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酵母源饲料原料在养殖业中的研究与应用

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摘 要:近年来,我国养殖业发展迅速,使得对饲料的需求量也逐年增加。如何解决日益增长的饲料原料需求和相对不足的饲料用粮的供应间的矛盾,是养殖业面临的一大难题。酵母源饲料原料因其含有丰富的营养及其功能性调节物质,并且适口性好、廉价易得、营养全面等优点,成为很有潜力的将来可规模使用的饲料原料。酵母源饲料是指包括饲料酵母活菌、酵母培养物、酵母水解物、酵母细胞壁及富集微量元素酵母等用作为饲料原料的酵母类产品。现在的研究表明酵母源饲料在促进养殖动物生长,增强免疫方面有着明显的效用,广泛应用与畜禽以及水产养殖行业。本文将就酵母源饲料的发展潜力及其在养殖业中应用的现状做一分析,以期为探索如何进一步开展酵母源饲料在养殖业中研究和应用推广做一文献梳理。

关键词:酵母;饲料原料;养殖;促生长;免疫

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Researches and Application of Yeast Derived Feedstuffs in Breeding Industry

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Abstract: In recent years, the breeding industry had a rapidly development in our country. Then, the requirements of feed were also increased year by year accordingly. However, the production of grains used as feedstuff were not increased with a similar fold. It is the most challenge to treat the contradiction between fast developed breeding industry and less increased grain production. The yeast derived feedstuffs have great potential to be used as future feedstuff in large scale for the specialty of good palatability, rich in nutrition and functional regulation substances, nutrition comprehensive and cheap. Yeast derived feedstuffs contain live yeast, yeast culture, yeast hydrolysate, yeast cell wall and yeasts enrichment with trace elements. Most of studies on yeast derived feedstuffs showed it's mainly function in breeding industry were growth and immunity enhancement in livestock and poultry and aquaculture industry. Here, we do our best to summarize the application and potential development of yeast derived feedstuffs.

Key words: yeast; feedstuff; breeding industry; growth enhancement; immunity

饲料是整个养殖业的发展基础。近年来,我国养殖业发展迅速,畜禽存栏量、畜禽产品以及水产品年产量也有很大程度的增加,相应地对饲料的需求量也逐年增加。与之相比,我国的粮食总产量一直在5亿吨多,饲料粮的供给并没有相应的增长,尤其是在推广玉米-豆粕型饲料之后,我国豆粕、鱼粉及玉米等优质饲料资源的短缺问题日益严重。养殖业的迅猛发展,导致了蛋白和能量饲料紧缺,使得整个饲料资源供求关系具有精饲料缺、蛋白质饲料缺、绿色饲料缺和总量不足,即“三缺一不足”的特

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征[1]。饲料原料短缺的问题一直影响着养殖业的发展,成为制约我国养殖业进一步发展的重要因素[2]。根据土地资源和人口资源现状分析,我国粮食的人均占有量将很难再有大幅度的提高,这也就意味着饲料行业难以得到更多的原料供应,积极寻找可替代的饲料原料在此时就显得尤为迫切。

