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籽实青贮的研究与利用进展

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摘要:随着城乡居民生活水平的不断提升,农产品消费结构发生显著变化,肉类消费比重逐年攀升,而口粮作物占比下降。为满足消费需求的转变,农业生产方式亟待调整,饲料资源的高效利用成为关键。籽实青贮作为一种有效的籽实饲料保存方法,具备高干物质回收率、节约劳动力、减少能源消耗的优势,成为缓解饲料资源紧缺现状的重要途径。本研究基于国内外籽实青贮的文献及团队的实践经验,综合分析了籽实青贮的发酵品质影响因素,包括收获期、含水量、破碎粒度、添加剂及贮藏时长,探讨了其在畜禽饲养中的利用价值,并展望了籽实青贮技术与现代农业科技体系融合的前景。本研究不仅为优质籽实青贮的调制和利用提供了理论支持和实践指导,还为保障国家粮食安全提供了方法和策略。

关键词:籽实;青贮;发酵品质;饲用价值

Progress in research and utilization of grain silage

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Abstract: With the ongoing improvement of living standards of urban and rural residents, the consumption pattern of agricultural products has undergone significant changes. Meat consumption has been increasing annually, while the per capita consumption of staple crops has declined. To meet the changing consumer demand, patterns of agricultural production need to be urgently adjusted, and the efficient utilization of livestock feed resources has emerged as a key component for change. Grain ensiling is an efficacious method for the conservation of feed grains, and offers many advantages, such as a high nutrient dry matter recovery rate, reduced labor requirement, and reduced energy consumption. Thus, grain silage provides an important option to address scarcity of feed resources for livestock. Drawing on both the research literature on grain silage and the practical experience of our research team, this study comprised an in-depth analysis of the factors affecting the fermentation quality of grain silages, including harvesting time, moisture content, crushed particle size, role of additives, and storage duration. Our study also explored the utilization and feed value of grain silage in livestock and poultry rearing and the potential for integrating grain silage technology into modern agricultural systems. Therefore, this study both provides theoretical support and practical guidance for the preparation and utilization of high-quality grain silage, and also addresses the need to identify methods and strategies for ensuring national food security.

Key words: grain; silage; fermentation quality; feeding value

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随着经济的发展和人民生活水平的提高，人们对于食物的需求正逐渐从简单的“吃得饱、吃得好”向“吃得营养、吃得健康”转变[1]。这一转变不仅推动了食物消费结构的变革，表现为口粮消费的下降和肉类、蛋类、奶制品、水果及蔬菜等非主粮食物消费的迅速增长，而且也对农业生产方式提出了新要求[2]。然而，我国农业生产结构调整的速度仍滞后于食物需求结构转变的速度，这导致了口粮有余而饲料短缺的矛盾日益凸显[3]。为了有效缓解这一矛盾，满足人们对多样化、高质量食物的需求，并保障农业的可持续发展，我国需要探索新的农业生产与饲料资源高效利用途径。

青贮籽实作为一种潜在的饲料资源，其研究与应用具有重要意义。相较于全株作物青贮，籽实青贮在营养价值保留、储存便利性及成本效益等方面具有独特优势，但相关研究却相对有限。因此，深入探究青贮籽实的生产技术及其在畜禽饲养中的应用，对于提高饲料资源利用效率、丰富食物供给、促进农业可持续发展具有重要意义。本研究旨在综合分析籽实青贮饲料生产的关键技术和应用价值，探讨其在我国农业生产与畜禽饲养中的实际应用前景，以期为有效利用畜禽饲料资源、提高食物多元化供给能力提供理论支持和实践指导。

1 籽实青贮的发展

籽实青贮技术的发展，源于对籽实饲料实现长期保存与营养价值保存双重需求的不断探索。传统的干燥方法虽然能够在一定程度上延长籽实饲料的保质期，但往往伴随着营养成分的损失和能耗的增加。而籽实青贮技术则通过收获成熟的籽实，并立即进行粉碎、压缩等处理后密封存储于青贮窖或青贮袋中，在厌氧环境中利用乳酸菌让籽实进行发酵并贮存，从而实现籽实的长期保存和营养价值的最大化[4]。这一技术的起源可追溯至20世纪80年代初，当时英国通过资金补贴鼓励建设籽实饲料贮存库，其中包括湿谷物贮存库，用于畜牧饲料的贮藏[5]。我国东北长期存在玉米(*Zea mays*)收获水分过高而烘晒条件又不足的矛盾，且随玉米产量增长使矛盾更显突出[6]。1982年，技术人员在东北地区开始引进该项技术，青贮试验取得成功[7]。1987年，日本专利局公布了Frees等申请的“青贮饲料和含水量较高的谷物保存法”专利，为籽粒特别是含水量高的籽实如玉米[8]的妥善贮藏提供了新方法，有效减少了营养成分的损失。籽实青贮技术的应用不仅能够有效降低因不良天气导致的籽实收获损失，还显著节约了劳动力和干燥成本。此外，它还能够避开集中收获，从而分散劳动力和收获机械的集中度。

