。同时, 《中华人民共和国药典》、《中国药用动物志》、《中国药用动物医药文献库》、《中药大辞典》和《中医大辞典》等相关工具书的出版, 进一步促进了药用昆虫的研

究和利用 (Feng *et al.*, 2009; 张星贤等, 2019)。目前《中国动物药资源》中已记录的药用昆虫共 389 种, 分布在 13 个目 71 个科中 (邓明鲁, 2007) (图 1)。

常见的药用昆虫包括僵蚕、蜜蜂、斑蝥、五倍子虫、冬虫夏草 *Cordyceps sinensis*、地鳖虫 (又称土鳖虫) *Eupolyphaga sinensis*、桑螵蛸、蝉蜕、蝼蛄和蚂蚁等 (王大伟等, 2014), 参考 2018 版《国家基本药用目录》、丁香园用药助手以及药智数据库, 查询获知目前已开发出药用昆虫制剂 39 种, 涉及昆虫纲的 6 个目 10 个科 (表 1)。依据药智数据库最新版药品说明书的作用与功效, 可将药用昆虫制剂分为百令胶囊、虫草清肺胶囊、金水宝胶囊、心肝宝胶囊、蛹虫草菌粉胶囊、生血宁片、九味健肾胶囊和健脑补肾口服液等补中益气药; 太极升降丸和天蚕片等发散风热药; 康复新液等化瘀止血药; 心脉隆注射液、肝龙胶囊、大黄廬虫丸、接骨七厘散、鳖甲煎丸和京万红软膏等活血药; 白蚁巢胶囊、通心络胶囊、复方蚂蚁活力胶囊和蚂蚁双参通痹丸等活络止痛药; 复方斑蝥胶囊、肝宁片、艾迪注射液和得力生注射液等化瘀散结药; 明目上清丸、金蝉止痒胶囊、黄氏响声丸和金嗓散结胶囊等清热药, 以及可以治疗风湿病的蜂毒注射液 (魏方超等, 2012; 邢相宜和彭芳, 2020)。此外, 还有部分制剂同时应用多种药用昆虫, 如鳖甲煎丸含有鼠妇 *Armadillidium vulgare*、土鳖虫和蜣螂 *Catharsius molossus*; 大黄廬虫丸含有土鳖虫和蛴螬; 红金消结胶囊含有鼠妇和黑蚂蚁 *Polyrhachis vicina*。这些药用昆虫制剂广泛应用于增强机体免疫、创伤治疗以及肿瘤治疗等方面, 为保护人类健康发挥了重要作用。

1.3 药用昆虫的入药形式

大部分药用昆虫以其本身或局部入药, 少数以衍生物、分泌物和病理产物等入药 (杨红珍, 2023) (表 2)。地鳖虫、九香虫 *Coridius chinensis*、洋虫 *Ulomoides dermestoides*、蚂蚁、螳螂和螳螂等以成虫入药; 大头金蝇 *Chrysomya megacephala*、黄足蚁蛉 *Hagenomyia micans* 和金凤蝶 *Papilio*

machaon 等以幼虫入药 (杨红珍, 2023); 黑蚂蚁 (鼎突多刺蚁) 以虫卵入药 (杨红珍, 2023); 桑螵蛸来源于螳螂科昆虫, 包括中华大刀螂 *Tenodera sinensis*、小刀螂 *Statilia maculata* 或巨斧螳螂 *Hierodula patellifera* 的干燥卵鞘 (孙立艳和窦志英, 2022); 蝉科昆虫黑蚱蝉 *Cryptotympana atrata* 羽化时脱落的蝉蜕 (钟可等, 2022)、家蚕 *Bombyx mori* 幼虫蜕皮形成的蚕衣和化蛹过程中形成的蚕茧、卵壳, 以及蜜蜂的蜂巢等, 均为昆虫生长发育过程中形成的可入药产物 (杨红珍, 2023)。蜜蜂及其衍生品有多种药用形式, 包括蜂房、蜂蜜、蜂王浆、蜂毒、蜂胶、蜂蜡和蜂蛹等 (Oršolić, 2012; Ratcliffe *et al.*, 2014)。家蚕感染白僵菌死亡后所形成的白僵蚕 (姜秋等, 2023), 以及麦角菌科真菌寄生在蝙蝠蛾科昆虫幼虫上形成的僵虫和菌子实体干燥体 (冬虫夏草) 均被药用 (刘静远等, 2020)。蚕沙和化香夜蛾 *Hydrillodes repugnalis* 幼虫的虫粪“虫茶”等也被用作药用材料。五倍子蚜虫 *Melaphis chinensis* 和没食子蜂 *Cynips gallae-tinctoriae* 等形成的虫瘿同样具有药用价值 (杨红珍, 2023)。与非药用昆虫相比, 药用昆虫的肠道微生物群落更加丰富, 且两者微生物群落结构存在显著差异, 这些微生物能够产生对人类健康有益的活性成分, 具有药用价值 (Geng *et al.*, 2022)。例如, 从美洲大蠊 *Periplaneta americana* 和家蝇 *Musca domestica* 中提取的金氏拟杆菌 *Parabacteroides goldsteinii* 和婴儿芽胞杆菌 *Bacillus infantis* 具有抗炎作用。在美洲大蠊肠道中提取的放线菌菌液具有抗菌活性 (方霞等, 2016)。

2 药用昆虫的活性成分

2.1 氨基酸、短肽类及蛋白质类

昆虫的蛋白质含量丰富, 通常高于鸡肉、猪肉和牛肉等常见肉类以及植物蛋白源大豆 (Churchward-Venne *et al.*, 2017)。昆虫蛋白质含有人体必需的氨基酸, 且易于消化吸收 (de Carvalho *et al.*, 2020), 是一种优质蛋白。干燥昆虫中的蛋白质含量一般介于 25%-75% 之间

表 1 我国药用昆虫药制剂
Table 1 Common medicinal insect preparations in China

目 Order	科 Family	物种名 Species	制剂 Preparation	药品说明书 Package insert (作用与功效 Role and efficacy)
鳞翅目 Lepidoptera	蝙蝠蛾科 Hepialidae	蝙蝠蛾 (冬虫夏草) <i>Hepiaua larva</i>	百令胶囊 Corbrin capsule	补益剂, 补肺肾, 益精气。主治疾病有肺肾两虚引起的咳嗽、气喘、腰背酸痛和慢性支气管炎的辅助治疗
			虫草清肺胶囊 Chongcaoqingfei capsule	润肺补气, 清肺化痰, 止咳平喘。用于气阴两虚, 痰热阻肺所致的咳嗽痰多, 气喘胸闷; 慢性支气管炎见上述证候者
			金水宝胶囊 Jinshuibao capsule	补益肺肾, 秘精益气。用于肺肾两虚, 精气不足, 久咳虚喘, 神疲乏力, 不寐健忘, 腰膝痠软, 月经不调, 阳痿早泄; 慢性支气管炎见上述证候者
			心肝宝胶囊 Xinganbao capsule	补虚损, 益精气, 保肺益肾, 扶正固本。用于乙型慢性活动性肝炎, 肝硬化; 房性、室性早搏, 心动过速、心动过缓, 顽固性失眠症及肾病综合症、癌症辅助治疗
			蛹虫草菌粉胶囊 Yongchongcaojunfen capsule	补肺益肾、止咳化痰。用于慢性支气管炎证属肺肾气虚、肾阳不足者。症见咳嗽气喘、咯痰、自汗、恶风、易感、身寒肢冷、腰酸肢软、乏力、头昏耳鸣等
			扶正化痰片 Fuzhenghuayu tablet	活血祛瘀, 益精养肝。用于乙型肝炎肝纤维化属“瘀血阻络, 肝肾不足”证者, 症见肋下痞块, 胁肋疼痛, 面色晦暗, 或见赤缕红斑, 腰膝酸软, 疲倦乏力, 头暈目涩, 舌质暗红或有瘀斑, 苔薄或微黄, 脉弦细
			宁心宝胶囊 Ningxinba capsule	本品有提高窦性心律, 改善窦房结, 房室传导功能, 改善心脏功能的作用。用于多种心律失常, 房室传导阻滞, 难治性缓慢型心律失常, 传导阻滞
			太极升降丸 Taijishengjiang pill	祛风泄热, 化痰镇惊。用于小儿时疫, 发热抽搐, 腮肿发颐, 乳食停滞, 痰热便秘等
			天蚕片 Tiancan tablet	祛风定惊, 化痰散结。用于惊风抽搐, 咽喉肿痛, 颌下淋巴结炎, 面神经麻痹, 皮肤瘙痒
			生血宁片 Shengxuening tablet	益气补血, 生血宁片用于缺血性贫血属气血两虚证者, 症见: 面部、肌肤萎黄或苍白, 神疲乏力, 眩晕耳鸣, 心悸气短, 舌淡或胖, 脉弱等。主要用于治疗因铁摄入不足、铁需求量增加、铁吸收不良、慢性失血、手术后失血等引起的缺血性贫血
蜚蠊目 Blattaria	蜚蠊科 Blattidae	美洲大蠊 <i>Periplaneta americana</i>	康复新液 Kangfuxin liquid	通利血脉, 养阴生肌。内服: 用于淤血阻滞, 胃痛出血, 胃、胃、十二指肠溃疡; 以及阴虚肺癆, 肺结核的辅助治疗。外用: 用于金疮、外伤、溃疡、瘰管、烧伤、烫伤、褥疮之创面
			心脉隆注射液 Xinmailong injection	益气活血, 通阳利水。为慢性心衰的辅助用药。可用于改善气阳两虚, 瘀血内阻的慢性充血性心力衰竭引起的心悸、浮肿、气短、面色晦暗、口唇发绀等症状

续表 1 (Table 1 continued)