在饲料原料中最重要的要数蛋白饲料,所以开发应用新型蛋白质饲料或促进饲料蛋白转化吸收功能的工艺或添加剂是解决上述问题的有效途径。早在一百多年前 ,通过发酵转化无机氮或者植物蛋白获得的菌体蛋白就被应用于养殖业。1967 年,第一次国际单细胞蛋白会议决定所有用单细胞微生物生产的蛋白质统称为单细胞蛋白。微生物种类涵盖酵母、细菌、放射菌、藻类和丝状真菌等。酵母蛋白作为单细胞蛋白的一种,是干燥酵母,除去多糖等其他成分富集而成的一种功能性蛋白,主要是菌体蛋白及酵母代谢产物。酵母蛋白作为一种优质天然完全蛋白质,能够促进幼龄动物的肠道发育,促进其主动免疫的建立,改善日粮适口性,提高营养物质利用率,是养殖业优良的蛋白质来源。酵母除含有丰富的蛋白外,还富含核苷酸、肌醇、维生素、小肽和糖类等动物生长所需的功能性物质,并且适口性良好。在动物饲料中适当添加,可以提高动物的采食量和饲料转化效率。干酵母一般含蛋白质 40% ~65% ,脂肪 1% ~8% ,糖类 25% ~40% ,灰分 6% ~9% ,同时还含有丰富的 B 族维生素及一些未知促生长因子。饲料酵母蛋白中大约含有 20 种氨基酸,含有几乎所有的必需氨基酸,尤其是赖氨酸、苏氨酸、亮氨酸、苯丙氨酸等含量较高[3]。饲料用酵母的使用可以追溯到 1910 年,德国 M. 德尔布吕克最先用啤酒生产过程中的酵母泥来作为补充饲料。现在的饲料酵母已经发展成为以生产酒精、甲醇、造纸、糖蜜、酿酒、乳清及乳清品等工业或农业副产品废料的水解糖液为主要原料,通过发酵培养基的制备、接种酵母菌、酵母繁殖、酵母分离、浓缩和干燥等工序制备而成的酵母菌体或其培养物,其成份组成与具体菌种、培养条件以及加工工艺有关。酵母以及几种衍生产品如酵母培养物,酵母浸出物以及酵母细胞壁等成分,都表现出促进动物生长和提升饲料转化率的效果[4]。除此之外,饲料酵母还具有性能稳定、安全性好、价格低廉等特点。因此被作为微生物饲料的重点研发方向之一,并广泛应用于畜禽以及水产等行业,市场前景广阔。

2013 年 12 月 19 日,中华人民共和国农业部公告第 2038 号文件对原有的《饲料原料目录》(以下简称“《目录》”)进行了修订,其中关于酵母的修订款项多达五条,它们分别是:7. 增补“食品酵母粉”进入《目录》,编号:12.2.4;8. 增补“酵母水解物”进入《目录》,编号:12. 2. 5;17. 将“酿酒酵母培养物”从《饲料添加剂品种目录》转人《目录》,编号:12.2.6;18. 将“酿酒酵母提取物”从《饲料添加剂品种目录》转入《目录》,编号:12. 2. 7;19. 将“酿酒酵母细胞壁”从《饲料添加剂品种目录》转人《目录》,编号:12.2.8。同时增补甜菜糖蜜酵母发酵浓缩液、食品酵母粉、酵母水解物、酿酒酵母培养物、酿酒酵母提取物和酿酒酵母细胞壁到《目录》第四部分“单一饲料品种”中。这也显示了养殖行业对酵母源饲料原料的认可。酵母源饲料已经成为我国饲料原料的重要来源。下面本文对各种酵母源饲料原料,包括酵母活菌、酵母培养物、酵母水解物、酵母细胞壁、富含微量元素酵母等分别进行总结阐述。

1 酵母活菌

养殖业使用的酵母活菌主要有从发酵液中直接分离的活性酵母菌以及活性干酵母。活性酵母菌就是处于不同生长阶段的酵母菌,较易理解。活性干酵母是由特殊培养的鲜酵母经压榨干燥脱水后仍保持强发酵能力的干酵母制品,是一种优质的益生菌类固态微生态制剂。其中,酵母菌含量超过 200 亿 cfu/g,含水量小于 6% 的活性干酵母被称为高活性干酵母。活性干酵母有两个基本特征:一是常温下长期贮存而不失去活性,二是将活性干酵母在一定条件下复水活化后,即恢复成自然状态并具有正常酵母活性的细胞[5]。活性干酵母耐受较低 pH 环境,在进入动物胃肠道后迅速复活,通过代谢消耗胃肠道的氧气并产酸,进而抑制大肠杆菌、沙门氏菌等有害菌群的生长繁殖,促进双歧杆菌、乳酸菌等有益菌的繁殖,改善动物消化道环境和菌群结构,维持胃肠道微生态平衡,提高动物抗应激能力。活性干酵母能分泌蛋白酶、淀粉酶、脂肪酶等消化酶提高饲料消化率,并分泌未知促生长因子,促进动物生长。活性干酵母还具有性能稳定、易于运输、使用方便,可直接混合配伍在粉状饲料中的特点,故其更多地应用在畜禽水产养殖领域。我国活性干酵母的研究和生产始于 20 世纪 70 年代。1974 年,上海酵母厂首先试制出面包活性干酵母。现在用量较大的为啤酒