常见籽实青贮饲料主要包括禾谷类籽实和豆类籽实，此外油菜(*Brassica napus*)、向日葵(*Helianthus annuus*)和亚麻(*Linum usitatissimum*)等籽实虽不属于这两大类别，但它们在籽实青贮中也展现出了一定的应用价值[9]。目前，籽实青贮饲料的研究领域虽然仍集中在玉米[10-12]，但越来越多的学者开始关注其他籽实[如高粱(*Sorghum bicolor*)[13]、稻谷(*Oryza sativa*)[14-15]、豌豆(*Pisum sativum*)[16]、大豆(*Glycine max*)[17]、羽扇豆(*Lupinus micranthus*)[18]等]的青贮潜力，这些新的研究方向不仅丰富了饲料资源，也为畜牧业的发展提供了更多元化的选择。综上所述，籽实青贮技术的发展不仅解决了饲料长期保存与营养价值保持的难题，还为畜牧业的可持续发展贡献了新的力量。

2 籽实青贮发酵品质的影响因素

2.1 收获期

青贮的发酵品质深受原材料营养成分的影响，其中收获期是一个至关重要的因素。研究表明，不同收获期会影响籽实的产量、干物质含量及营养品质[19]，进而间接影响籽实的青贮发酵品质[20]。相较于整株植物青贮的研究，目前针对收获期对籽实青贮发酵品质影响的研究虽然有限，但已有的研究成果仍提供了宝贵的见解。王兴亚等[21]分别在含水量20%～30%、30%～40%、40%～50%时收获玉米籽粒并发酵90 d后，发现含水量为30%～40%、40%～50%时乳酸菌大量繁殖，pH值更低，霉菌数量与呕吐毒素含量也显著低于含水量为20%～30%时。Maruyama等[22]详细研究了稻谷从乳熟至完熟期化学成分的变化以及青贮的发酵特性，发现随着成熟阶段的推进，稻谷的产量、干物质含量逐渐增加，粗纤维含量逐渐降低，粗蛋白、粗脂肪、粗灰分以及水溶性碳水化合物含量保持相对稳定，青贮稻谷的pH值显著上升，氨态氮(ammonia nitrogen，NH_3-N)、乳酸、乙酸含量降低。这表明，适当推迟收获期能够有效提升稻谷的总产量，但过度推迟可能导致稻谷含水量下降，增加青贮长期保存中腐败菌滋

生的风险。Nakui 等[23]的研究进一步强调了稻谷成熟阶段对青贮饲料品质的重要性。结果表明，稻谷在成熟过程中，碳水化合物含量显著增加，而粗蛋白和中性洗涤纤维含量则逐渐下降，青贮后 pH 值相应升高。这不仅深化了对稻谷成熟特性的理解，更强调了把握最佳收获时机的重要性。综上所述，适时收获籽实能够平衡其产量和品质，优化青贮发酵效果，为畜牧业提供更加优质的饲料资源。一般来说，早期收获籽实虽能提供较高的营养品质，但可能伴随较低的产量；而晚期收获的籽实虽能提供较高的产量，但青贮品质可能难以达到最佳水平[24]。因此，在选择籽实收获期时，需要在产量和品质之间取得平衡，综合考虑农业生产的目标，如稻谷可以在黄熟期收获，玉米可以在蜡熟期收获，以确保最大化产量并同时获得最佳品质的青贮饲料。为了达到这一目的，建议将收获期控制在籽实的生理成熟期，此时植物已停止向籽实输送养分，且籽实的含水量适中，比较适合青贮加工。

2.2 含水量

在籽实青贮过程中，适宜的水分含量是确保乳酸菌正常活动、提升发酵品质的关键因素。籽实水分含量过高，梭菌大量繁殖会降低发酵品质，并影响适口性，使得家畜对饲料的采食量减少、干物质的摄入不足，难以满足动物生长发育所需的营养需求[25]。相反，水分含量过低，则会影响压实效果，促进霉菌、细菌等好氧有害微生物的繁殖，抑制乳酸菌的生长。这种不平衡的微生物活动容易导致青贮饲料发生腐败或霉变，严重影响其发酵品质和有氧稳定性，最终对家畜的健康和生产性能构成潜在威胁[26]。因此，在青贮加工过程中，必须控制原料的含水量在适宜的范围内。Huck 等[27]将田间干燥至含水量 14% 的高粱籽粒调节至 25%、30% 和 35% 含水量，青贮 90 d 后饲喂母牛，发现水分含量为 25%～30% 时进行青贮，可以改善青贮高粱的发酵特性，提高饲养场母牛的增重效率。Tamra 等[28]通过在干玉米籽实中添加不同水平的湿豆腐渣提高其水分含量，结果表明当豆腐渣的添加量不超过 200 $g \cdot kg^{-1}$时，混合后的玉米籽实水分能够控制在 50% 以内，能提高蛋白质含量，降低 NH_3-N 含量；当湿豆腐渣添加量超过 200 $g \cdot kg^{-1}$时会导致水分过高，有氧稳定性下降。一般情况下，青贮饲料的发酵品质与其有氧稳定性之间存在一定的矛盾，即发酵品质越好，其有氧稳定性往往越差[29]。Silva 等[30]研究玉米籽实直接青贮与添加水分青贮发现，添加水分能够提升发酵品质，但同时也增加了有氧稳定性下降的风险。为了缓解这一问题，可以通过添加接种剂提高有氧稳定性[31]。一般来说，籽实青贮适宜含水量为 25%～35%，具体的水分含量还应根据籽实类型和当地实际情况进行相应调整。

