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中草药在水产养殖中的应用研究进展

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摘要

随着人们对水产食品安全关注的不断加强，越来越多的化学合成药物在水产养殖中被禁用。同时，由于中草药具有绿色天然的优点，近年来其在水产养殖领域被广泛应用。研究表明，中草药具有促进养殖鱼类生长、提高抗病力、改善肌肉品质等多方面的作用。中草药所含生物活性物质不仅能够增加鱼类摄食量和消化酶活性，而且可能影响养殖产品风味。许多中草药种类还能够显著提升养殖鱼类的特异性和非特异性免疫力。然而，由于中草药的植物成分非常复杂，有效地分离提纯药用成分是开发应用的关键。本文回顾了中草药关于生长表现和饲料利用，免疫和抗病力以及养殖产品质量方面的最新研究和应用进展。本文同时介绍了中药材化学成分研究的新技术和方法，分析了中草药在水产养殖应用方面存在的问题，认为未来中草药研究应重点关注如何经济地提炼有效成分以及最佳的用药途径。

1. 引言

中草药在中国已有上千年的应用历史，天然和安全是中草药的重要特征[1]。中草药含有的活性成分主要包括多糖、生物碱、类黄酮、挥发油、有机酸、单宁等，同时还包含多种营养素，如氨基酸、碳水化合物、矿物质和维生素等[2]。研究表明，中草药所含的这些活性成分具有增进食欲[3,4]、加快新陈代谢、促进蛋白质的合成[5,6]、增加酶活性[7]、提高机体免疫力[8,9]、增强抗病性[10]、提高肌肉品质[11,12]等作用（图1）。

长期以来，中草药作为诱食剂、促生长剂[13]、抗菌剂和免疫增强剂在水产养殖领域广泛应用[14]，被认为是抗生素、合成抗菌药、疫苗和其他化学药物的有效替代品[15]。由于中草药的天然无害、经济易得、对养殖鱼类和环境无明显副作用等优点，近年来其在水产养殖方面的应用得到了大量的研究[16]。中草药制剂可以是整株植物，也可以是植物的一部分（如叶、根或种子），可以在饲料中单独使用或将提纯后的制品与其他饲料添加剂组合使用，还可以将中草药直接投放到水中对鱼进行浸洗处理[17]。然而，由于中草药的药用成分复杂，药效不够稳定，只有通过进一步的研究，深入了解中草药的化学结构和功能机制才能够实现中草药的科学高效

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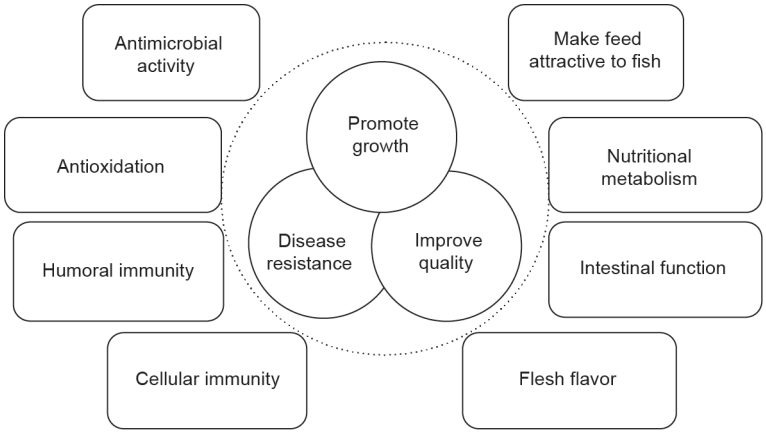


图1. 中草药对鱼类的作用和主要途径。

应用[18,19]。本文介绍了目前水产养殖应用中草药的功能成分及其提取和纯化技术研究进展，同时对中草药在鱼类养殖方面取得的研究成果进行了阐述。

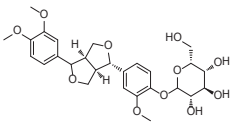
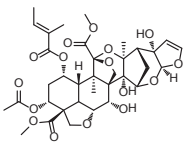
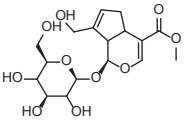
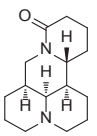
2. 传统中药材化学成分研究