酵母,是啤酒产业的副产物,干啤酒酵母已因富含蛋白和 B 族维生素,被作为免疫增强剂在市场上流通,广泛应用养殖行业[6]。

1.1　在单胃动物养殖领域的研究与应用

日粮适量添加活性干酵母可提高哺乳母猪采食量,改善母猪胃中微生物区系组成[7,8],但对所产仔猪断奶前重量的作用效果并不一致[9]。高剂量活性酵母的添加也可通过改变结肠内微生物组成,促进营养物质的消化[10]。活性饲料酵母粉添加水平达到 2.0×10^{7} cfu/g 时,对断奶仔猪生产性能的改善作用最为显著[11]。然而,对于单胃动物,活性酵母在饲料中的添加主要功能为增强动物免疫。饲料中添加酵母制剂可改善 21 日龄断奶仔猪消化道微生物区系,促进有益菌的增殖,对大肠杆菌等有害菌的生长有抑制效果。在怀孕后期和泌乳期,日粮添加酿酒酵母可增加乳汁中丙种球蛋白[12],可增加初乳中的 IgG 含量并能维持 IgA 的含量,有效降低仔猪腹泻率[9]。在妊娠后期、哺乳期以及断奶后期,饲料添加活啤酒酵母有益于缓解由产肠毒素大肠杆菌诱发的母猪和仔猪腹泻[13]。添加活性酵母可有效降低大肠杆菌攻毒仔猪血液中 C 反应蛋白的浓度以及 Toll 样受体的表达[14]。饲料中添加酿酒酵母可在一定程度上替代黄霉素等药物添加剂,其中以 0.1% 酿酒酵母(含菌量 108 亿 cfu/g)添加效果最佳[15]。

1.2　在反刍动物养殖领域的研究与应用

活酵母的添加可以促进瘤胃微生物的菌群数量和代谢活性[16],增强乳酸代谢和瘤胃 pH 值调节[17]。只有干酵母中活酵母的含量超过 150 亿 cfu/g 时,才能在瘤胃发酵中呈现效能[18]。饲料添加酵母能促进泌乳奶牛的瘤胃发酵(高挥发酸浓度、高瘤胃 pH 值以及低乙酸含量),原因可能和增加纤维素分解菌和乳酸利用菌有关[19]。饲料添加酵母可以显著增加纤维素的降解速度,而对其总体降解效率的影响并不大[20]。犊牛日粮中添加活性酵母,可改善日增重及饲料转化率[21];酵母添加可以明显增加荷斯坦泌乳母牛干物质采食量,缓减体质量下降,增加标准奶产量,乳脂率[22]。添加活性酿酒酵母可以加快阉羊对酸中毒的适应[23]。饲料补加活性啤酒酵母可提升饲料转化率和瘤胃发酵性能,但不能提高幼龄马尔普拉羊的生长性能和肉质[24]。酵母可有效提高限时饲喂羊对牧草的细胞壁的消化[25]。

1.3　在禽类养殖领域的研究与应用

饲料添加酵母可提高岭南黄肉鸡在 0~49 日龄的平均末重、平均日增重和成活率,降低料重比[26];可以促进肉鸡体重,促进甲状腺激素的代谢,降低胆固醇和脂质蛋白的含量[27]。另有研究发现,饲料添加酵母的应用效果还与养殖动物自身的生长状态相关。全酵母的添加对火鸡的影响结果与火鸡本身的炎症状态相关[28]。