2.3 破碎粒度

籽实破碎是籽实青贮前的关键环节，直接影响青贮饲料的发酵品质与动物的消化率。完整的玉米、稻谷等籽粒因其自然状态下被坚韧的种皮所包裹，表面营养物质有限，水分含量低，且自然附着的乳酸菌数量不足，导致青贮发酵进程缓慢[32]。此外，环境因素（如温度、湿度等）波动以及青贮管理不当，都可能为腐败菌的滋生提供可乘之机，从而极大地增加了青贮失败的风险。对籽实饲料进行适当压扁或者破碎处理，不仅可以提高青贮发酵品质[33]，还能提升动物的利用率，进而提高动物的生产性能[34]。然而，过度处理籽实不仅会提升加工成本，还会降低青贮籽实的消化率并增加动物瘤胃酸中毒的风险[35-36]。Inoue 等[37]研究发现，将完全成熟的饲料稻谷粉碎后青贮 60 d，显著降低了 pH 值，提高了乳酸含量，同时显著减少了丁酸和乙醇的生成量。Saylor 等[38]将含水量约 30% 的玉米籽粒分别进行粗磨[平均粒度（3789±40）μm]与精磨[平均粒度（984±42）μm]处理并青贮 28 d 后，发现精磨处理增加了乳酸的浓度并降低了 pH 值，同时提高了瘤胃内淀粉的降解效率。Saylor 等[39]在保持籽实颗粒完整性的前提下用锤子手工破碎玉米籽实，并将完整和破碎的玉米籽实青贮 30 d，结果表明经破碎处理的玉米籽实在青贮过程中 pH 值显著降低，乳酸含量显著增加，且淀粉的消化率显著提高。在合理粒度范围内，青贮原料的干物质含量越高，则粉碎应越细；干物质含量越低，则应适当增大粉碎粒度[40]。将籽实进行压碎但仍保持颗粒完整性能显著提高其发酵品质，值得注意的是，合理粉碎粒度需根据饲喂对象及籽实种类相应调整，以确保在优化发酵品质的同时，满足动物对饲料的需求和消化特性。

2.4 添加剂

青贮发酵是一个复杂的微生物活动和生物化学变化的过程[41]。由于青贮原料上附着乳酸菌较少，自然发酵早期乳酸菌无法大量繁殖成为主导微生物，尤其是裹包完整的籽实饲料容易发酵失败。为确保青贮时乳酸菌成

为优势菌种，通常会添加乳酸菌制剂，增加青贮饲料中的乳酸菌数量，使pH值迅速下降。Miyaji等[42]研究认为，对低水分的稻谷进行适当加水、接种乳酸菌及碾碎处理，能促进稻谷发酵，提高青贮的整体发酵品质。Silva等[43]研究发现，接种布氏乳杆菌(*Lactobacillus buchneri*)可提高添加水分的玉米籽实开窖后的营养品质和发酵品质，提高有氧稳定性。Taylor等[44]报道，添加布氏乳杆菌虽然不影响高水分玉米籽实的发酵速度，但在长期贮藏(92 d)后，较高的添加量可以增加乙酸的产生，并显著提高有氧稳定性。除了传统的乳酸菌制剂外，青贮添加剂还包含有机酸及其盐类、酶制剂、营养性添加剂及复合添加剂类等。部分植物的次生代谢产物如肉桂醛、香叶醇和柠檬醛等具有抑菌、抗氧化、促生长和免疫调节等生物活性功能，还能抑制黄曲霉等霉菌毒素的生长，防止饲料霉变[45]。张帆等[46]将布氏乳杆菌、嗜酸乳杆菌(*Lactobacillus acidophilus*)和丙酸钠直接添加到玉米籽实后青贮60 d，发现添加微生物的青贮饲料pH值显著降低，其中添加嗜酸乳杆菌的pH值最低(pH值为4.8)，添加丙酸钠可有效抑制有害菌的生长，增加青贮玉米籽实的有氧稳定性。Nakui等[23]报道指出添加丙酸和氨水可以防止稻谷青贮料好氧变质。在籽实青贮制作过程中不同添加剂处理对其发酵品质的改善效果有所差异。罗攖宁等[47]研究表明添加短乳杆菌(*Lactobacillus brevisi*)能降低青贮甜玉米籽实NH_3-N含量，添加香草醛在显著降低青贮甜玉米籽实NH_3-N含量的同时还能提高其干物质和可溶性糖含量，降低干物质损失率。梁丹丹等[48]通过在玉米籽粒中添加肉桂醛、柠檬醛和丁香酚发酵14 d，发现肉桂醛对玉米中黄曲霉毒素B1的生长及产毒抑制性最强。Rezende等[49]研究发现，组合添加植物乳杆菌(*Lactobacillus plantarum*)、乳酸片球菌(*Pediococcus acidilactici*)和粪肠球菌(*Enterococcus faecium*)的青贮玉米籽实有氧稳定性显著高于对照。为保证籽实青贮发酵质量，提高有氧稳定性，在籽实青贮过程中选择适宜的添加剂是非常有必要的。