中药材的化学成分结构复杂，功能物质含量细微，分析鉴定难度较大。然而，随着高分子化合物分析新技术的发展，越来越多的传统中草药经过详细研究，其关键的有效成分被确定出来（表1）。

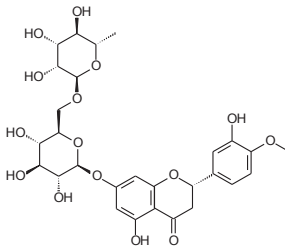
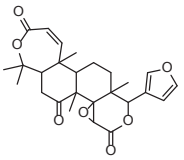
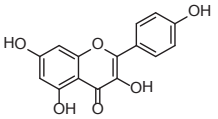
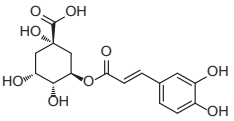
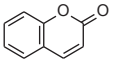
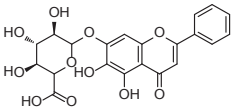
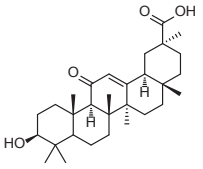
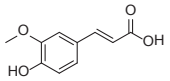
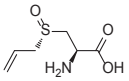
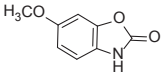
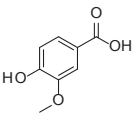
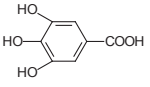
2001年，采用超声技术提取到中草药中的生物碱、类黄酮、蒽醌和多糖[20]。2004年，超临界流体色谱（SFC）成为分析挥发性大分子成分如磷脂、甘油三酯和类胡萝卜素的有效方法。超临界流体技术具有选择性高的优点，可以与气相色谱（GC）、高效液相色谱（HPLC）和气相色谱/质谱（GC/MS）等技术结合，精确分析中草药的活性成分[21]。2005年，随着毛细管电泳技术的发展，结合其他化学分析技术，建立了有效的中草药痕量活性成分的分离方法[22]。

2006年，分子蒸馏技术用于提取白术、大蒜、当归和连翘挥发油，取得了良好的效果[23]。2008年，固定膜界面萃取技术、高速逆流色谱分离技术和分子印迹分离技术被应用于中药材化学分析[24]。2009年，研究人员发现纤维素酶可以提高植物多糖的提取率[25]。傅里叶变换离子回旋共振质谱/多级质谱（FTICRMS/MSn）技术结合高效液相色谱（HPLC）可分析获得精确的成

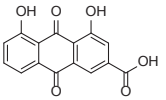
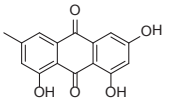
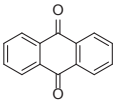
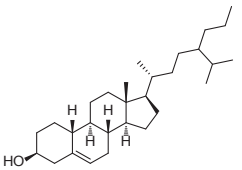
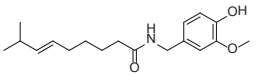
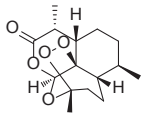
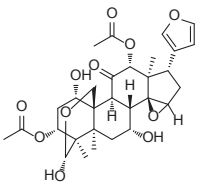
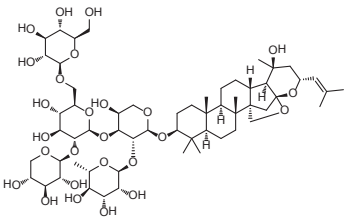
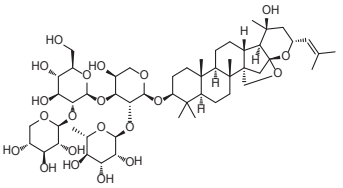
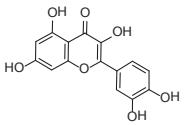
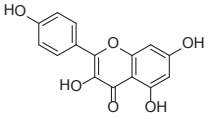
表1 水产养殖应用（部分）中草药的主要活性成分及其化学结构式