1.4　在水产动物养殖领域的研究与应用

饵料添加酵母可提高池塘饲养的养殖后期鲤鱼的平均体重和平均增重,降低饵料系数,同时还可显著降低水体的氨氮以及活性磷酸盐浓度,为鲤鱼的生长提供了良好的水质环境[29];用酵母替代部分鱼粉作为蛋白源,在水库网箱中养殖淡水白鳗,能提高增重率,降低饵料系数,以添加 17% 的酵母效果最好[30];饵料活性干酵母可促进中华绒螯蟹的生长,且能有效地增强中华绒螯蟹的抗病力[31];饲料中添加高活性干酵母(高于 800 mg/kg BW)时,可明显提高中华鳖血清中溶菌酶的浓度,并可显著增强中华鳖幼鳖血清中补体 C3 和 C4 的活性[32],显著增强中华鳖幼鳖对人工感染嗜水气单胞菌的抵抗力适宜添加量以 1200 mg/kg BW 为宜。饲料添加汉姆孙酵母 C21(*Hanseniaspora opuntiae* C21)能有效抑制海参中黄海西瓦式菌(*Shewanella marisflavi*)AP629[33]和灿烂弧菌(*Vibrio splendidus*)NB13 的生长[34];可促进仿刺参(*Apostichopus japonicus*)的免疫,增强其对灿烂弧菌的抵抗力[35];饵料添加活酿酒酵母还可以增强鲈鱼的抗氧化性能[36]。

2　酵母培养物

酵母培养物,是指在特定工艺条件控制下由酵母菌在特定的培养基上经过充分的厌氧发酵后形成并加工处理得来的酵母类制品。其主要成分为酵母细胞外代谢产物、经过发酵后变异的培养基和少量已无活性的酵母细胞。酵母培养物的生物活性并不依赖于活的酵母菌体,而是发酵的代谢产物[37]。酵母培养物中含有大量寡糖、氨基酸、多肽、蛋白质、有机酸、维生素、生物酶和其他有益的未知生长因子[38]。酵母培养物在饲料行业的使用始于 20 世纪 20 年代中期,最早是作为反刍动物的蛋白质补充饲料。饲料添加酵母培养物可有效提高家畜对饲料粗蛋白质、粗纤维、矿物质、维生素等养分及能量的消化吸收;促进幼、病畜胃肠道发育,增强机体的免疫

力和抗病力，预防和治疗腹胀腹泻等消化不良症状，提高家畜生产性能。因为酵母培养物具有绿色无污染、营养丰富、易消化吸收、促生长、提高免疫力且不产生耐药性等优点，已被广泛应用于畜禽水产养殖等领域。

2.1 在单胃动物养殖领域的研究与应用

酵母培养物在单胃动物中的应用较少，但也显示了其对动物生长性能的促进作用。日粮中添加酵母培养物对缓解仔猪断奶应激和促进断奶后仔猪生长发育和预防仔猪腹泻有一定的作用[39]。酵母培养物具有免疫调节功能，可以扰动断奶仔猪和肠道微生物间的相互关系，增强其免疫功能[40]。

2.2 在反刍动物养殖领域的研究与应用

酵母类产品可以影响反刍动物肠道微生物区系组成[41]、影响瘤胃中挥发性脂肪酸的产量，最终促进泌乳奶牛牛乳中的蛋白和脂肪含量[42]。对于产奶量的作用，有关饲喂酵母的结果则不统一，多数确定酵母有明显的促进牛奶产量[41,43-46]，少数试验只表现出了促进趋势[47-49]，也有无作用的研究结果出现[50,51]。日粮添加酵母培养物提高幼龄反刍动物的生长性能[52]和饲料转化率[53]；以麦秸为基础日粮配伍添加酵母培养物并不能影响干物质采食量，产奶量与其质量，但可促进丙酸的产生[54]。山羊添加产甘油酵母培养液可以提高血浆葡萄糖浓度、瘤胃挥发酸以及丙酸比例，降低氨态氮[55]水平。日粮添加酵母培养物可提高绒山羊血清谷胱甘肽过氧化物酶活力提高、血浆超氧化物歧化酶活力及总抗氧化能力，提升了绒山羊的抗氧化能力[56]。