2.5 青贮时长

青贮饲料的生产过程一般分为4个主要阶段：初始有氧、主要发酵期、稳定贮藏期和饲喂期[50]。青贮过程中的化学变化在发酵2周左右会迅速达到稳定状态，但细微的生化变化可能持续数月，从而影响青贮饲料质量。适当增加青贮时长有利于乳酸积累，创造酸性条件抑制有害微生物繁殖，从而提高籽实的发酵品质[51]。Carvalho等[52]研究发现，随着添加水分的玉米籽实青贮时间的延长，可利用氧气含量降低，青贮饲料pH值下降，好氧菌群逐渐减少，有利于特定耐酸微生物的生长，促进青贮发酵。Silva等[53]研究表明，青贮90 d的高水分玉米籽实相比青贮21 d的，pH值和乙醇含量显著降低，发酵品质得到改善。Inoue等[54]通过调整粉碎稻谷的含水量至30%并接种乳酸菌，将青贮时长从60 d延长到365 d后，发现青贮稻谷的乳酸含量虽有所降低，但pH值仍保持在小于4.2的可接受范围。对于富含淀粉的籽实而言，随着青贮时间的延长，虽然青贮后瘤胃原位淀粉消化率更高，但青贮籽实中整体可利用的营养成分却呈下降趋势[55]。这是因为长时间的青贮会降低籽实可溶性糖和淀粉的含量，甚至在极端情况下(如青贮超过1年)，可能导致严重的蛋白质水解反应，进一步降低饲料的营养价值[56]。因此，在追求淀粉高消化率的同时，也需关注青贮时间对籽实整体营养成分的潜在影响。综合上述研究结果，建议籽实青贮的适宜时长在60 d以上，但不要超过356 d。

3 青贮籽实利用研究

目前国内外谷物的青贮与利用大多局限于农场内自产自销或就地销售，其利用对象主要是牛、猪、禽类等[57-60]。

3.1 猪的利用

在猪的饲养方面，籽实青贮饲料表现出多重显著优点。断奶仔猪由于消化系统尚未成熟，加之断奶、饲料转换及环境变化的压力，容易出现体重下降和腹泻等问题[61]。籽实青贮饲料中富含乳酸和乙酸等有机酸，作为天然的酸化剂，能有效调节仔猪肠道pH值，抑制有害菌的生长，维持肠道内环境的稳定，平衡肠道菌群，从而预防腹泻，缓解断奶综合征的症状[62]。同时，在日粮中添加籽实青贮料可改善饲料的风味，刺激猪的食欲，增加猪采食量和料重比，进而提高猪的生长性能[63]。黄修奇等[64]和王中华等[65]研究发现，在断奶仔猪日粮中添加玉米籽实青贮料能抑制仔猪肠胃中大肠杆菌、肠球菌、梭状芽孢杆菌等有害菌的活动，同时促进有益菌群的生长繁殖，有利于胃肠道内环境的稳定，降低仔猪腹泻率，增加采食量和日增重，改善猪的生长性能。Wang等[66]研究探讨了用嗜酸乳

杆菌、乳酸片球菌发酵的高水分玉米籽实饲喂断奶仔猪,发现添加剂发酵能够调节断奶仔猪的肠道微生物菌群,降低结肠中细菌微生物群的多样性和丰富度,且减少了粪便中大肠菌群数量。Niven等[67]研究发现,向高水分玉米籽实青贮中添加植酸酶,可以显著提升青贮籽实中可溶性磷含量,同时有效释放植酸结合的钾,从而有利于提高猪的生长速度。

3.2 禽类的利用

在禽类饲料中添加青贮籽实,能显著提升采食量和生长速度,缩短养殖周期。在蛋鸡饲料中适量添加玉米籽实青贮料不仅可优化肠道环境,还可改善蛋品质,如增加蛋重及降低破损率。王中华等[68]和方磊涵等[69]发现在蛋鸡的饲料中添加青贮玉米籽实能显著提高产蛋率并降低料蛋比,增强蛋鸡免疫功能,提升免疫指标。Kunishige等[70]发现,在蛋鸡的饲养中添加青贮玉米籽实可以显著提高采食量,并使其肌肉在色泽上展现出更高的亮度和黄度,为饲料配方优化提供了新的视角。添加青贮籽实至饲料中,对肉鸡具有替代部分传统饲料的潜力,在维持或提高生产性能的同时,促进肠道健康,并降低生产成本。Barcellos等[71]研究发现,在肉鸡日粮中高单宁含量(1.14% DM)的青贮高粱籽实可替代33%的玉米籽实,而低单宁含量(0.69% DM)的青贮高粱籽实则能完全替代玉米籽实,这两个替代策略非但未对肉鸡的生产性能造成负面影响,反而有助于降低单位生产成本。Konieczka等[72]研究表明,高水分玉米籽实在肉鸡日粮中适量替代干玉米籽实,显著提高了肉鸡血红蛋白浓度、盲肠α-半乳糖苷酶活性,降低了α-阿拉伯呋喃糖苷酶活性,优化了生产性能及肠道健康。Cruz-Polycarpo等[73]进一步研究证实,高水分玉米籽实在肉鸡饲料中的替代率可达40%~60%,从肉鸡生产性能角度出发,可替代日粮中40%的干玉米籽实;若以营养消化率为考量,则替代率可高达60%。