Herb name	Effective ingredient	Molecular formula	Structure
Forsythia suspensa	Phillyrin	$C_{27}H_{34}O_{11}$	
Azadirachta indica	Azadirachtin A	$C_{35}H_{44}O_{16}$	
Gardenia jasminoides Ellis	Geniposide	$C_{17}H_{24}O_{10}$	
Sophora flavescens	Matrine	$C_{15}H_{24}N_2O$	

（续表）

Herb name	Effective ingredient	Molecular formula	Structure
Citrus aurantium L.	Hesperidin	$C_{28}H_{34}O_{15}$	
Phellodendron chinense Schneid	Obacunone	$C_{26}H_{30}O_7$	
Rhizoma Kaempferiae	Kaempferol	$C_{15}H_{10}O_6$	
Eucommia ulmoides	Chlorogenic acid	$C_{16}H_{18}O_9$	
Angelica dahurica	Coumarin	$C_9H_6O_2$	
Scutellaria baicalensis	Baicalin	$C_{21}H_{18}O_{11}$	
Glycyrrhiza uralensis	Glycyrrhetic acid	$C_{30}H_{46}O_4$	
Angelica sinensis	Ferulic acid	$C_{10}H_{10}O_4$	
Allium sativum	Alliin	$C_6H_{11}NO_3S$	
Rhizoma Phragmitis	Coixol	$C_8H_7NO_3$	
	Vanillic acid	$C_8H_8O_4$	
Rhus chinensis Mill.	Gallic acid	$C_7H_6O_5$	

（续表）

Herb name	Effective ingredient	Molecular formula	Structure
Rheum officinale	Rhein	$C_{15}H_8O_6$	
	Emodin	$C_{15}H_{10}O_5$	
Euphorbia humifusa	Anthraquinone	$C_{14}H_8O_2$	
Acalypha australis	Sitosterol	$C_{29}H_{50}O$	
Capsicum frutescens L.	Capsaicin	$C_{18}H_{27}NO_3$	
Artemisia carvifolia	Arteannuin	$C_{15}H_{22}O_5$	
Melia azedarach	Methyl kulonate	$C_{30}H_{38}O_{11}$	
Semen Ziziphi Spinosae	Jujuboside A	$C_{58}H_{94}O_{26}$	
	Jujuboside B	$C_{52}H_{84}O_{21}$	
Toona sinensis	Thiophene	C_4H_4S	
Rosa chinensis	Quercetin	$C_{15}H_{10}O_7$	
	Kaempferol	$C_{15}H_{10}O_6$	

分质量数据。研究人员首先通过高分辨质谱法获得中草药中各种化学成分的准确质量，然后结合多级质谱碎片信息分析，高效地鉴定出淫羊藿的功能成分[26]。2012年，吕惠敏采用紫外（UV）分光光度法鉴定和定量中草药的活性成分，测定了各种多糖、生物碱、类黄酮和挥发油的浓度[27]。2013年，刘晓洁利用咪唑类离子液体作为萃取剂，采用微波提取法从香椿和月季中获得槲皮素和山奈酚[28]。

2014年，濮玲等通过12种中药材的主成分分析得到了三个主成分和相应的主成分方程，将主成分分析用于综合评价中草药质量[29]。2015年，黎人恺将磁铁矿（Fe_3O_4）磁性纳米粒子用作中药载体，用于分离从黄芩和甘草中提取的活性成分，从而建立了一种中药分离纯化的新方法[30]。