2.3 在禽类养殖领域的研究与应用

肉仔鸡日粮中添加 0.25% 剂量的酵母培养物可以强化免疫机能，并对营养素的消化率、肠粘膜形态起着有益的作用，在应激条件下添加量可适当提高[57]；在玉米-豆粕-杂粕型饲粮基础上添加适量酵母培养物，能够改善蛋鸡料蛋比、提高产蛋率和平均蛋重、延长产蛋高峰期、降低死淘率，添加量为 0.22% 表现优异[58]。间隔添加酵母培养比持续低剂量添加更能有效降低应激对火鸡饲料利用率的降低[59]。

2.4 在水产动物养殖领域的研究与应用

在养殖现场水池中放置塑料网箱，饵料添加酵母培养物可提高养殖水池塑料网箱内的南美白对虾的成活率；能显著促进虾生长、降低饲料系数、提高存活率和增强虾耐运输能力[60,61]。

3 酵母水解物

酵母水解物是酵母细胞的水解产物，通过自溶或添加外源酶水解得到，成份含有丰富的氨基酸、小肽、B 族维生素、矿物质等多种营养物质[62]，因此在设计动物饲料配方时，可以将酵母水解物作为氨基酸、多肽及 B 族维生素的补充剂。酵母水解物因含有部分仍具有活性的酶，以激活赭曲霉素的生物转化，降低毒素的损害[63]。酵母水解物中核苷酸物质的含量在一般在 2.3% ~8% 以上，是酵母水解物中最重要的成分之一。酵母源大分子物质的有益作用主要得益于其中的核苷酸[64]，核苷酸可以通过增加空肠粘液蛋白、DNA 浓度以及双糖酶活性，促进断奶大鼠发育肠道细胞的增殖和分化[65]。酵母水解物中的核苷酸对动物尤其是幼年动物具有重要的营养作用。核苷酸具有增强机体免疫力、促进细胞再生与修复、促进幼年动物肠道正常发育、抗氧化及维持肠道正常菌群的作用；另外，水解物中的肌苷酸和鸟苷酸可作为增鲜呈味剂，在促进动物采食方面具有较好的应用前景。小肽、维生素、肌醇等营养物质有利于肠道健康，核苷酸在 DNA/RNA 合成和复制中起着重要作用，它同样参与调节新陈代谢和细胞的信号传导，体内一定的核苷酸水平是动物快速生长的重要保障。酶解酵母可以促进营养物质的消化吸收和促进饲料转化，不过这一效果可被同时饲料添加的枯草芽孢杆菌抵消[66]。

3.1 在单胃动物养殖领域的研究与应用

仔猪断奶后失去了十分重要的母乳核苷酸营养源，而额外补充核苷和核苷酸能显著改善仔猪肠道形态及降低腹泻发生率。适当的核苷酸水平可以促进肠道的早期发育及其结构的完整性，并且某些核苷酸，如肌苷酸、鸟苷酸也具有一定的诱食作用，可以促进幼龄动物的采食量，提高增重和饲料转化率。断奶仔猪日粮添加酵母核苷酸能提高日增重、提高饲料转化率，不同程度地降低腹泻率；能不同程度地提高仔猪肠道中双歧杆菌、乳酸杆菌的数量，降低大肠杆菌的数量，改善断奶仔猪肠道菌群结构[67]。短期添加酵母核苷酸并不影响仔猪小肠内消化酶的活性[68]。组合使用酵母培养物和酶解物可以增加哺乳过度期奶牛产奶中脂肪、蛋白、乳糖以及 β-羟基丁酸的量，降低葡萄糖的量，但对产乳量没有影响，对摄食行为与代谢有作用[69]。

3.2　在反刍动物养殖领域的研究与应用

酵母培养物在反刍动物营养中研究与应用较少。酵母培养物可以提高乳牛泌乳性能,酶解酵母可以促进牛乳蛋白含量和乳房健康[70]。

3.3　在禽类养殖领域的研究与应用

酵母源大分子物质可明显提肉鸡高绒毛高度和绒毛/隐窝比值,提升其消化吸收能力。另外,还可促进局部和系统的促炎性因子和抗炎性因子的表达,对盲肠扁桃体的作用更为明显,明显减低死亡率[71]。酵母核苷酸显著提高了胸肌粗蛋白含量,降低粗脂肪含量[72]。