3.3 牛、羊的利用

青贮籽实被广泛用于提升牛、羊的饲养效益,通过增加产奶量、日增重、采食量和消化率,显著降低饲养成本[74]。研究发现,破碎的青贮高水分玉米籽实能有效缓解瘤胃淀粉发酵,从而优化瘤胃环境,显著提高阉牛的日增重和干物质消化率[75-77],同时对泌乳奶牛的牛奶和蛋白质产量产生积极影响[78-80]。此外,将玉米籽实加到甘蔗(*Saccharum officinarum*)中进行青贮能增强肉牛瘤胃对淀粉的消化能力[81]。Miyaji等[42]研究发现,饲喂粉碎后进行青贮的稻谷能改善肉牛营养消化效率及瘤胃发酵特性,特别是粗蛋白与粗脂肪的整肠消化率得到了提升。此外,Podversich等[82]研究发现,粉碎的青贮高粱籽实可以增加肉用母牛采食量。综上所述,青贮籽实在提高肉牛的肥育性能和奶牛的产奶量方面具有潜在的优势。值得注意的是,湿贮籽实混合饲料虽能促进牛瘤胃发酵,提升经济效益,但需谨慎控制饲喂量,以免对瘤胃菌群造成不利影响[83-84]。青贮籽实对羊的饲喂效果研究较少。Cardoso-Gutiérrez等[85]在以全株玉米青贮为主的日粮中添加87 $g\cdot kg^{-1}$的青贮葵花籽,提高了奶羊对中性洗涤纤维和酸性洗涤纤维的摄入量和消化率,且不会显著改变奶羊的生产参数。Ítavo等[86]研究发现,在以蕨麻(*Argentina anserina*)干草为主要粗饲料的基础上,高水分玉米青贮可作为高粱青贮的有效替代品,不会影响羊对营养物质的消化、吸收和利用。Hara[87]研究发现,与磨碎相比,氢氧化物和氨处理对青贮稻谷的总可消化营养物质含量没有积极影响,且粪便中未被消化的米粒颗粒的比率较高,因此应将软稻谷磨碎,以提高绵羊稻谷的利用效率。这表明在羊的饲养中需要更加注意饲料的加工处理,以确保最佳的饲养效果。

4 小结与展望

籽实青贮技术作为应对食品需求结构转变与饲料资源短缺挑战的举措,正逐步展现出在农业可持续发展中的重要价值。该技术有效减少了恶劣天气对籽实收获的影响,通过青贮处理,省去了传统干燥环节,具有降低生产成本的潜力,并大幅节约了劳动力与能源消耗。同时,其分散收获时段的特点,灵活规避了集中收获期的压力,有效缓解了劳动力与机械资源的紧张,提升了农业生产流程的整体效率与可持续性。青贮籽实作为一种潜在的饲料资源,其关键技术在于适时收获、控制水分、适当破碎以及加入适宜添加剂,能够有效改善籽实的发酵品质,提高其在畜禽饲养中的应用效果。这些关键技术有助于青贮籽实在猪、禽、牛、羊等畜禽饲养中被更广泛应用,并提升动物的生产性能、肠道健康和饲养效益。展望未来,籽实青贮技术将与现代农业科技体系深度融合,以精准农业为导向,融合微生物组学、生物信息技术等尖端科技,实现青贮过程的精细化调控与高效管理。未来期待,通

过持续的研究与实践,籽实青贮技术能够成为推动农业绿色转型、保障国家粮食安全的重要力量,为构建更加可持续、高效的农业生产模式贡献力量。

参考文献 References:

[1] Zhang C, Zhou Z. An analysis of China's grain production and demand situation in the medium and long term from the perspective of population structure transition and policy suggestions. Macroeconomics, 2022(12): 126-139, 167.
张琛, 周振. 人口结构转型视角下中长期中国粮食产需形势分析与政策建议. 宏观经济研究, 2022(12): 126-139, 167.

[2] Fan Z Y, Sun Y S. Big food view: Scientific connotation, value implications, and practical requirements. Journal of Northwest A&F University (Social Science Edition), 2023, 23(6): 68-75.
樊志远, 孙云舒. 论大食物观的科学内涵、价值意蕴与实践要求. 西北农林科技大学学报(社会科学版), 2023, 23(6): 68-75.

[3] Tan G W, Wang X D, Wang J M, *et al*. National food security strategy in the new situation. Strategic Study of CAE, 2023, 25(4): 1-13.
谭光万, 王秀东, 王济民, 等. 新形势下国家食物安全战略研究. 中国工程科学, 2023, 25(4): 1-13.

[4] Chen W Z. Study on wet storage and feeding value of cereal abroad. Feed Research, 1979(6): 40-42.
陈唯真. 国外谷物湿贮与饲用价值的研究. 饲料研究, 1979(6): 40-42.

[5] Алешина И М, Chen Z Y. Organization of feed production in England. Grassland and Turf, 1984(6): 8-12.
Алешина И М, 陈樟勇. 英国饲料生产的组织. 草原与牧草, 1984(6): 8-12.

[6] Liu R Z. Wet storage of corn. Crop, 1992(2): 39-40.
刘瑞征. 玉米湿储法. 作物杂志, 1992(2): 39-40.