目 Order	科 Family	物种名 Species	制剂 Preparation	药品说明书 Package insert (作用与功效 Role and efficacy)
蜚蠊目 Blattaria	蜚蠊科 Blattidae	美洲大蠊 <i>Periplaneta americana</i>	肝龙胶囊 Ganlong capsule	疏肝理脾, 活血解毒。主治胁痛肝郁脾虚兼瘀血症, 症见肋肋胀痛或刺痛, 恶心嗳气, 神疲乏力、食欲不振、食后腹胀、大便秘, 舌色淡或紫, 脉象细涩或脉弦等。用于慢性乙型肝炎见上述症状者
		黑翅土白蚁 <i>Odontotermes formosanus</i>	白蚁巢胶囊 Baizichao capsule	补益肝肾, 通络止痛。用于肝肾两亏型痹症, 症见筋骨疼痛, 神疲乏力, 腰膝酸软, 头昏目眩
	鳖蠊科 Corydidae	地鳖虫 <i>Eupolyphaga sinensis</i>	大黄虻虫丸 Dahuangzhechong pill	活血破瘀, 通经消痞。用于瘀血内停, 腹部肿块, 肌肤甲错, 目眶黯黑, 潮热羸瘦, 经闭不行, 慢性乙型肝炎
			通心络胶囊 Tongxinluo capsule	益气活血, 通络止痛。用于冠心病心绞痛属心气虚乏、血瘀络阻证, 症见胸部憋闷, 刺痛、绞痛, 固定不移, 心悸自汗, 气短乏力, 舌质紫暗或有瘀斑, 脉细涩或结代。亦用于气虚血瘀络阻型中风病, 症见半身不遂或偏身麻木, 口舌歪斜, 言语不利
			鳖甲煎丸 Biejia fried pill	活血化痰, 软坚散结。适用于胁下徵块
			京万红软膏 Jingwanhong ointment	活血解毒, 消肿止痛, 去腐生肌。用于轻度水、火烫伤, 疮疡肿痛, 创面溃烂
			宫瘤清胶囊 Gongliuqing capsule	活血逐瘀, 消癥破积。用于瘀血内停所致的妇女癥瘕, 症见小腹疼痛、经色紫黯有块, 经行不爽; 子宫肌瘤见上述后者
			接骨七厘散 Jieguqili pulvis	活血化痰, 接骨止痛; 用于跌打损伤, 续筋接骨, 血瘀疼痛
			伤科接骨片 Shangkejiegupian	活血化痰, 消肿止痛, 舒筋壮骨。用于跌打损伤, 闪腰岔气, 伤筋动骨, 瘀血肿痛, 损伤红肿等症。对骨折需经复位后配合使用
			活血止痛散 Huoxuezhitong pulvis	活血散瘀, 消肿止痛。用于跌打损伤, 瘀血肿痛
			颈复康颗粒 Jingfukang granules	活血通络, 散风止痛。用于风湿瘀阻所致的颈椎病, 症见头晕、颈项僵硬、肩背酸痛、手臂麻木
			舒筋活血丸 Shujinhuoxue pill	舒筋通络, 活血止痛。用于跌打损伤, 闪腰岔气, 筋断骨折, 瘀血痛
			复方斑蝥胶囊 Fufangbanmao capsule	破血消瘀, 攻毒蚀疮。用于原发性肝癌、肺癌、直肠癌、前列腺癌、膀胱癌、恶性淋巴瘤、妇科恶性肿瘤(卵巢癌、子宫内膜癌、乳腺癌、绒毛膜癌等)、甲状腺癌、骨癌、鼻咽癌等恶性肿瘤治疗
鞘翅目 Coleoptera	芫菁科 Meloidae	南方大斑蝥 <i>Mylabris phalerata</i>		

续表 1 (Table 1 continued)

目 Order	科 Family	物种名 Species	制剂 Preparation	药品说明书 Package insert (作用与功效 Role and efficacy)
鞘翅目 Coleoptera	芫青科 Meloidae	南方大斑蝥 <i>Mylabris phalerata</i>	肝宁片 Gannin tablet	清热解暑, 利湿, 化痰散结。用于治疗各种急性慢性肝炎, 尤其对乙型肝炎患者的肝功能异常和表面抗原阳性者有显著疗效, 并可预防乙肝癌变
			艾迪注射液 Aidi injection	清热解暑, 消痰散结。用于原发性肝癌, 肺癌, 直肠癌, 恶性淋巴瘤, 妇科恶性肿瘤等
			得力生注射液 Delisheng injection	益气扶正, 消癥散结。用于中晚期原发性肝癌气虚瘀滞证, 症见右肋腹积块, 疼痛不移, 腹胀食少, 倦怠乏力等
			蜂毒注射液 Apistoxin injection	用于风湿性关节炎、类风湿性关节炎、强直性脊柱炎等风湿类疾病, 周围神经炎及神经痛等的辅助治疗
膜翅目 Hymenoptera	蜜蜂科 Apidae	中华蜜蜂 <i>Apis cerana</i>	复方蚂蚁活络胶囊 Fufangmayihuoluo capsule	舒筋活络, 祛风散寒。适用于风湿痹阻引起的关节疼痛, 肿胀, 屈伸不利的辅助治疗
		黑蚂蚁 <i>Polyrhachis vicina</i>	九味健肾胶囊 Jiuweijianshen capsule	温补肾阳。适用于肾阳虚证, 症见畏寒肢冷, 腰膝酸软, 失眠健忘, 头晕目眩及夜尿频多
	蚁科 Formicidae		蚂蚁双参通痹丸 Mayishuangcantongbi pill	补肾健脾, 祛风散寒, 活血通络, 强筋壮骨。用于脾肾两虚, 风寒痹阻, 瘀血阻络型痹症, 见有关节疼痛、肿胀、屈伸不利等症的辅助治疗
			红金消结胶囊 Hongjinxiaoie capsule	痹医: 补知凯扎诺, 且凯色士, 哈息黑。中医: 舒肝理气, 软坚散结, 活血化痰、消肿止痛, 用于气滞血瘀所致乳腺小叶增生, 子宫肌瘤, 卵巢囊肿
半翅目 Hemiptera	蝉科 Cicadidae	黑蚱蝉 (蝉蛻) <i>Cryptotympana atrata</i>	健脑补肾口服液 Jiannaobushen oral liquid	健脑补肾, 益气健脾, 安神定志。用于健忘失眠, 头晕目眩, 耳鸣心悸, 腰膝酸软, 神经衰弱
			明目上清丸 Mingmushangqing pill	清热泻火, 散风止痛。用于头痛眩晕, 目赤耳鸣, 咽喉肿痛, 口舌生疮, 牙龈肿痛, 大便秘结
			金蝉止痒胶囊 Jinchanzhiyang capsule	清热解暑, 燥湿止痒。用于湿热内蕴所引起的丘疹性荨麻疹, 夏季皮炎等皮肤瘙痒症状
			黄氏响声丸 Huangshi xiangsheng pill	疏风清热, 化痰散结, 利咽开音。用于声音嘶哑, 咽喉肿痛, 咽干灼热, 咽中有痰, 或寒热头痛, 或便秘尿赤; 急、慢性喉炎
螳螂目 Mantodea	螳螂科 Mantidae	中华大刀螂 (桑螵蛸) <i>Tenodera sinensis</i>	金嗓散结胶囊 Jinsangsanjie capsule	清热解暑, 活血化痰, 利湿化痰。用于热毒蓄结、气滞血瘀而形成的慢喉暗(声带小结、声带息肉、声带粘膜增厚)及由此而引起的声音嘶哑等症
			乌鸡白凤丸 Wujibaifeng pill	补气养血, 调经止带。用于气血两虚, 身体瘦弱, 腰膝酸软, 月经量少、后错, 带下

表 2 昆虫的入药形式
Table 2 Medicinal forms of insects

入药形式 Form of medicine	入药虫态及形态 The insect state and morphology of the drug
昆虫本身 Insects	成虫 Imago: 地鳖虫 <i>Eupolyphaga sinensis</i> , 九香虫 <i>Coridius chinensis</i> , 洋虫 <i>Ulomoides dermestoides</i> , 美洲大蠊 <i>Periplaneta americana</i> , 中华大刀螳 <i>Tenodera sinensis</i> 虫蛹 Chrysalides: 蚕蛹 <i>Silkworm chrysalides</i> 幼虫 Larvae: 大头金蝇 (五谷虫) <i>Chrysomya megacephala</i> , 黄足蚁蛉 (地牯牛) <i>Hagenomyia micans</i> , 金凤蝶 (茴香虫) <i>Papilio machaon</i> 虫卵 Insect egg: 鼎突多刺蚁卵 Egg of <i>Polyrhachis vicina</i>
昆虫分泌物 Secretions of insects	蜂蜜 Honey, 蜂毒 Bee venom, 蜂胶 Propolis, 蜂蜡 Beeswax, 蜂王浆 Royal jelly, 紫草茸 (紫胶) Shellac
昆虫生长发育的产物 The product of insect growth and development	虫茧 Insect cocoons: 蚕衣 Silk cocoon 虫巢 Insect nests: 蜂巢 Honeycomb 虫蛻 Moults: 蝉蛻 Cicada slough 卵鞘 Ootheca: 蚕蛻纸 <i>Silkworm egg sheet</i> , 桑螵蛸 <i>Mantis egg-case</i>
昆虫的排泄物 The excrement of insects	蚕沙 <i>Silkworm guano</i> , 虫茶 <i>Insect tea</i>
昆虫病理产物 Insect pathological products	僵蚕 <i>Bombyx batryticatus</i> , 冬虫夏草 <i>Chinese caterpillar fungus</i>
虫瘿 Insect gall	五倍子蚜虫 <i>Melaphis chinensis</i> , 没食子蜂 <i>Cynips gallae-tinctoriae</i>