3. 中草药对鱼类生长和饲料利用的影响

一些中草药可以通过刺激养殖鱼的味蕾来提高饲料的适口性，从而增加饲料摄入量。例如，将丁香和陈皮等以0.2%的比例添加到基础饲料中可以显著提高鲤鱼（*Cyprinus carpio*）的摄食量[31]。黄芪、淮山药、山楂、枸杞、陈皮和黄柏对金鱼（*Carassius auratus*）具有显著的诱食作用。报道显示，含有小檗碱和山奈酚的中药饲料添加剂对促进施氏鲟（*Acurenser schrenckii*）摄食产生一定的作用[16]。此外，陈皮、山楂、丁香、杜仲和五味子的0.4%（*w/w*）水提取物在增进锦鲤（*Cyprinus carpio*）摄食量中起到明显作用[32]。

王裕玉研究认为，陈皮中的游离氨基酸、核苷酸和生物碱可能是对养殖鱼类产生诱食效果的原因[14]。大多数学者认为，正是中草药独特的气味和味道（如肉桂、当归、山楂、八角、茴香等）导致其在促进鱼类摄食过程中起重要作用[33]。此外，中草药可以刺激消化液的分泌并加快肠蠕动，这也可以解释为摄食量增加的原因[13]。

研究表明，中草药所含生物活性物质可以通过增强新陈代谢、促进蛋白质的合成、激活消化酶从而改善鱼的生长表现。在人工饲料中添加2.0%的黄芩和茯苓等组成的添加剂养殖眼斑拟石首鱼（*Sciaenops ocellatus*），实验组增长率比对照组增加10.4%~32.3%[34]。另有研究表明，一些中草药（如连翘、黄连和茯苓）中的木质素、黄芩苷、多糖和小檗碱可以作为生长促进剂应用于凡纳滨对虾（*Litopenaeus vannamei*）的养殖[35]。通过将茯苓添加到饲料中可以显著增加黄鳝（*Monopterus albus*）的生长速度[36]。饲料中添加党参和甘草在加速鲇鱼（*Silurus asotus*）生长的同时使饲料蛋白质利用率提高了33.6%[37]。实验显示，黄芩、黄芪、当归、党参、金银花、刺五加、陈皮等按照1.0%的添加比例配制成复方中草药饲料添加剂可显著改善瓦氏黄颡鱼（*Pelteobagrus vachelli*）的生长表现[38]。饲料中添加0.3%（*w/w*）剂量的大蒜素和陈皮的混合物可以使养殖草鱼（*Ctenopharyngodon idellus*）的生长速度加快31%。饲料中添加杜仲叶也可能改善草鱼的生长表现[39]。另一项研究表明，鱼腥草、金银花、甘草和茯苓的复方制剂可以通过提高体内溶菌酶活性而改善草鱼的生长状况[12]。由山楂、杜仲、孜然、肉桂等组成的复方中药制剂能够使黄鳝的蛋白酶活性较对照组增加61.33%，从而提高了营养物质的消化率和鱼体生长速度[7]。研究还发现，改善肠道吸收功能、促进营养素代谢同样是中草药的重要作用[40]。剂量为1000~1500 $mg \cdot kg^{-1}$的黄芪多糖补充到养殖罗非鱼（*Oreochromis mossambicus*）的饲料中可以增加罗非鱼肠道绒毛的长度、加深隐窝深度、增加肌肉厚度和肠黏膜细胞的数量，并同时增加上皮组织内的淋巴细胞数量[41]。饲料中添加0.5%（*w/w*）的陈皮、黄芪和当归混合制剂可促进鳜鱼（*Siniperca chuatsi*）肠绒毛的生长并提高肝细胞质密度[42]。在日粮中添加1.0 $g \cdot kg^{-1}$的枇杷多糖可显著增加金鱼消化道肠绒毛长度和肠壁肌层厚度[5]。实验发现在鲫鱼（*Carassius auratus*）饲料中添加2.0%的山楂能够使饲料蛋白质的表观消化率提高10.2%，肠蛋白酶活性提高25.68%[6]。