[7] Xu L Z, Lv G Y, Han M T. Wet storage and feeding of grain corn. Heilongjiang Animal Science and Veterinary Medicine, 1982(4): 18-20.
徐立志, 吕国英, 韩名堂. 籽粒玉米湿贮和饲喂. 黑龙江畜牧兽医, 1982(4): 18-20.

[8] Han M. Silage and high moisture cereal preservation methods. Feed China, 1988(4): 39-41.
寒梅. 青贮饲料和含水量高的谷物保存法. 饲料广角, 1988(4): 39-41.

[9] Mombach R, Kennelly Y J, Kramer K G, *et al*. Effect of grain type and processing method on rumen fermentation and milk rumenic acid production. Animal, 2010, 4(8): 1425-1444.

[10] Kaufman T D. The effects of planting techniques on maize grain yield and silage production. Bloomington-Normal: Illinois State University, 2013.

[11] Junges D, Morais G, Spoto M H F, *et al*. Short communication: Influence of various proteolytic sources during fermentation of reconstituted corn grain silages. Journal of Dairy Science, 2017, 100(11): 9048-9051.

[12] Ferraretto L F, Taysom K, Taysom D M, *et al*. Relationships between dry matter content, ensiling, ammonia-nitrogen, and ruminal *in vitro* starch digestibility in high-moisture corn samples. Journal of Dairy Science, 2014, 97(5): 3221-3227.

[13] Paschoaloto J R, Guimaraes L A, Matos E M A, *et al*. Performance of Nellore bulls fed with rehydrated corn silage or rehydrated sorghum silage or sorghum grain in substitution of corn grain. Journal of Animal Science, 2020, 97(3): 419.

[14] Uegaki R, Kawano K, Ohsawa R, *et al*. Effect of different silage storing conditions on the oxygen concentration in the silo and fermentation quality of rice. Journal of Agricultural and Food Chemistry, 2017, 65(24): 4877-4882.

[15] Uegaki R, Kobayashi H, Inoue H, *et al*. Changes of fumonisin production in rice grain during ensiling. Animal Science Journal, 2013, 84(1): 48-53.

[16] Bachmann M, Wensch-Dorendorf M, Kuhnitzsch C, *et al*. Changes in composition and diversity of epiphytic microorganisms on field pea seeds, partial crop peas, and whole crop peas during maturation and ensiling with or without lactic acid bacteria inoculant. Microbiology Spectrum, 2022, 10(4): e0095322.

[17] Jobim C C, Junior M C, Junior V H, *et al*. Chemical composition and quality of conservation of corn (*Zea mays* L.) grain silages with differents levels of soy grains (*Glycine max* Merril). Semina-Ciencias Agrarias, 2010, 31(3): 773-782.

[18] Gefrom A, Ott E M, Hoedtke S, *et al*. Effect of ensiling moist field bean (*Vicia faba*), pea (*Pisum sativum*) and lupine (*Lupinus* spp.) grains on the contents of alkaloids, oligosaccharides and tannins. Journal of Animal Physiology and Animal Nutrition, 2013, 97(6): 1150-1160.

[19] Park J H, Cheong Y K, Kim K H, *et al*. Feed value and fermentation quality of wheat grain silage with respect to days after heading in Honam region of Korea. Journal of the Korean Society of Grassland and Forage Science, 2018, 38(2): 112−119.

[20] Park J H, Oh Y J, Cheong Y K, *et al*. Feed value and fermentation quality of covered barley grain silage with respect to days after heading in Honam region of Korea. Korean Journal of Crop Science, 2017, 62(1): 16−23.

[21] Wang X Y, Zhang S M, Guo Y Q, *et al*. Effects of harvest time on quality and mycotoxin of high-moisture corn kernel during wet storage. Shandong Agricultural Sciences, 2022, 54(4): 146−150.
王兴亚,张守梅,郭玉秋,等. 收获期对高水分玉米籽粒湿贮品质及真菌毒素的影响. 山东农业科学, 2022, 54(4): 146−150.

[22] Maruyama S, Yokoyama I, Asai H, *et al*. Influence of ripening stages on the quality of whole crop silage and grain silage of fodder rice. Asian-Australasian Journal of Animal Sciences, 2005, 18(3): 340−344.

[23] Nakui T S, Masaki T, Aihara N, *et al*. The nutritive value of unhulled rice stored as high moisture grain feed. Tohoku Agricultural Research, 1986(39): 177−178.

[24] Song T H, Oh Y J, Kang H J, *et al*. Effect of feed value and fermentative quality according to harvesting time of barley and wheat grain silage. The Korean Society of Crop Science, 2015, 60(2): 174−179.

[25] Pereira D M, Santos E M, Oliveira J S, *et al*. Effect of cactus pear as a moistening additive in the production of rehydrated corn grain silage. The Journal of Agricultural Science, 2021, 159(9/10): 731−742.

[26] Wang Y, Wang C, Zhou W, *et al*. Effects of wilting and *Lactobacillus plantarum* addition on the fermentation quality and microbial community of *Moringa oleifera* leaf silage. Frontiers in Microbiology, 2018, 9(1): 1817.

[27] Huck G L, Kreikemeier K K, Bolsen K K. Effect of reconstituting field-dried and early-harvested sorghum grain on the ensiling characteristics of the grain and on growth. Animal, 1999, 77(5): 1074−1081.