(Oonincx and Finke, 2021), 等翅目和鞘翅目昆虫的蛋白质含量约占 40%, 蜚蠊目和直翅目昆虫的蛋白质含量约占 60% (Churchward-Venne *et al.*, 2017)。昆虫干燥品不仅富含人体所需的各种氨基酸, 还含有丰富的抗菌肽、多种维生素和矿物质 (Eleftherianos *et al.*, 2021), 具有补充能量、提高免疫力、抗菌消炎、抗风湿、保健、抗高血糖、抗高血压和抗癌等作用, 在食品、医药、保健品和饲料等领域均有较多应用。例如, 黄粉虫 *Tenebrio molitor* 粉, 对高脂血症肥胖大鼠降脂效果显著 (Gessner *et al.*, 2019)。蚕蛹和黑菌虫 *Alphitobius diaperinus* 也富含蛋白质, 尤其是亮氨酸, 有助于增强力量和改善肌肉质量 (Vangsoe *et al.*, 2018), 可作为运动后补充剂 (Nowakowski *et al.*, 2022)。

昆虫抗菌肽 (Antimicrobial peptides, AMPs) 是昆虫受到外界刺激时, 通过免疫应答反应在体内诱导产生的具有抗菌活性的阳离子短肽类物质 (柳傲和杨中侠, 2018)。根据其结构或独特

序列, 昆虫 AMPs 分为 4 个家族: (1) α -螺旋肽 (天蚕素 Cecropins 和家蚕抗菌肽 Moricin); (2) 富含半胱氨酸的肽 (防御素 Defensin 和果蝇抗真菌肽 Drosomycin); (3) 富含脯氨酸的肽 (蜜蜂抗菌肽 Apidaecin、果蝇抗菌肽 Drosocin 和斜纹夜蛾 *Spodoptera litura* 抗菌肽 Lebocin); (4) 富含甘氨酸的肽 (樗蚕素 Attacin 和葛佬素 Glovirin) (Yi *et al.*, 2014)。自 1980 年首次在惜古比天蚕 *Hyalophora cecropia* 中发现抗菌肽-天蚕素以来, 对昆虫抗菌肽的研究逐渐深入 (Yi *et al.*, 2014)。昆虫抗菌肽在抗菌、抗癌等方面应用广泛, 具有调节免疫和促进伤口愈合等作用 (Wu *et al.*, 2018; Jin and Weinberg, 2019)。抗菌肽对革兰氏阳性和革兰氏阴性细菌、病毒、古细菌、真菌和寄生虫等均有活性 (Wu *et al.*, 2018)。例如, Attacin 和 Leboins 对革兰氏阳性和阴性菌都有活性 (Li *et al.*, 2012; Yi *et al.*, 2014), Defensin 主要对革兰氏阳性菌具有活性 (Yi *et al.*, 2014)。Drosocin 对铜绿假单胞菌

Pseudomonas aeruginosa 有抗菌活性 (Wu *et al.*, 2018)。Cecropins 对恶性肿瘤有溶解和抗增殖活性 (Răileanu and Bacalum, 2023), Cecropins A 和 Cecropins B 以剂量依赖性方式抑制膀胱癌细胞增殖和活性, 具有很好的细胞选择性和抗增殖效果 (Suttman *et al.*, 2008)。

抗菌肽具有双重作用模式, 可通过刺激趋化性、调节 Toll 样受依赖性的炎症反应和启动适应性免疫来提高宿主免疫力 (Mahlapuu *et al.*, 2016), 还可通过破坏细菌细胞膜的完整性, 或与细胞内的核酸、蛋白质、酶、细胞壁和细胞器等发生相互作用, 直接杀死病原微生物 (Corrêa *et al.*, 2019)。抗菌肽的作用靶点并不单一, 具有多个靶点, 即使一个靶点失效, 其他靶点仍然可以继续发挥作用 (Nuti *et al.*, 2017)。此外, 抗菌肽具有两亲性, 可以与细菌细胞膜相互作用, 破坏细菌细胞膜, 其机制多样, 包括桶板模型、地毯模型、离子通道模型、洗涤剂模型和环形孔模型等模型 (Li *et al.*, 2021; Dho *et al.*, 2023)。抗菌肽因其独特的抗菌机制和复杂的抗菌作用被认为是抗生素的替代品, 为应对多重耐药菌开辟了新的应用前景 (Xuan *et al.*, 2023), 但由于抗菌肽存在溶血作用、毒性、不稳定性和半衰期短等问题, 导致其应用受限。因此, 需要进一步深入研究并加以改良, 以降低其毒性 (Wei and Zhang, 2022)。

昆虫蛋白质有着极大的用途, 但在应用昆虫蛋白质时也存在致敏风险。家蟋 *Acheta domesticus* (De Marchi *et al.*, 2021)、家蚕、黄粉虫、豌豆象 *Bruchus pisorum*、中华蛭蟥 *Acrida cinerea* 和蜜蜂的蛋白质均有人类食用过敏的记录 (de Gier and Verhoeckx, 2018), 如家蚕和黄粉虫中发现的精氨酸激酶等致敏成分 (Broekman *et al.*, 2017; de Gier and Verhoeckx, 2018)。

2.2 生物碱类

昆虫中常见的生物碱有胺类、咪唑类 (组胺和尿囊素) 及嘌呤等, 其中大多以毒素的形式存在于昆虫的分泌物 (粘液) 和身体中, 具有抗菌、抗癌、抗炎、抗病毒、抗血小板聚集、抗心律失常和抗高血压等作用 (Cushnie *et al.*, 2014)。研

究发现昆虫体内的部分生物碱可以由氨基酸转化而来, 这使得昆虫生物碱作为先导化合物具有巨大的应用潜力, 成为近年来的研究热点。从美洲大蠊脱脂产物的正己烷提取物中鉴定出多种生物碱 (吡咯、哌啶和哌嗪等, 约占总质量的 6.55%), 进一步分离出的 3,4-二氢-2-喹啉酮 (蒋文贤等, 2015) 是 c-AMP-特异性酶的抑制剂, 能够有效抑制血小板聚集和血栓形成, 同时增强心肌收缩力和扩张血管 (Wu and Piao, 2013)。从地鳖虫中提取的吡嗪类生物碱, 临床应用于抗血小板聚集、扩张小动脉、改善微循环和脑血流等 (马贺, 2017)。冬虫夏草和蛹虫草 *Cordyceps militaris* 中提取的嘌呤类生物碱虫草素, 可以通过激活 A3 腺苷受体诱导肿瘤细胞凋亡、阻滞细胞周期、抑制血小板聚集, 以及抑制基质金属蛋白酶, 从而减缓癌细胞的侵袭和转移 (Nakamura *et al.*, 2015; Cao *et al.*, 2017), 还可以通过抑制 c-Jun N 端激酶 (c-JunN-terminalkinase, JNK)、丝裂原活化蛋白激酶 (Mitogen-activated protein kinase, MAPK)、AMP 依赖的蛋白激酶 (Adenosine 5'-monophosphate (AMP)-activated protein kinase, AMPK)、磷酸肌醇 3 激酶 (Phosphatidylinositol 3-kinase, PI3K/Akt) 和细胞外信号调节激酶 (Extracellular regulated protein kinases, ERK) 等激酶的活性, 控制或延缓肿瘤生长 (Khan and Tania, 2023)。此外, 虫草素也能通过激活 AMPK 信号通路, 降低脂肪和甘油三酯的累积及炎症细胞浸润, 改善肝脏脂肪变性、炎症、肝损伤和纤维化, 保护代谢应激下的小鼠肝脏组织 (Lan *et al.*, 2021)。蚂蚁中的生物碱可以杀死各种微生物, 从火蚁属中分离的哌啶类物质可以杀死真菌、革兰氏阳性和阴性细菌; 从小家蚁属毒液中提取出的吡咯烷对革兰氏阳性和阴性细菌有抑制作用; 收获蚁属用于巢穴消毒的假木贼碱也有类似的抗生素活性 (Fox and Adams, 2022)。

2.3 甾类物质

甾类物质主要存在于昆虫的性激素和蜕皮激素等激素中 (雷琼, 2011)。关于昆虫激素的研究主要集中在激素对昆虫生长发育的作用和

影响上,同时这些研究也为害虫防治提供了新思路。然而,在药理作用领域,相关研究相对较少。蜕皮类固醇是甾醇类物质,可以促进哺乳动物的生长发育,通过刺激蛋白质的合成促进肌肉生成,同时还具有促进细胞增殖分化,降血糖和胆固醇等作用(Lafont and Dinan, 2003)。蚕蛹水提物可能含有雌激素,能够增加卵巢切除大鼠的子宫重量和雌二醇含量,有助于预防和治疗由女性性激素缺乏引起的更年期症状(Yang *et al.*, 2010)。

2.4 脂类

脂类物质在能量代谢和生命活动过程中起着至关重要的作用。其中,必需脂肪酸人体无法合成,只能靠食物获取(Das, 2006)。药用昆虫脂质成分的药用价值主要体现在饱和脂肪酸、单不饱和脂肪酸和多不饱和脂肪酸类,如油酸、棕榈酸、亚油酸和硬脂酸等(Kolobe *et al.*, 2023)。所有可食用昆虫中亚油酸的含量均超过了人类和家禽所需的最低水平, α -亚麻酸等 n-3 脂肪酸在蝗虫体内的积累量高于向日葵、橄榄和大豆等常见植物油(Fombong *et al.*, 2021; Kolobe *et al.*, 2023)。作为功能性食品,食用昆虫能够提供人体所需的必需脂肪酸,有助于降低血压、治疗炎症、提高免疫力以及预防心血管疾病(Sales-Campos *et al.*, 2013)。蚕蛹富含 n-3 和 n-6 必需脂肪酸,对糖尿病和心血管疾病的治疗至关重要,具有改善胰岛素敏感性、降低血压、预防血栓和动脉硬化形成、抗炎和抗心律失常,以及改善血管内皮功能的作用(Hăbeanu *et al.*, 2023)。洋虫的脂肪酸也具有降血糖的作用(Jasso-Villagomez *et al.*, 2018)。