4. 中草药对鱼类免疫力和抗病性的影响

许多中草药作为天然的抗菌和杀菌剂，可以显著增强动物的免疫力和抗病能力[43,44]。由于溶菌酶、碱性磷酸酶、血清蛋白和超氧化物歧化酶是鱼类非特异性免疫能力的重要评价参数，这些指标通常被用于研究中草药对鱼类免疫力的影响。已有研究发现中草药中的生物活性成分（如多糖、皂角苷、生物碱、蒽、植物精油和有机酸等）具有提升这些免疫学指标的作用，中草药还能增强机体对抗原的免疫应答程度[45,46]。

是动物外周免疫器官，是免疫细胞响应于抗原而进行增生的地方，同时免疫器官的发育又与身体的免疫状态密切相关[47]。对于鱼类来说，体表黏膜层是有助于抵抗病原体的重要屏障，不仅可以保护身体免受寄生

虫、真菌、细菌和其他有害生物的侵蚀，而且可以使皮肤维持正常的渗透性[48]。

黄芪含有多种影响鱼类体液和细胞免疫的活性功能成分，并且能够增强淋巴因子激活免疫和免疫调节因子的活性[49]。党参具有滋补和抗炎作用，可以缓解罗非鱼对养殖环境的胁迫反应，增强其抗病力[50]。当归不但有助于改善血液流变性，同时具有抗炎、抗肿瘤和抗菌等多种功能，饲喂剂量为50 mg·kg^{-1}的当归多糖饲料可以增加点带石斑鱼（*Epinephelus coioides*）血液中的白细胞数量，增强白细胞吞噬作用[51]。

研究发现利用连翘、猪苓、黄芩、茯苓和黄连等五种中草药的水提物饲喂眼斑拟石首鱼28天后，白细胞吞噬百分率和溶菌酶活性分别增加了5.89%和138.7 U·mL^{-1}[52]。将牛膝、板蓝根、甘草、陈皮、肉桂、大麦和神曲等粉碎混合，按照基础饲料2.0%（*w*/*w*）剂量配制成复方中药添加剂投喂大菱鲆（*Scophthalmus maximus*），血清溶菌酶和抗蛋白酶活性显著增加，硝基四氮唑蓝（NBT）阳性细胞数量增加[53]。通过在饲料中添加1.0%（*w*/*w*）的黄芩、茯苓、板蓝根、黄芪、大黄、甘草和金银花等七种草药水提混合物饲喂黄颡鱼，可以观察到生长速度加快及白细胞吞噬活性和溶菌酶活性显著增加[54]。盛竹梅等[55]的研究表明，饲料中添加浓度为400~800 mg·kg^{-1}的麻黄、苦参、黄芩和五倍子可以提高黄颡鱼白细胞的吞噬活性和溶菌酶活性。利用黄芪、白术、大黄、板蓝根、黄芩、党参和菊花等的混合物饲喂罗非鱼（*Oleochromis mossambica*×*O. aureus*）可以极显著增加血清中白细胞的吞噬活性、NBT阳性细胞数量及超氧化物歧化酶、过氧化氢酶和溶菌酶的酶活性[51]。由刺五加、枸杞、金银花和黄芪四种中草药组合的复方中药制剂能够明显增加散鳞镜鲤幼鱼的白细胞数量，增强网状内皮细胞吞噬作用，同时能够促进干扰素、抗体和淋巴细胞的产生[56]。饲料中添加剂量为1.0%和2.0%的复方中草药添加剂可使宝石鲈（*Scortum barcoo*）血清、脾脏、肝脏和肾脏中超氧化物歧化酶、溶菌酶和过氧化氢酶的活性显著增加[57]。此外，一些中草药可以通过激发肾上腺皮质垂体，诱导鱼类激素样或促性腺激素样作用[45]。