[28] Tamra T T, Bueno A V I, Jobim C C, *et al*. Effect of okara levels on corn grain silage. Revista Brasileira de Zootecnia, 2020, 49(1): e20190184.

[29] Santos M V F, Gómez C A G, Perea J M, *et al*. Factors affecting the nutritive value tropical forages silages. Arquivos de Zootecnia, 2010, 59(R): 24−43.

[30] Silva C M, Amaral P N C, Baggio R A, *et al*. Stability of high moisture corn silage and corn rehydrated. Revista Brasileira de Saude e Producao Animal, 2016, 17(3): 331−343.

[31] Horrocks R D, Vallentine J F. Harvested forages. California, USA: Academic Press, 1999: 325−337.

[32] Zhang N J, Liu J L, Lin B, *et al*. Research progress on composition characteristics of epiphytic microorganisms of green forage and their effects on silage quality. Chinese Journal of Animal Nutrition, 2023, 35(5): 2828−2835.
张男吉,刘江莉,林波,等. 青绿饲料附生微生物组成特点及其对青贮品质影响的研究进展. 动物营养学报, 2023, 35(5): 2828−2835.

[33] Yan X, Wu Z Z, Zuo Y C, *et al*. Silage characteristics of different corn plant parts and strategies for improving their silage quality. Acta Agrestia Sinica, 2023, 31(8): 2275−2286.
严旭,吴子周,左艳春,等. 玉米植株不同部位的青贮特征及其品质提升策略. 草地学报, 2023, 31(8): 2275−2286.

[34] Du M Y. Effects of different TMR diets on performance, gastrointestinal microbiome and metabolome of fattening lambs. Tai'an: Shandong Agricultural University, 2022.
杜美妤. 不同TMR日粮对育肥羊生产性能、胃肠道微生物组及代谢组的影响研究. 泰安: 山东农业大学, 2022.

[35] Koenig K M, Beauchemin K A, Rode L M. Effect of grain processing and silage on microbial protein synthesis and nutrient digestibility in beef cattle fed barley-based diets. Journal of Animal Science, 2003, 81(4): 1057−1067.

[36] An J. Nutritional mechanism and prevention of rumen acidosis in ruminant. China Feed, 2007(2): 23−26.
安娟. 反刍动物发生瘤胃酸中毒的营养机制及其防治. 中国饲料, 2007(2): 23−26.

[37] Inoue H, Tohno M, Kobayashi H, *et al*. Effects of moisture control, addition of glucose, inoculation of lactic acid bacteria and crushing process on the fermentation quality of rice grain silage. Grassland Science, 2013, 59(2): 63−72.

[38] Saylor B A, Casale F, Sultana H, *et al*. Effect of microbial inoculation and particle size on fermentation profile, aerobic stability, and ruminal *in situ* starch degradation of high-moisture corn ensiled for a short period. Journal of Dairy Science, 2020, 103(1): 379−395.

[39] Saylor B A, Diepersloot E C, Heinzen C, *et al*. Effect of kernel breakage on the fermentation profile, nitrogen fractions, and *in*

vitro starch digestibility of whole-plant corn silage and ensiled corn grain. JDS Communications, 2021, 2(4): 191－195.

[**40**] Dai Z X, Li Z, Liao C X, *et al*. Analysis on key points of high moisture corn silage making. China Feed, 2022(17): 111－116.
戴志翔, 李征, 廖晨星, 等. 高湿玉米青贮制作关键点分析. 中国饲料, 2022(17): 111－116.

[**41**] Muck R E, Nadeau E M G, McAllister T A, *et al*. Silage review: Recent advances and future uses of silage additives. Journal of Dairy Science, 2018, 101(5): 3980－4000.

[**42**] Miyaji M, Inoue H, Kawaide T, *et al*. Effects of conservation method and crushing method of rice grain on rumen fermentation and nutrient digestibility in steers. Animal Feed Science and Technology, 2017, 227(1): 75－83.

[**43**] Silva N C D, Nascimento C F, Nascimento F A, *et al*. Fermentation and aerobic stability of rehydrated corn grain silage treated with different doses of *Lactobacillus buchneri* or a combination of *Lactobacillus plantarum* and *Pediococcus acidilactici*. Journal of Dairy Science, 2018, 101(5): 4158－4167.

[**44**] Taylor C C, Kung L. The effect of *Lactobacillus buchneri* 40788 on the fermentation and aerobic stability of high moisture corn in laboratory silos. Journal of Dairy Science, 2002, 85(6): 1526－1532.

[**45**] Chao S C, Young D G, Oberg C J. Screening for inhibitory activity of essential oils on selected bacteria, fungi and viruses. Journal of Essential Oil Research, 2000, 12(5): 639－649.

[**46**] Zhang F, Han S M, Li J C, *et al*. Effect of different additives on fermentation quality of maize seed. Journal of Grassland and Forage Science, 2018(A01): 14－15.
张帆, 韩淑敏, 李井春, 等. 不同添加剂对玉米籽实发酵品质的影响. 草学, 2018(A01): 14－15.

[**47**] Luo Y N, Luo Y, Bao J Z, *et al*. Effects of adding lactic acid bacteria and vanillin on silage quality of corn seed. Feed Industry, 2020, 41(19): 50－53.
罗攖宁, 罗盈, 包锦泽, 等. 添加乳酸菌和香草醛对甜玉米籽实青贮饲料品质的影响. 饲料工业, 2020, 41(19): 50－53.