2.5 黄酮类

黄酮类化合物是一类多酚类次生代谢物,广泛分布于各种生物资源中,普遍具有抗氧化和抗炎作用。黄酮类化合物不仅参与昆虫身体最终颜色的形成,而且有助于昆虫抵抗细菌。由于昆虫生长繁殖速度快,其体内的黄酮类化合物积累也相对迅速,这一特点使其在黄酮类物质的积累上区别于植物,具有明显的优势。在人体中,黄酮

类化合物可以清除体内自由基,具有抗脂质过氧化的作用,并能促进胰岛素分泌,降低糖尿病患者的血糖水平,预防并发症。因此,黄酮类化合物是一种理想的先导化合物,具有很大的开发潜力(Liang *et al.*, 2022)。

美洲大蠊中黄酮类化合物的含量为 16.0-19.7 mg/g,高于稻蝗 *Oxya chinensis* (3.79-18.6 mg/g) 和南方大斑蝥 *Mylabris phalerata* (4.12-18.5 mg/g) (Liang *et al.*, 2022)。在美洲大蠊的 70% 甲醇提取物中发现了 2 种异黄酮,其中 12-(16-羟基,17,18-二甲基)-易戊基-13-氧代(19,20-二甲基)-pyro 环氧己烯基- Δ 11,12-(4'-甲氧基)-苯基-5-羟基异黄酮是一种对革兰氏阳性菌枯草芽孢杆菌 *Bacillus subtilis* 具有抗菌活性的新化合物;另一种 5,7-二羟基-40-羟基苯基异黄酮常见于豆类,具有雌激素样功效(尹卫平等, 2012),与冬虫夏草中的异黄酮作用类似,属于“植物雌激素”类,具有显著的雌激素活性,对卵巢摘除模型大鼠具有显著的雌激素作用,可以预防和改善雌激素缺乏引起的骨质流失(Zhang *et al.*, 2014a)。蚕蛹和蜂胶中分离的黄酮类化合物显示出显著的抗氧化能力(Kocot *et al.*, 2018; Yeruva *et al.*, 2023),蚕蛹中的黄酮类化合物主要是木犀草素,具有抗肿瘤和抗炎等特性,通过增加一氧化氮(NO)的产生,改善血管系统和提高胰岛素敏感性(Yeruva *et al.*, 2023)。此外,蜂蜜中还含有其他酚类化合物,如类黄酮类、酚酸、香豆素和单宁,这些多酚类化合物可以抑制细胞周期、抑制细胞生长和增殖,对白血病癌细胞的凋亡起诱导作用,具有治疗白血病的潜力(Abubakar *et al.*, 2012)。

2.6 多糖及核苷类

多糖是由糖苷键连接的 10 个或更多的单糖组成的多羟基大分子(Luo *et al.*, 2021),是自然界(尤其是药用昆虫)中必需的一种生物聚合物,与蛋白质和核酸并列,在多种生命活动中起着重要作用。多糖的结构和性质极其复杂多样,具有多种重要的生理功能,如抗肿瘤和免疫调节,因此在药物化学和药剂学领域受到越来越多的关注(Hou *et al.*, 2020)。动物多糖主要包括

几丁质、壳聚糖、糖元以及蛋白聚糖和脂多糖等多糖复合物 (Mohan *et al.*, 2020)。从双斑蟋蟀 *Gryllus bimaculatus* 中分离出的糖胺聚糖具有抗炎作用,可以降低脂多糖处理后 RAW264.7 巨噬细胞中的前列腺素 E2 (Prostaglandin E2, PGE-2) 水平,并抑制紫外线诱导的人永生化角质形成细胞 (HaCaT 细胞) 中核因子 κ B (Nuclear factor κ -B, NF- κ B) 活性及肿瘤坏死因子- α (Tumor necrosis factor- α , TNF- α) 的分泌 (Ahn *et al.*, 2014)。地鳖虫的多糖可以提高血清中干扰素- β (Interferon- β , IFN- β)、TNF- α 和白介素-6 (Interleukin-6, IL-6) 的水平,增强人体的先天免疫力,抑制乙型肝炎病毒 (Zhang *et al.*, 2022),具有抑制肿瘤活性的作用 (Xie *et al.*, 2020)。由蝉蜕、蜜蜂、蝇蛆和蚕蛹等昆虫体壁中富含的甲壳素衍生而来的壳聚糖,也称为氨基多糖 (李彦艳等, 2015),具有良好的生物相容性和生物降解性,能够促进伤口愈合和抗菌,是良好的伤口敷料 (Matica *et al.*, 2019)。美洲大蠊提取的低聚糖通过调节 Th1/Th2 细胞、减少氧化应激、保持肠道屏障完整性和抑制 TLR4/MAPK/NF- κ B 通路,表现出抗炎活性,调节急性结肠炎小鼠模型的肠道微生物群 (Lu *et al.*, 2021)。冬虫夏草的多糖通过增加结肠长度、减轻结肠组织损伤和抑制 NF- κ B 通路活化等方式显著缓解结肠炎 (Chen *et al.*, 2023)。

核苷是生物体的基本成分,常用作主要的抗病毒和抗肿瘤治疗药物。目前对核苷类药物的研究主要集中在碱基和糖基的结构修饰上,以获得具有不同活性的药物 (Li *et al.*, 2004)。动物和植物中存在的天然核苷一般可分为嘧啶核苷和嘌呤核苷 (Yamamoto *et al.*, 1997)。美洲大蠊提取物“康复新液”含有次黄嘌呤、三甘碱、尿嘧啶、腺苷和肌苷 (吴红梅等, 2013),中药制剂“心脉隆注射液”的主要活性成分也是由核苷类化合物组成。

2.7 萜类

萜类化合物是天然产物中最大的类群,结构多样,活性广泛,具有重要的药用和经济价值。斑蝥素 ($C_{10}H_{12}O_4$), 2,3-二甲基-7-氧杂-双环

[2.2.1]庚烷-2,3-二羧酸酐,是一种单萜类化合物,主要作为斑蝥体内的防卫性物质,属于单萜烯毒素,主要来源于芫青科南方大斑蝥或黄黑小斑蝥 *Mylabris cichorii*。斑蝥素通过抑制蛋白质与核酸的合成抑制肿瘤,同时还能够增强机体免疫力,因此被认为是一种极为有效的抗癌药物,但因其具有较强的毒性,临床使用受到限制。

斑蝥素是选择性蛋白磷酸酶 2A (Protein phosphatase 2A, PP2A) 和热休克转录因子-1 (Heat shock proteins 1, HSF-1) 的抑制剂 (Naz *et al.*, 2020),可以有效抑制血管平滑肌细胞的增殖和迁移 (Qiu *et al.*, 2019)。此外,斑蝥素还可以通过多种机制对抗肿瘤,包括:(1)通过抑制 PI3K-AKT-mTOR 信号通路抑制肿瘤细胞的生长和迁移 (Liu *et al.*, 2018; Song *et al.*, 2020);(2)通过降低细胞周期蛋白 E、周期蛋白依赖性蛋白激酶-6 (Cyclin-dependent kinases 6, CDK-6) 和细胞周期蛋白 D 的蛋白水平调节细胞周期,同时增加细胞凋亡死亡受体 DR4、DR5 和 TRAIL 的蛋白水平,诱导癌细胞凋亡 (Li *et al.*, 2017a);(3)通过抑制 Jak/Stat 通路,活化 NF- κ B,增强免疫应答来抵抗肿瘤 (Li *et al.*, 2023)。斑蝥素在肿瘤治疗中有着重要的作用,但其强烈的毒性和副作用使其临床应用受到限制。目前,临床应用最多的是其衍生物,衍生物的毒性显著降低,药性更加温和,并且选择性更广泛。例如,去甲斑蝥素、甲基斑蝥素胺和斑蝥素镁等衍生物展现出更好的药用前景 (李济森等, 2019)。

3 药用昆虫的药理作用及其临床应用

传统中医认为药用昆虫具有攻坚破积、消痈散结、活血祛瘀、息风定惊、宣风泻热、搜风解毒、行气和血、壮阳益肾、收敛生肌和补益培本等多种功效 (杨红珍, 2023)。随着现代医学研究的发展,药用昆虫的药理作用在传统中医理论的基础上得到了深入的探索和拓展,这些研究不仅阐明了药用昆虫的作用机理,还扩大了其临床应用,揭示了新的疗效,从而拓宽了药用昆虫在

现代医学中的应用范围和深度 (Zhang *et al.*, 2023)。目前对斑蝥、美洲大蠊、冬虫夏草、家蚕和中华蜜蜂 *Apis cerana cerana* 等昆虫研究较多, 其活性成分在抗恶性肿瘤、抗菌消炎、心血管疾病、骨关节疾病、代谢性疾病、保护创面和抗衰老等方面具有独特的疗效 (表 3)。