五味子、大黄和乌梅对嗜水气单胞菌（*Aeromonas hydrophila*）具有较好的抑制作用，有助于防治鱼类的败血症[58]。大蒜和大黄属对鳙鱼（*Aristichthys nobilis*）和鲢鱼（*Hypophthalmichthys molitrix*）腐皮病具有治疗作用。地锦和苦楝可用于防治鳙鱼和鲤鱼的细菌性烂鳃病，而辣蓼和铁苋菜对鲢鱼和鳙鱼的白头白嘴病具有明显的疗效[59]。将黄姜、辣椒和青蒿的提取物分别以5.0 mg·L^{-1}、2.5 mg L^{-1}和1 mg·L^{-1}浓度混合浸洗鱼体，对小瓜虫病有非常显著的治疗效果，24 h杀虫率达到100%[60]。印楝的提取物印楝素对鱼体寄生车轮虫的抑杀作用与用药浓度呈正相关，0.8 mg·L^{-1}浓度的印楝素杀虫率超过90%[10]。研究发现苦参、苦楝、烟草、百部等中草药对于车轮虫等养殖鱼类易感寄生虫都有一定的防治作用[46]。浓度为2.75 g·L^{-1}的苦楝配合浓度为5.67 g·L^{-1}的苦参同时使用，处理48 h后，鲤斜管虫被全部杀灭[61]。

5. 中草药对养殖鱼类肌肉品质的影响

中草药可以通过影响肌肉口感或颜色来改善鱼类产品肉质。养殖鱼类肌肉的口感受其化学成分的影响。肌肉中的氨基酸、不饱和脂肪酸、醛类和酚类的种类与含量是影响肌肉口感的重要因子。将大蒜、杜仲和沙棘作为肌肉品质改良剂按照60 mg·kg^{-1}浓度添加到饲料中能够明显增加肌肉粗蛋白含量和呈味氨基酸百分率[62]。

将茯苓、白芍、鱼腥草和大黄的复方制剂按照0.5%（*w*/*w*）的比例添加到基础饲料中养殖施氏鲟，肌肉的粗蛋白含量和脂肪酸含量均表现增加[11]。黄芪、当归、金银花和板蓝根等组成的复方中草药制剂能够显著增加尼罗罗非鱼（*Tilapia nilotica*）肌肉中的肌苷酸浓度，同时改善其口感风味[63]。将黄芩、茯苓、板蓝根、黄芪、大黄、甘草、金银花和杜仲等8种中药材的混合物按1.0%（*w*/*w*）的比例添加到饲料中饲喂鲤鱼，观察到肌肉中谷氨酸和天冬氨酸的含量显著增加，肌肉的风味受到影响[64]。

6. 中草药在水产养殖中的应用问题

目前，中草药在水产养殖领域的应用仍然存在一些问题。首先，由于中草药的活性成分纷繁复杂，通常较难分离和鉴别出所有活性成分。另外，植物中活性成分的生物效价受植物生长发育阶段和种植地理位置的影响。因此，中草药在实际应用中的用药剂量不容易精确把握，需要研究如何控制中草药制品的质量稳定[65,66]。其次，目前中草药主要采用原药材简单加工配制成饲料或直接施于水中的应用方法，成本高且操作不便。如何经济高效地提取中草药的活性功能成分（尤其

在活性成分含量很低时）是实现中草药高效利用必须解决的问题[67]。第三，关于中草药的功能机制研究很缺乏。已有的资料显示，涉及水产养殖领域中草药研究主要集中在鱼类的生长和生理表现上，大多数药剂的作用机制不明确。此外，中国传统的中医药学理论主要是针对人类研究开展的，可能并不适用于解释中草药作用于水生动物的真实机制，因为鱼类具有不同的代谢和免疫机制[46]。

总之，现有研究已经明确了中草药在水产养殖领域对鱼类生长、免疫和抗病等方面的积极作用。然而，对中草药功能机制研究的不足以及药剂质量不稳定导致许多种类在应用中存在较大的不确定性。建议今后中草药的研究重点集中在如何经济高效地提取有效活性成分，同时还应对这些成分的功能机制进行深入研究。

Compliance with ethics guidelines

Hongyu Pu, Xiaoyu Li, Qingbo Du, Hao Cui, and Yongping Xu declare that they have no conflict of interest or financial conflicts to disclose.

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