3.4　在水产动物养殖领域的研究与应用

以加酶饲料酵母替代秘鲁鱼粉饲养丰鲤,主要生长指标及饲料系数均无显著差异,但饲料成本显著降低,替代比例为 25% ~75%[73];添加酵母核苷酸可显著提高凡纳滨对虾部分免疫指标酶的活性,提高对虾的生长速度,降低饲料系数,同时能有效改善对虾对低氧和低温的耐受能力,综合效果以 344 g/t 试验组最好[74];基础饲料添加 172 mg/kg 酵母核苷酸组鲫鱼血清中溶菌酶和碱性磷酸酶的活性显著提高,添加 344 mg/kg 酵母组异育银鲫的生长和饲料利用均得到了明显地改善[75];添加量在 1000 mg/kg ~2000 mg/kg 的范围内,酵母水解物对中华鳖的诱食效果均显著优于未添加组,且以 2000 mg/kg 的添加饵料组诱食效果最佳[76]。

4　酵母细胞壁

酵母细胞壁的厚度为 0.1 ~0.3 μm,重量占细胞干重的 18% ~30%,其结构分为三层:外层为甘露糖和蛋白质结合物,中间层为 β-(1,3)、β-(1,6)葡聚糖,内层为几丁质。在过去 20 多年里,酿酒酵母细胞壁一直在动物养殖领域大量应用[77-78]。应用与饲料行业的酵母细胞壁是通过将酵母培养后,收集酵母细胞,并将其通过超声波等手段使其细胞裂解,然后经过多次清洗过滤,将其中的可溶性物质在高温、酸碱处理后进行离心分离,提取的细胞壁于特定的温度和压强下进行喷雾干燥而得到的一类绿色无污染的产品。酵母细胞壁活性成分主要由 β-葡聚糖(57.0%)、甘露寡糖(6.6%)、糖蛋白(22.0%)和几丁质组成,其它成分如蛋白质、核酸、类脂和灰分占其干重的 20.0% 以下[79]。酵母细胞壁成分的添加可以促进肠道粘膜层的发育[4,80]。从酵母细胞壁分离得到的酵母多糖包含多种物质如 β-葡聚糖以及甘露寡糖,已被作为益生元广泛应用与畜禽养殖以及水产行业[81-83]。β-葡聚糖是可以促进机体体重增加和饲料转化率的增强[84]。

酵母细胞壁物质在酸解过程中较稳定,其碎片能完好无损地通过胃或皱胃,作为一种免疫促进剂,通过激发和增强机体免疫力,改善动物健康来提高生产性能,尤其是能充分发挥幼龄动物的生长潜力。酵母细胞壁成分可以促进多种动物中的体液免疫,包括牛[85]、猪[86]和鸡[87]。β-葡聚糖作为一种生物调节物质对动物免疫产生作用,虽然效果并不一致[88-92]。酵母细胞壁成分中的甘露寡糖是乳酸菌的发酵基质和能量来源[93],还可促进肠道粘膜层完整性,抑制病原菌的入侵[94]。甘露寡糖能够结合病原微生物的 D-甘露糖受体,阻断其附着于肠道表面,使病原微生物失去在肠道定殖的能力,并与甘露寡糖一同被排出体外[95,96]。酵母细胞壁作为抗生素的替代品被用于动物生产和人类保健食品行业[97]。酵母源甘露寡糖和葡聚糖具有很好的抗氧化性能[98,99]。酵母水解物和酵母细胞壁都可促进肉鸡的生长和饲料转化效率的增强,考虑到增强的生长特性以及体液免疫的作用,酵母细胞壁是一更好的生长促进剂[100]。