3.1 抗恶性肿瘤

药用昆虫活性成分对抗肿瘤细胞的机制包括, 抑制肿瘤细胞粘附、抑制细胞迁移和侵袭、引发细胞周期阻滞和诱导凋亡 (Naz *et al.*, 2020; Malek *et al.*, 2023)。如斑蝥素能诱导人三阴性乳腺癌细胞系 (Triple-negative breast cancer, TNBC) 细胞在体内外发生凋亡, 并通过抑制 *Beclin-1* 基因的表达而抑制三阴性乳腺癌 (Li *et al.*, 2017b)。此外, 斑蝥素可通过诱导肿瘤细胞凋亡治疗皮肤癌 (Li *et al.*, 2017a) 和口腔鳞状细胞癌 (Su *et al.*, 2016); 通过增强 T 细胞的增殖浸润和细胞因子生成来抑制人小细胞肺癌 (Zhang *et al.*, 2017); 通过抑制 PI3K/Akt 信号传导抑制胃癌细胞的生长、迁移和侵袭 (Song *et al.*, 2020)。美洲大蠊提取物“康复新液”通过抑制 MAPK/ERK 信号通路诱导胃癌细胞凋亡 (Ma *et al.*, 2018)。异香豆素对人肝癌细胞 (HepG2) 和人乳腺癌细胞 (MCF-7) 细胞具有显著的细胞毒活性 (Luo *et al.*, 2014)。蜂毒可以阻滞细胞周期, 抑制癌细胞增殖和迁移, 用于治疗肝细胞癌 (Mansour *et al.*, 2021) 和宫颈癌 (Kim *et al.*, 2020), 以及预防胰腺癌 (Zhao *et al.*, 2022)。蜂毒肽通过哺乳动物雷帕霉素靶点 (Mammalian target of rapamycin, mTOR) 信号通路诱导自噬以导致人肺癌细胞凋亡 (Yu *et al.*, 2022)。地鳖虫提取的多糖通过增强体外淋巴细胞的活性 (自然杀伤 NK 细胞) 促进淋巴细胞增殖, 抑制肝癌细胞生长, 并增加小鼠脾脏和胸腺指数, 显著刺激小鼠体内免疫 (Xie *et al.*, 2020)。蚕蛹蛋白通过干扰癌症细胞的分裂周期和诱导凋亡因子的产生促进细胞凋亡, 对人类胃癌细胞、乳腺癌细胞和肝癌细胞具有细胞毒性, 从而发挥抗癌作用 (Zhou *et al.*, 2022)。

3.2 抗炎、抗菌、抗病毒和抗寄生虫

药用昆虫的活性成分可以起到对抗炎症的作用, 如双斑大蟋 *Gryllus bimaculatus* 水提物能抑制肝脏和小肠中活性氧介导的氧化应激反应, 从而减轻酒精诱导的肝脏脂肪变性和细胞凋亡反应, 并降低肠道对细菌内毒素的通透性, 以保护肝脏和小肠 (Hwang *et al.*, 2019)。三开蛻螂 *Copris tripartitus* 中提取的多肽 CopA3, 能够增强上皮屏障和诱导结肠上皮细胞增殖, 与表皮生长因子相似。该多肽抑制艰难梭菌毒素 A (*Clostridium difficile* toxin A, TcdA) 诱导的急性小鼠肠炎及葡聚糖硫酸钠诱导的慢性小鼠结肠炎 (Kim *et al.*, 2016)。家蚕的血细胞提取物可以抑制由脂多糖诱导的人单核细胞白血病细胞、细胞因子和诱导型一氧化氮合酶 (Inducible nitric oxide synthase, iNOS) 的表达, 还可通过抑制 NF- κ B 的活化发挥抗炎作用 (Kim *et al.*, 2017b)。

在临床上, 药用昆虫的抗菌、抗病毒作用主要依赖于所含的抗菌肽、不饱和脂肪酸 (王奎等, 2013)、蛋白质 (凝集素和溶菌酶) (Huang *et al.*, 2021; Tamilarasan *et al.*, 2021) 和体内微生物 (Long *et al.*, 2022)。抗菌肽在临床上主要用于治疗耐甲氧西林金黄色葡萄球菌 (Methicillin-resistant *Staphylococcus aureus*, MRSA)、艰难梭菌感染、口腔念珠菌病、皮肤脓疱病、糖尿病足溃疡和感染、败血症和龋齿等疾病 (Nuti *et al.*, 2017)。丽蝇科铜绿蝇 *Lucilia cuprina* 的排泄/分泌物被证实可以抑制裂谷热病毒和柯萨奇 B4 病毒 (Abdel-Samad, 2019)。

此外, 一些昆虫的分泌物能抑制原生动物或线虫的活性。丽蝇科丝光绿蝇 *Lucilia sericata* 的排泄/分泌物在体内和体外等不同条件下均显示出对利什曼原虫的毒性作用。这些排泄/分泌物通过分泌多种酶 (如蛋白酶和核酸酶)、抗菌肽和小活性分子促进伤口愈合, 有效治疗利什曼原虫寄生引起的皮损 (Sherafati *et al.*, 2022)。黑腹果蝇 *Drosophila melanogaster* 的抗菌肽 Mtk-1 和 Mtk-2 能显著抑制恶性疟原虫的生长 (Tonk *et al.*, 2019)。

表 3 常见药用昆虫的作用与功效
Table 3 The action and efficacy of common medicinal insects

目 Order	科 Family	物种名 Species	活性成分 Active constituent	作用机制 Mode of action	功效 Efficacy
鞘翅目 Coleoptera	芫青科 Meloidae	斑蝥 <i>Mylabris phalerata</i>	斑蝥素 Cantharidin	抑制肿瘤细胞侵袭和转移、诱导细胞凋亡、调节细胞周期和增强免疫力; 抑制血管平滑肌异常增殖	治疗三阴性乳腺癌 (Li <i>et al.</i> , 2017b)、皮肤癌 (Li <i>et al.</i> , 2017a) 等多种癌症 (Naz <i>et al.</i> , 2020) ; 抑制血管成形术后新生内膜增生和再狭窄 (Qiu <i>et al.</i> , 2019)
				Inhibit tumor cell invasion and metastasis, induce cell apoptosis, regulate the cell cycle, and enhance immunity; Inhibit abnormal proliferation of vascular smooth muscle	Treatment of triple-negative breast cancer (Li <i>et al.</i> , 2017b), skin cancer (Li <i>et al.</i> , 2017a) and so on a variety of cancers; Inhibiting neointimal hyperplasia and restenosis after vascular intervention (Qiu <i>et al.</i> , 2019)
	金龟甲科 Scarabaeoidea	蛻螂 <i>Catharsius molossus</i>	糖胺聚糖 Glycosaminoglycan	降低炎症因子水平，恢复循环系统中的稳态	抗炎、抗衰老作用 (Ahn <i>et al.</i> , 2017)
				Reduce the levels of inflammatory cytokines and restore homeostasis in the circulatory system	Anti-inflammatory and anti-aging effects (Ahn <i>et al.</i> , 2017)
		三开蛻螂 <i>Copris tripartitus</i>	多肽 CopA3 Polypeptide CopA3	促进表皮生长	治疗结肠炎 (Kim <i>et al.</i> , 2016)
				Promote epidermal growth	Treating colitis (Kim <i>et al.</i> , 2016)
拟步甲科 Coleoptera		洋虫 <i>Ulomoides dermestoides</i>	不饱和脂肪酸和超氧化物歧化酶	清除自由基，提高大鼠体内超氧化物歧化酶水平	抗衰老 (王雷, 2006)，降血糖 (Jasso-Villagomez <i>et al.</i> , 2018)
				Scavenging free radicals and increasing the level of superoxide dismutase in rats	Anti-aging (王雷, 2006), and reduce blood sugar level (Jasso-Villagomez <i>et al.</i> , 2018)
		黄粉虫 <i>Tenebrio molitor</i>	蛋白质 Protein	降低甘油三酯和胆固醇	降血脂 (Gessner <i>et al.</i> , 2019)
				Lowering triglycerides and cholesterol	Reduce blood lipid (Gessner <i>et al.</i> , 2019)
		美洲大蠊 <i>Periplaneta americana</i>	异香豆素 Isocoumarin	尚不明确	对人肝癌细胞和人乳腺癌细胞有毒性 (Luo <i>et al.</i> , 2014)
				Not yet clear	et al., 2014)
蜚蠊目 Blattaria	蜚蠊科 Blattidae				Toxic to human HepG2 cells and MCF-7 cells (Luo <i>et al.</i> , 2014)
					保护心血管，治疗充血性心力衰竭 (Zhang <i>et al.</i> , 2024)
			N-乙酰多巴胺低聚物 N-Acetyldopamine oligomers	抗炎和扩张血管，改善心功能	Protecting the cardiovascular system, and treating congestive heart failure (Zhang <i>et al.</i> , 2024)
				Anti-inflammatory and vasodilation, and improving heart function	2024
					Protecting the cardiovascular system, and treating congestive heart failure (Zhang <i>et al.</i> , 2024)

续表 3 (Table 3 continued)

目 Order	科 Family	物种名 Species	活性成分 Active constituent	作用机制 Mode of action	功效 Efficacy
蜚蠊目 Blattaria	蜚蠊科 Blattidae	美洲大蠊 <i>Periplaneta americana</i>	氨基酸类、多元醇类、核苷类、肽类等物质 (康复新液)	抑制 MAPK/ERK/ERK 信号通路, 诱导细胞凋亡, 抑制 TGF- β 1、NF- κ B 和 α -SMA 表达	促进黏膜修复, 抗炎 (Li <i>et al.</i> , 2018), 治疗胃癌 (Ma <i>et al.</i> , 2018)
			Amino acids, polyols, nucleosides, peptides and other substances (Kangfluxin solution)	Inhibiting the MAPK/ERK/ERK signaling pathway, inducing apoptosis, and suppressing the expression of TGF- β 1, NF- κ B, and α -SMA	Promoting mucosal repair, anti-inflammatory (Li <i>et al.</i> , 2018), and treatment of gastric cancer (Ma <i>et al.</i> , 2018)
			生物碱	抑制 c-AMP-特异性酶活性	增强心肌收缩力和扩张血管 (Wu and Piao, 2013)
			Alkaloid	Inhibiting c-AMP-specific enzyme activity	2013)
			异黄酮	抗菌机制尚不明确, 调节雌激素水平	Enhancing cardiac contractility and dilating blood vessels (Wu and Piao, 2013)
			Isoflavone	Antibacterial mechanism is still unclear, and regulating estrogen levels	抗菌 (Liang <i>et al.</i> , 2022), 雌激素样功效 (尹卫平等, 2012)
			低聚糖	免疫调节	Antibacterial (Liang <i>et al.</i> , 2022) and estrogen-like effects (尹卫平等, 2012)
			Oligosaccharide	免疫调节	抗炎 (Lu <i>et al.</i> , 2021)
			吡嗪类生物碱	免疫调节	Anti-inflammatory (Lu <i>et al.</i> , 2021)
			Pyrazine alkaloids	抗血小板聚集、扩张小动脉	保护心脑血管 (马贺, 2017)
膜翅目 Hymenoptera	蜜蜂科 Apidae	中华蜜蜂 <i>Apis cerana</i>	多糖	Anti-platelet aggregation and small artery dilation	Protecting the cardiovascular and cerebrovascular system (马贺, 2017)
			Polysaccharide	强体外淋巴细胞活性, 增强人体先天免疫	抗乙型肝炎病毒 (Zhang <i>et al.</i> , 2022), 抑制肝癌细胞生长 (Xie <i>et al.</i> , 2020)
			活性肽 DP-17、AR-9	Enhancing lymphocyte activity in vitro and boosting innate immunity in the human body	Anti-hepatitis B virus (Zhang <i>et al.</i> , 2022), inhibiting the growth of hepatocellular carcinoma cells (Xie <i>et al.</i> , 2020)
			Bioactive peptide DP-17, AR-9	激活 AMPK/mTOR 信号通路, 调节肠道菌群	降血脂 (姜珊等, 2020; Wang <i>et al.</i> , 2022a)
			酚类化合物	Activating the AMPK/mTOR signaling pathway and regulating the gut microbiota	Lowering blood lipids (姜珊等, 2020; Wang <i>et al.</i> , 2022a)
			Phenolic compounds	抑制细胞周期、抑制细胞生长和增殖	2022a)
				Inhibiting cell cycle progression, and suppressing cell growth and proliferation	治疗白血病 (Abubakar <i>et al.</i> , 2012)
					Treatment of leukemia (Abubakar <i>et al.</i> , 2012)

续表 3 (Table 3 continued)

目 Order	科 Family	物种名 Species	活性成分 Active constituent	作用机制 Mode of action	功效 Efficacy
膜翅目 Hymenoptera	蜜蜂科 Apidae	中华蜜蜂 <i>Apis cerana</i>	蜂毒 Bee venom	阻滞细胞周期, 抑制癌细胞增殖和迁移, 诱导细胞凋亡; 抑制炎症因子 Blocking the cell cycle, inhibiting cancer cell proliferation and migration, and inducing apoptosis; Inhibiting inflammatory factors	治疗肝癌细胞癌 (Mansour <i>et al.</i> , 2021)、宫颈癌 (Kim <i>et al.</i> , 2020) 和肺癌 (Yu <i>et al.</i> , 2022); 预 防胰腺癌 (Zhao <i>et al.</i> , 2022); 治疗风湿性疾病 (Jagua- Gualdrón <i>et al.</i> , 2020) Treatment of hepatocellular carcinoma (Mansour <i>et al.</i> , 2021), cervical cancer (Kim <i>et al.</i> , 2020), and lung cancer (Yu <i>et al.</i> , 2022); Preventing pancreatic cancer (Zhao <i>et al.</i> , 2022); Treating rheumatic diseases (Jagua- Gualdrón <i>et al.</i> , 2020)
			蜂蜜 Honey	加速皮肤修复, 降低感染风险; 阻滞细胞 周期、诱导细胞凋亡 Accelerate skin repair, and reduce the risk of infection; Arrest the cell cycle, and induce apoptosis	促进伤口愈合 (Scepankova <i>et al.</i> , 2021); 降低 HCT-116 细胞活性 (Afrin <i>et al.</i> , 2018) Promoting wound healing (Scepankova <i>et al.</i> , 2021); Reduce the activity of HCT-116 cells (Afrin <i>et al.</i> , 2018)
			蜂胶 Propolis	抗炎促进表皮生长 Anti-inflammatory and promotion of epidermal growth	抗溃疡 (Zulkiflee <i>et al.</i> , 2022) Anti-ulcer (Zulkiflee <i>et al.</i> , 2022)
			蜂王浆 Royal jelly	增加抗氧化酶活性 Increasing levels of antioxidant enzymes	抗衰老 (Qiu <i>et al.</i> , 2020) Anti-aging (Qiu <i>et al.</i> , 2020)
鳞翅目 Lepidoptera	蛾科 Formicidae	双齿多刺蚁 <i>Polyrhachis dives</i>	吡啶类生物碱 Pyridine alkaloids	抗炎, 保护基底膜 Anti-inflammatory and protective of the basement membrane	治疗糖尿病肾病 (Tang <i>et al.</i> , 2015) Treatment of diabetic nephropathy (Tang <i>et al.</i> , 2015)
		家蚕 (僵蚕) <i>Bombyx mori</i>	蛋白质 Protein	补充蛋白质, 改善肌肉质量; 促进细胞凋 亡; 抑制血管紧张素转化酶活性 Supplementing protein to improve muscle mass; Promoting apoptosis; Inhibiting the activity of angiotensin-converting enzyme	运动后补充剂 (Nowakowski <i>et al.</i> , 2022); 治疗 癌症 (Zhou <i>et al.</i> , 2022); 降压 (Wang <i>et al.</i> , 2014) Post-exercise supplement (Nowakowski <i>et al.</i> , 2022); Treatment for cancer (Zhou <i>et al.</i> , 2022); Reduce blood press (Wang <i>et al.</i> , 2014)
			雌激素 Estrogen	补充雌激素 Supplementing estrogen	预防和治疗更年期症状 (Yang <i>et al.</i> , 2010) Prevention and treatment of menopause symptoms (Yang <i>et al.</i> , 2010)

续表 3 (Table 3 continued)

目 Order	科 Family	物种名 Species	活性成分 Active constituent	作用机制 Mode of action	功效 Efficacy
鳞翅目 Lepidoptera	蚕蛾科 Bombycidae	家蚕 (僵蚕) <i>Bombyx mori</i>	脂肪酸 Fatty acid	改善胰岛素敏感性, 降压抗血栓 Improving insulin sensitivity, reducing blood pressure, and anti-thrombotic effects	糖尿病, 保护心脑血管 (Håbeanu <i>et al.</i> , 2023) Treatment of diabetes and protection of cardiovascular and cerebrovascular health (Håbeanu <i>et al.</i> , 2023)
			黄酮类化合物 Flavonoids compounds	增加 NO 的产生 Increase the production of nitric oxide	抗氧化, 改善血管系统 (Yeruva <i>et al.</i> , 2023) Antioxidant, and improving the vascular system (Yeruva <i>et al.</i> , 2023)
			血细胞提取物 Hemocyte extract	抑制 NF- κ B 信号通路 Inhibiting the NF- κ B signaling pathway	抗炎 (Kim <i>et al.</i> , 2017b) Anti-inflammatory (Kim <i>et al.</i> , 2017b)
			1-DNJ、槲皮素、胰岛素样肽 1-DNJ, quercetin and insulin-like peptides	降低血糖 Lowering blood sugar	治疗糖尿病肾病 (Miyazaki <i>et al.</i> , 2017) 及辅助治疗糖尿病肾病 (Zhang <i>et al.</i> , 2016) Treatment of diabetic nephropathy (Miyazaki <i>et al.</i> , 2017) and adjuvant treatment of diabetic nephropathy (Zhang <i>et al.</i> , 2016)
		蚕茧 Silkworm cocoon		调控糖脂代谢; 增加胶原蛋白和吸水 Regulating sugar and lipid metabolism; Increasing collagen and water retention	降低胆固醇和血糖 (Singh <i>et al.</i> , 2002); 促进创面愈合 (Lehmann <i>et al.</i> , 2022) Reduce cholesterol and blood sugar (Singh <i>et al.</i> , 2002); Promote wound healing (Lehmann <i>et al.</i> , 2022)
		蝙蝠蛾 (冬虫夏草) 虫草素 <i>Cordyceps sinensis</i> Cordycepin		激活 A3 腺苷受体, 抑制 JNK、MAPK 等激酶活性; 减少前列腺素 1 和 NO; 抑制中性粒细胞浸润, 保护血脑屏障 Activating A3 adenosine receptors, and inhibiting the activity of kinases such as JNK and MAPK; Reducing prostaglandin 1 and NO; Inhibiting neutrophil infiltration, protecting the blood-brain barrier	抗炎、免疫调节、抗氧化、抗肿瘤; 缓解风湿性疼痛 (Ying <i>et al.</i> , 2014); 保护神经系统 (Wei <i>et al.</i> , 2021) Anti-inflammatory, immunomodulatory, antioxidant, and anti-tumor; Alleviate rheumatic pain (Ying <i>et al.</i> , 2014); Protect the nervous system (Wei <i>et al.</i> , 2021)
		异黄酮 Isoflavone		改善雌激素水平 Improving estrogen levels	预防雌激素缺乏引起的骨质流失 (Zhang <i>et al.</i> , 2014a) Prevent bone loss caused by estrogen deficiency (Zhang <i>et al.</i> , 2014a)
		多糖 Polysaccharide		保护肠组织; 增加抗氧化酶活性 Protecting intestinal tissue; Increasing the activity of antioxidant enzymes	缓解结肠炎 (Chen <i>et al.</i> , 2023); 抗衰老 (Zhu <i>et al.</i> , 2020) Relieve colitis (Chen <i>et al.</i> , 2023); Anti-aging (Hu <i>et al.</i> , 2020)

续表 3 (Table 3 continued)