谷物储存过程中添加汉姆逊酵母可以有效抑制霉菌和多种肠杆菌的定殖[101]。酵母的组分细胞壁也和饲料行业麻烦面对的毒素问题相关。饲料添加酵母细胞壁可以减缓环孢霉素 A 对肉鸡免疫能力的损伤[102],缓解黄曲霉素对母羊的损害[103],部分中和自然霉变中的镰刀菌素的毒害作用[104]。甘露寡糖对黄曲霉毒素、玉米赤霉烯酮和猪曲霉毒素的结合率分别为 82.51%、51.6% 和 26.4%,其中对黄曲霉毒素的结合能力主要取决于 pH、毒素的浓度以及甘露寡糖的剂量[105]。酵母细胞壁成分可有效屏蔽玉米烯酮,其效果要优于水合铝硅酸钠钙,即便是在低 pH 值溶液中,也和后者对玉米烯酮的效果一致[106],虽然也有不同的看法[107]。

4.1　在单胃动物养殖方面的研究与应用

断奶仔猪日粮中添加酵母葡聚糖在一定程度上可提高机体对蛋白质的利用效率,减轻饲料蛋白质供应不足对仔猪生长和体液免疫的影响[108];而添加酵母甘露寡糖同样可增加猪初乳中 IgG 含量[109]。

4.2　在反刍动物养殖方面的研究与应用

犊牛饲料每日添加酵母细胞壁,可有效降低粪便中大肠杆菌数量以及呼吸道疾病发生概率[110];

饲料添加酵母葡聚糖可以激活特异性或非特异性的免疫应答，提高犊牛的免疫功能，减少小牛应激，提高其对细菌和病毒的抵抗能力[111]。

4.3 在禽类养殖方面的研究与应用

啤酒酵母细胞壁可以促进肉鸡肠道食糜中营养物质吸收[80]。饲料添加酵母细胞壁有益于1～60日龄蛋鸡的生长性能和肠道组织形态[112]。酵母细胞壁不仅能促进肠道微生物区系向着有利用机体健康的方向发展[113]，还可增强肉鸡和蛋鸡中的抗体反应[114-116]；酵母提取物可调节火鸡氧化应激条件下的天然免疫[117]。酵母细胞壁促进空肠代谢以及健康相关基因的表达，并有利于肉鸡的抗病毒以及抗细菌反应[118]。酵母(*Pichia guilliermondii*)细胞壁的添加可以促进球虫感染后的肉鸡生长性能，降低粪便中卵囊数目，增强炎症因子的表达[119]，抑制肉鸡因球虫感染引发的盲肠大肠杆菌和沙门氏菌的定制，并促进IFNγ的表达[120]。甘露寡糖的添加可以通过T辅助细胞通路促进产气荚膜梭菌感染肉鸡的炎症反应[121]。

4.4 在水产动物养殖方面的研究与应用

酵母多糖的添加可以促进多种鱼类的生长及其免疫性能[50,122]。饲喂或腹腔注射酵母多糖能显著地提高凡纳对虾、克氏原螯虾肝胰腺、血清中的酸性磷酸酶和碱性磷酸酶的活性，明显增强对哈维弧菌感染的抵抗能力[31]；饵料添加酵母多糖可以增强斑点叉尾鮰鱼血液中白细胞吞噬能力，促进其肠道发育[123]。酵母源β-葡聚糖和甘露寡糖可增强大西洋鳕鱼对病原菌的抵抗[124]；全雄奥尼罗非鱼饲料中添加1.0%～1.5%的β-葡聚糖可以明显改善其生长性能和抗嗜水气单胞菌感染的能力[125]；在鲤鱼饲料添加酵母甘露寡糖可提高鲤鱼的免疫功能[126]。