目 Order	科 Family	物种名 Species	活性成分 Active constituent	作用机制 Mode of action	功效 Efficacy
鳞翅目 Lepidoptera	蝙蝠蛾科 Hepialidae	蝙蝠蛾 (冬虫夏草) <i>Cordyceps sinensis</i>	冬虫夏草提取物 <i>Cordyceps sinensis</i> extract	清除肌酐, 减少蛋白尿 Clearing creatinine, and reducing proteinuria	保护肾脏 (Zhang <i>et al.</i> , 2014b) Protect the kidneys (Zhang <i>et al.</i> , 2014b)
	蟋蟀科 Grylloidea	双斑大蟋 <i>Gryllus bimaculatus</i>	糖胺聚糖 Glycosaminoglycan	降低炎症因子水平, 减轻氧化应激 Reducing levels of inflammatory cytokines, and alleviating oxidative stress	治疗慢性关节炎 (Ahn <i>et al.</i> , 2014); 保护肝脏和小肠 (Hwang <i>et al.</i> , 2019) Treat chronic arthritis (Ahn <i>et al.</i> , 2014); Protect the liver and small intestine (Hwang <i>et al.</i> , 2019)
直翅目 Orthoptera				增强上皮屏障和诱导结肠上皮细胞增殖 Enhancing the epithelial barrier and inducing proliferation of colon epithelial cells	治疗肠道炎症 (Kim <i>et al.</i> , 2016) Treat intestinal inflammation (Kim <i>et al.</i> , 2016)
	螳螂科 Mantidae	螳螂 <i>Copris tripartitus</i>	多肽 CopA3 Polypeptide CopA3	抗病毒, 促进伤口愈合 Antiviral, and promoting wound healing	抑制裂谷热病毒和柯萨奇 B4 病毒 (Abdel-Samad, 2019) Inhibit Rift Valley fever virus and Cocksackievirus B4 (Abdel-Samad, 2019)
双翅目 Diptera	丽蝇科 Calliphoridae	铜绿蝇 <i>Lucilia cuprina</i>	排泄/分泌物 Excrete/secretate	抗菌, 杀菌, 促进伤口愈合 Antibacterial, bactericidal, and promoting wound healing	抑制利什曼原虫 (Sherafati <i>et al.</i> , 2022) Inhibit <i>Leishmania parasites</i> (Sherafati <i>et al.</i> , 2022)
	果蝇科 Drosophilidae	黑腹果蝇 <i>Drosophila melanogaster</i>	抗菌肽 Mtk-1 和 Mtk-2 Antimicrobial peptides Mtk-1 and Mtk-2	破坏细胞膜 Disrupting the cell membrane	抑制恶性疟原虫 (Tonk <i>et al.</i> , 2019) Inhibit <i>Plasmodium falciparum</i> (Tonk <i>et al.</i> , 2019)
半翅目 Hemiptera	蝉科 Cicadidae	黑蚱蝉 (蝉蛻) <i>Cryptotympana atrata</i>	壳聚糖 Chitosan	促进伤口愈合和抗菌 Promoting wound healing and antibacterial	伤口敷料 (Matica <i>et al.</i> , 2019) Wound dressing (Matica <i>et al.</i> , 2019)
			环肽 Cyclic peptides	缓解神经毒性 Alleviate neurotoxicity	干预神经退行性疾病 (Thapa <i>et al.</i> , 2021) Intervene in neurodegenerative diseases (Thapa <i>et al.</i> , 2021)
			抗菌肽 Antimicrobial peptides	提高宿主免疫力, 直接杀死病原微生物 Enhancing host immunity, and directly killing pathogenic microorganisms	抗菌 (Nuti <i>et al.</i> , 2017) Antibacterial (Nuti <i>et al.</i> , 2017)

3.3 治疗心血管疾病

斑蝥素是血管成形术后新生内膜增生和再狭窄的潜在抑制剂,可以显著抑制血管平滑肌细胞的异常增殖和迁移,并且能够抑制 IL-6 和 TNF- α 等炎症因子的表达,从而有效减轻炎症反应 (Qiu *et al.*, 2019)。蚕蛹蛋白水解物显著抑制血管紧张素转化酶活性,能够降低自发性高血压大鼠的收缩压,该物质在体外和体内均具有降压活性,可作为降压药物或降压食品补充剂开发应用 (Wang *et al.*, 2014)。由美洲大蠊为原料研制的心脉隆注射液,主要成分为 N-乙酰多巴胺寡聚物,具有抗炎和血管舒张活性的功效,被用于治疗充血性心力衰竭 (Zhang *et al.*, 2024)。

3.4 治疗神经性疾病

虫草素可改善创伤性脑损伤小鼠的长期神经功能障碍并减少神经元组织损失,通过抑制创伤性脑损伤后中性粒细胞的浸润,从而维持血脑屏障的完整性,并改变小胶质细胞和巨噬细胞的极化状态 (Wei *et al.*, 2021)。蜂毒含有肽和酶等几种活性分子,具有治疗帕金森、阿尔茨海默症和肌萎缩侧索硬化症等中枢神经系统疾病的潜力 (Wehbe *et al.*, 2019)。从蝉蜕中分离得到的一种环肽通过诱导转录因子 Nrf2 的表达,增强抗氧化能力,从而拯救了鱼藤酮介导的神经毒性,表明该化合物也能够干预帕金森类神经退行性疾病 (Thapa *et al.*, 2021)。

3.5 治疗代谢性疾病

家蚕中的活性成分对于高血糖和高血脂有较好的治疗效果,从蚕茧中提取的叶绿醇能够有效降低胆固醇和血糖水平。家蚕幼虫中的胰岛素样生长因子 II (Insulin-like growth factor II, IGF II) 和脂肪动力激素 (Adipokinetic hormone, AKH) 也能够降低血糖和血脂 (Singh and Jayasomu, 2008)。此外,家蚕中的 1-脱氧野尻霉素 (1-Deoxynojirimycin, 1-DNJ) 和槲皮素均具有较高的降血糖活性,有望成为糖尿病肾病治疗的新药 (Zhang *et al.*, 2016)。从蚕蛹中分离的胰岛素样肽,具有潜在的降血糖作用

(Miyazaki *et al.*, 2017)。地鳖虫的活性肽 DP17 (姜珊等, 2020) 和 AR-9 (Wang *et al.*, 2022a) 具有降低高胆固醇的作用,DP17 可显著减少高血脂大鼠肝脏组织的脂质积累,通过调节机体能量代谢平衡,激活 AMPK/mTOR 信号通路发挥降血脂作用,AR-9 通过调节肠道菌群及其代谢物来降低高脂肪饮食诱导的高脂血症大鼠的血脂和肝脂肪含量。

3.6 保护骨关节、肝肾及胃肠道

药用昆虫治疗风湿病和关节炎与其活性成分的抗炎和抗氧化作用有关,如蜂毒肽对关节炎和风湿病有良好的疗效 (Ullah *et al.*, 2023)。蜂毒可抑制环氧化酶-2 (Cyclooxygenase-2, COX-2)、iNOS、PGE-2 和一些蛋白酶的表达,从而减轻炎症,显著改善膝关节炎、疼痛和身体机能 (Jagua-Gualdrón *et al.*, 2020)。双斑大蟋提取的糖胺聚糖通过抑制 c 反应蛋白 (C-reactive protein, CRP) 和类风湿因子起作用,具有显著的抗水肿疗效,有助于治疗慢性关节炎 (Ahn *et al.*, 2014)。虫草素可以减轻骨关节炎的疼痛 (Ashraf *et al.*, 2019),并显著抑制白细胞介素 1 β 诱导的 PGE-1 和 NO 的产生 (Ying *et al.*, 2014)。此外,虫草素能够阻止炎症诱导的软骨自噬,并干预炎症反应,发挥其软骨保护作用 (Xia *et al.*, 2017)。

冬虫夏草可以保护肾脏,改善肾移植功能,并降低急性排斥反应,与常规免疫抑制剂联用对肾移植有益 (Ong and Aziz, 2017)。此外,冬虫夏草还能降低血清肌酐水平、增加肌酸清除率、减少蛋白尿和缓解慢性肾病相关的并发症 (Zhang *et al.*, 2014b)。美洲大蠊提取物可改善肝纤维化大鼠的肝功能,减轻或逆转肝纤维化相关的病理损伤,并有效抑制肝纤维化的进展 (Li *et al.*, 2018)。中国双齿多刺蚁 *Polyrhachis dives* 能够抑制高糖诱导的肾小球系膜细胞分泌粘连蛋白、IV 型胶原和 IL-6,促进淋巴细胞和 TNF- α 增殖,抑制 COX-1、COX-2 和 Jak3 激酶活性,对糖尿病肾病具有保护作用 (Tang *et al.*, 2015)。

此外,药用昆虫的活性成分可以消炎并保护

创面,抑制癌细胞增殖,对胃肠道疾病有独特的疗效。如美洲大蠊的低聚糖和抗菌肽在保护消化道方面效果很好(Yoon *et al.*, 2017; Lu *et al.*, 2021)。冬虫夏草多糖可显著缓解结肠炎(Chen *et al.*, 2023)。蜂产品如蜂胶、蜂蜜、蜂王浆和蜂毒等具有抗结肠癌的潜力(Moskwa *et al.*, 2023);蜂胶对胃肠疾病如口腔黏膜炎、胃炎、结肠炎和黏膜炎溃疡有良好的治疗效果(Zullkiflee *et al.*, 2022);麦卢卡蜂蜜通过降低人结肠癌 HCT-116 细胞的增殖能力、阻滞细胞周期、诱导凋亡细胞,以及抑制细胞周期基因和蛋白质的表达,明显降低人结肠癌细胞(HCT-116)活力(Afrin *et al.*, 2018)。

3.7 抗溃疡并促进创面愈合

虫药促进创面愈合的作用机制包括:(1)各种细胞与细胞生长因子对创面的网络相互作用调节;(2)增强免疫活性细胞对创面的氧化代谢功能;(3)改善创面微循环;(4)保持伤口湿润等(Liang *et al.*, 2022)。

丝光绿蝇幼虫的分泌物/排泄物在促进伤口愈合方面效果显著,被称为蛆疗法。蛆疗法能够更快速有效地清除无活性组织,促进肉芽组织生长并减少伤口面积(Mohd Zubir *et al.*, 2020),其主要作用成分为血管生成素酶-1(Angiopoietins, ANG-1)(Alipour *et al.*, 2020)和丝氨酸蛋白酶(Pöppel *et al.*, 2016)。美洲大蠊的乙醇提取物中含有表皮生长因子,能促进肉芽组织增殖,介导上皮细胞的黏膜修复作用,愈合率高于总多糖和总蛋白(Zhu *et al.*, 2018)。蜂蜜能加速皮肤修复和上皮化,促进血管生成,增强免疫反应以及减少病原微生物的感染,从而加快伤口愈合(Scepankova *et al.*, 2021)。蜂毒因其抗菌、抗病毒、抗氧化和抗炎作用被应用于促进伤口愈合(El-Ashram *et al.*, 2021)。家蚕蚕茧中的蚕丝蛋白可以激活胶原蛋白的产生并减小创面大小,且具有较强的吸水能力,能加速创面上皮的形成促进愈合(Lehmann *et al.*, 2022)。壳聚糖为甲壳素的衍生物,因其独特的生物化学特性和抗菌疗效,使其在伤口敷料中具有重要地位(Matica

et al., 2019)。

3.8 抗衰老作用

药用昆虫的活性成分如超氧化物歧化酶、多糖和不饱和脂肪酸均能起到抗衰老作用。衰老是生物体生理能力逐渐下降的过程,表现为整个系统水平的累积变化和不稳定性(Hou *et al.*, 2012)。蛻螂糖胺聚糖能降低 SD(Sprague-dawley)大鼠的脂肪组织重量,并使游离脂肪酸、谷丙转氨酶、葡萄糖和尿酸的血清水平正常化,从而恢复老年大鼠循环系统的稳态,具有抗衰老的应用潜力(Ahn *et al.*, 2017)。生物体自由基累积过多时会破坏细胞膜、蛋白质和 DNA 等生物大分子,进而导致细胞衰老和机体衰老(Pomatto and Davies, 2018)。超氧化物歧化酶、谷胱甘肽转移酶以及过氧化氢酶,是生物体抗氧化酶体系中重要的酶类抗氧化剂。超氧化物歧化酶是生物体抗氧化系统的第一道防线,能够清除超氧阴离子自由基,保证生物体内活性氧的平衡,延缓机体衰老进程(章慧慧和励建荣, 2007)。冬虫夏草的多糖具有显著的抗氧化和抗衰老活性,通过上调果蝇抗氧化相关基因的表达水平,增加过氧化氢酶和谷胱甘肽过氧化物酶的活性,有助于延长果蝇寿命(Zhu *et al.*, 2020)。蜂王浆通过增加总超氧化物歧化酶、谷胱甘肽过氧化物酶和过氧化氢酶等细胞抗氧化酶的酶活,同时降低丙二醛和羰基蛋白的含量,从而缓解氧化损伤,起到抑制衰老的作用(Qiu *et al.*, 2020)。洋虫含有大量的不饱和脂肪酸、氨基酸、超氧化物歧化酶和微量元素(金长炼等, 1997),可作药食两用,增强免疫力,且其水提物和蛋白酶解液具有良好的清除自由基能力,有助于延缓衰老(王雷, 2006; 初众和严善春, 2008)。

3.9 其他

药用昆虫的功效与作用在不断的探索和实践逐渐明晰。药用昆虫及其活性成分还具有其他临床应用,如食用蟋蟀不仅能供给人体充足的能量,还富含铁和锌,有助于预防儿童营养性贫血(Menasria *et al.*, 2018)。家蚕粉末可显著降低

由紫外线引起的小鼠背部皮肤异常色素沉着,影响皮肤色素沉着和黑色素生成 (Kim *et al.*, 2017a)。冬虫夏草的提取物虫草素具有抗疲劳的功效 (Chai *et al.*, 2022)。

4 总结与展望

药用昆虫是中国医药领域的重要组成部分,中医在药用昆虫的应用方面积累了丰富独特的经验。药用昆虫的疗效显著,活性成分含量高且活性强,在新药源发掘和疑难杂症治疗等方面具有巨大潜力,但现阶段对药用昆虫活性成分的研究尚不够深入,其作用机制仍未得到清晰阐释,而现代组学技术极大推动了药用昆虫的药理机制研究。近年来,家蚕、金凤蝶、白蜡虫 *Ericerus pela*、苏州乳白蚁 *Coptotermes suzhouensis*、意大利蜜蜂 *Apis mellifera ligustica*、美洲大蠊、沙漠蝗虫 *Schistocerca gregaria*、九香虫和中国豆芫菁 *Epicauta chinensis* 等药用昆虫的基因组已组装完成 (罗惠等, 2023)。通过对家蚕基因组的测序,发现其拥有最大的天蚕素基因家族,且抗菌活性与诱导家蚕转录活性呈正相关,这对提高抗菌肽的产量有重要意义 (Xia *et al.*, 2014)。对赤拟谷盗 *Tribolium castaneum* 基因组的分析发现,有 13 个脯氨酸特异性肽酶序列来自丝氨酸和金属依赖性肽酶家族,其中 11 个序列也在幼虫的肠道转录组中发现,表明该消化肽酶可以完全水解免疫原性麦醇溶蛋白肽,有望成为治疗乳糜泻和麸质不耐受的新型药物 (Tereshchenkova *et al.*, 2022)。通过蛋白质组学技术分离纯化昆虫的蛋白质和酶类,可为其功效研究提供生物学依据,有助于研制新的抗菌药物 (Zhang *et al.*, 2014c)。利用比较蛋白质组学分析家蚕被寄生虫寄生前后的蛋白质变化,可以深入了解家蚕对寄生的反应机制,揭示蛆虫的感染途径,有助于保护家蚕养殖产业的经济利益 (Xu *et al.*, 2019)。利用非靶向代谢组学和广泛靶向代谢组学探索蜂王浆蛋白抗氧化和抗炎机制,结果表明蜂王浆蛋白可以通过“多组分-多靶点-多途径”机制介导非酒精性脂肪性肝病的进展,是缓解非酒精性脂肪性肝病的理想功能性食品 (Zhu *et al.*, 2022)。

利用非靶向液相色谱-质谱 (Non-targeted liquid chromatography-mass spectrometry, LC-MS) 代谢组学方法,鉴定出以金合欢为食的蜜蜂所产蜂蜜中的抗氧化物质主要是生物碱和类黄酮,类黄酮衍生物不仅是有效的抗氧化剂,也是金合欢蜂蜜的关键标志物,可作为理想的抗衰老食品 (Chuah *et al.*, 2023)。虽然中国的药用昆虫资源丰富,但真正应用于临床治疗的仍占少数,许多昆虫的药用价值还未被发掘,因此仍需通过组学技术加大对药用昆虫的深入挖掘和研究。

药用昆虫在开发食品及保健品领域也有显著优势,其富含蛋白质、苷类和脂肪酸等营养成分。目前,开发利用较为深入的有虫草、斑蝥、蚂蚁和蜜蜂等品种,但也应注意药用昆虫作为食品的致敏性。研究显示,食用昆虫的蛋白质可能引发原发性过敏,并存在与其他过敏源[如尘螨和海鲜 (鱼和虾) 等]之间的交叉过敏风险,且经过热处理或消化的昆虫过敏源仍然无法消除其致敏性 (Broekman *et al.*, 2017)。家蟋 (De Marchi *et al.*, 2021)、家蚕、黄粉虫、豌豆象、中华蛭蟥和蜜蜂的蛋白质,均有引起荨麻疹、瘙痒、皮疹、腹痛、恶心、呕吐、哮喘和呼吸困难等过敏症状的报道 (de Gier and Verhoeckx, 2018)。常见的食用昆虫过敏源有原肌球蛋白和精氨酸激酶,如家蚕的精氨酸激酶和副肌球蛋白可诱发原发性过敏 (de Gier and Verhoeckx, 2018); 黄粉虫精氨酸激酶、原肌球蛋白、肌球蛋白轻链和重链,以及幼虫角质层蛋白可诱发原发性过敏及交叉过敏,同时对虾过敏的患者也存在对黄粉虫过敏的风险 (Broekman *et al.*, 2017)。此外,从黄粉虫中检测出的丝氨酸蛋白酶被认为是一种新型过敏源 (王南溪, 2019)。

我国对于传统中医的关注日渐提高,中药领域得以发展壮大,药用昆虫的研究和临床应用正在不断深入和完善。2022 年基于原家蚕基因组生物学国家重点实验室,由西南大学联合中国农业科学院蜜蜂研究所联合优化和组建的资源昆虫高效养殖与利用重点实验室,为药用昆虫养殖行业的强劲增长提供了支持。我国幅员辽阔,适合多种昆虫生长,由于昆虫生长周期短、繁殖速

度快,且养殖技术难度和成本较低,使其具备较高的经济效益(张振玲,2016)。现主要养殖的药用昆虫有斑蝥、冬虫夏草、蜜蜂、蟑螂、土元、蚂蚁、蚱蝉和家蚕,主要分布在山东、江苏、河北和云南等地(尹馨雪等,2022)。专业化的昆虫养殖不仅可以提供充足且符合标准的药材资源,满足工业和饲料的需求,同时也有助于行业的发展。例如,通过对冬虫夏草发酵过程的优化及其代谢产物的探索,揭示了适合虫草生长的环境条件,促进了虫草人工养殖行业的发展(Wang et al., 2022b)。但目前关于冬虫夏草和僵蚕等药用昆虫养殖和培育的资料仍不完善,养殖昆虫的病害防治报道较少,且养殖行业缺乏专业养殖人员。因此,药用昆虫养殖行业仍需加大投入,培养专业养殖人员,完善养殖技术,以促进规范化养殖。同时,应建立规范快捷的虫药交易平台,多维度推动养殖产业的发展。

未来应加大对药用昆虫资源的研究与利用,深入挖掘药用昆虫中的活性成分及其作用机理,同时也要加强对昆虫资源的调查与保护,提升人工饲养药用昆虫产业质量和规模,实现药用昆虫的可持续发展。

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