5 富集微量元素酵母

矿物质是养殖个体所必需的营养物质，虽然用量很少，但在机体生长代谢中必不可少。现在主要通过在饲料中添加无机矿物质来补充。由于无机矿物质的生物利用率较低，使得多数饲料中的矿物质随同养殖粪便排泄到环境中。在饲料中使用的矿物质纯度远低医药行业，往往同时含有砷、铬、镉、锰等重金属，给生态带来沉重的压力[127]。提高矿物质的生物利用率对养殖业的可持续发展尤为重要。对于如何提高，利用工业微生物，尤其以酵母为载体富集微量元素，使之由无机态转为有机态，提高生物利用率，已成为国内外研究重点。目前饲料工业上用酵母生产的有机微量元素主要有铜、铬、硒、铁、锌等[128]。具体为在酵母培养过程中加入金属的无机盐，使金属离子以有机离子的形式在酵母中富集。矿物质元素均是以离子或分子形式同蛋白质结合成稳定的有机体，既消除了无机金属盐的特有气味，也提高其利用率。单胃和复胃动物对酵母菌体蛋白质结合的矿物质元素，均比无机盐元素更易吸收。酵母中的有机矿物质元素比无机矿物质元素利用性也更好[129,130]。羔羊饲喂添加酵母，还可以促进和改善钾、铜、锌等矿物质的沉积。

5.1 在单胃动物养殖方面的研究与应用

微量元素硒通过参与合成含硒酶中的硒代半胱氨酸呈现生理功能[131]，影响机体抗氧化、甲状腺激素代谢、氧化还原蛋白等过程[132]以及免疫功能[133]。硒还参与微生物的蛋白分解[134]。饮食添加酵母硒可比无机硒有效提高血液和乳汁中的硒浓度[135]。与亚硒酸钠比，饲料添加酵母硒可降低肥育猪肌肉中滴水损失，提高Huntera值[136]；饲料添加酵母锌可以提高断奶仔猪的平均日采食量，降低饲料的料肉比，日粮中添加200 mg/kg酵母锌即可达到添加2000 mg/kg氯化锌的促生长效果。对于断奶仔猪，饲料添加酵母铜可得到比无机铜更好的促生长效果，并可有效增强机体抗氧化能力，最佳添加量为100 mg/kg[137]。

5.2 在反刍动物养殖方面的研究与应用

随着补硒天数的增加，乳牛血清中淋巴细胞的转化能力增强，T淋巴细胞百分率增多，说明硒对T淋巴细胞免疫功能有增强作用[138]。酵母硒有效提高牛初乳以及乳汁中的硒含量，增强牛乳的抗氧化功能[139]。结合在酵母细胞蛋白质分子中的有机金属离子，能在瘤胃里被瘤胃微生物分解由前胃吸收，或直接进入小肠被肠内消化酶水解而吸收。

5.3 在禽类养殖方面的研究与应用

酵母硒较之无机硒在降低鸡肉的肌肉滴水损失、改善嫩度方面效果更强[140]；更能促进胚胎发育和雏鸡出壳，雏鸡出生最初几天的抗氧化能力也与蛋中的硒含量有关，使雏鸡的成活率和整齐度得到提高，有机硒组所产鸡蛋的硒含量比无机硒组高出了30%[141]；酵母铬在一定程度上能缓解热应激对蛋鸡的负面影响，即能显著降低破蛋率，略微提高蛋鸡的采食量、产蛋率和平均蛋重[142]；饲料添加酵母

碘可促进蛋鸡产蛋中的碘含量[143]。

5.4　在水产动物养殖方面的研究与应用

与无机硒比较而言,酵母硒能更好地提高斑点叉尾鮰谷胱甘肽过氧化物酶活性,促进其生长[144];酵母硒也可积极地影响中华鳖的免疫力和抗氧化力[145]。

6　小结

本文综述了酵母源饲料原料在养殖业中的研究与应用。明确了现有的有关酵母源饲料原料的研究重点为不同酵母源饲料原料对养殖动物整体的影响,主要聚焦在贴近实际生产。具体包涵酵母源饲料对养殖动物生长性能、免疫性能以及常规生理生化指标。整体来讲,饲料配伍使用酵母源饲料可以促进养殖动物生长性能,营养物质的消化吸收以及增强机体天然免疫。对于酵母源饲料有益于养殖动物生长健康的机理研究相对较少,对其效能机理的进一步阐释应该是将来的研究方向。

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