[**48**] Liang D D, Xing F G, Wang Y, *et al*. Inhibitory of the growth of *Aspergillus flavus* and aflatoxin B_1 in maize by plant extracts. Cereal & Feed Industry, 2015, 12(8): 51－56.
梁丹丹, 邢福国, 王奭, 等. 植物提取物抑制玉米中黄曲霉生长及产毒研究. 粮食与饲料工业, 2015,12(8): 51－56.

[**49**] Rezende A V, Rabelo C H S, Veiga R M, *et al*. Rehydration of corn grain with acid whey improves the silage quality. Animal Feed Science and Technology, 2014, 197(1): 213－221.

[**50**] Wallace R J, Chesson A. Biotechnology in animal feeds and animal feeding. Weinheim, Germany: VCH, 1995: 33－54.

[**51**] Schmidt R J, Hu W, Mills J A, *et al*. The development of lactic acid bacteria and *Lactobacillus buchneri* and their effects on the fermentation of alfalfa silage. Journal of Dairy Science, 2009, 92(10): 5005－5010.

[**52**] Carvalho P D A, Fernandes J, Silva É B, *et al*. Effects of hybrid, kernel maturity, and storage period on the bacterial community in high-moisture and rehydrated corn grain silages. Systematic and Applied Microbiology, 2020, 43(5): 126－131.

[**53**] Silva T, Smith M L, Barnard A M, *et al*. The effect of a chemical additive on the fermentation and aerobic stability of high-moisture corn. Journal of Dairy Science, 2015, 98(12): 8904－8912.

[**54**] Inoue H, Tohno M, Matsuo M, *et al*. Farm-scale method for producing high-quality rice grain silage. Grassland Science, 2013, 59(4): 226－229.

[**55**] Baron V S, Stevenson K R, Buchanan-Smith J G. Proteolysis and fermentation of corn-grain ensiled at several moisture levels and under several simulated storage methods. Canadian Journal of Animal Science, 1986, 66(2): 451－461.

[**56**] Hoffman P C, Esser N M, Shaver R D, *et al*. Influence of ensiling time and inoculation on alteration of the starch-protein matrix in high moisture corn. Journal of Dairy Science, 2011, 94(5): 2465－2474.

[**57**] Diogenes L V, Edvan R L, Medeiros E D S, *et al*. Physicochemical composition and fatty acid profile of goat kids' meat fed ground-corn-grain silage rehydrated with different additives. Animals, 2022, 13(1): 31.

[**58**] Oliveira K S, Salvati G S, Morais G, *et al*. Effect of length of storage and chemical additives on the nutritive value and starch degradability of reconstituted corn grain silage. Agronomy, 2023, 13(1): 209.

[**59**] Torres R N S, Ghedini C P, Coelho L M, *et al*. Meta-analysis of the effects of silage additives on high-moisture grain silage quality and performance of dairy cows. Livestock Science, 2021, 251(9): 104618.

[**60**] Neto A M S, Goulart L, Ribeiro A, *et al*. Propionic acid－based additive with surfactant action on the nutritive value of rehydrated corn grain silage for growing ewe lambs performance. Animal Feed Science and Technology, 2022, 294(12): 115515.

[61] Fu X G. Prevention and treatment of weaning stress syndrome in large-scale pig farm piglets. Livestock and Poultry Industry, 2020, 31(9): 87－89.
伏秀阁. 规模化猪场仔猪断奶应激综合症的防治. 畜禽业, 2020, 31(9): 87－89.

[62] Liu Y, Qin X G. Application of chemical agents in the production of weaned piglets. Feed Research, 2005, 28(6): 32－34.
刘勇, 秦绪光. 酸化剂在断奶仔猪生产中的应用. 饲料研究, 2005, 28(6): 32－34.

[63] Lan J W, Wang L, Zhao W J, *et al*. Research progress on application of acidifiers in pig production. Feed Research, 2023, 46(12): 159－162.
兰静雯, 王磊, 赵文俊, 等. 酸化剂在猪生产中的应用研究进展. 饲料研究, 2023, 46(12): 159－162.

[64] Huang X Q, Wang Z H. Effect of acidified maize on growth performance and gastrointestinal environment in weaned piglets. Chinese Journal of Animal Science, 2011, 47(17): 31－33.
黄修奇, 王中华. 酸化玉米对断奶仔猪生长性能和胃肠道内环境的影响. 中国畜牧杂志, 2011, 47(17): 31－33.

[65] Wang Z H, Zhou D Z. Effects of maize seed silage on growth performance and immune function of weaning piglets. Cereal & Feed Industry, 2011, 12(10): 51－53.
王中华, 周德忠. 青贮玉米籽实对断奶仔猪生长性能和免疫功能的影响. 粮食与饲料工业, 2011, 12(10): 51－53.

[66] Wang J Q, Yin F G, Zhu C, *et al*. Evaluation of probiotic bacteria for their effects on the growth performance and intestinal microbiota of newly-weaned pigs fed fermented high-moisture maize. Livestock Science, 2012, 145(1/2/3): 79－86.

[67] Niven S J, Zhu C, Columbus D, *et al*. Impact of controlled fermentation and steeping of high moisture corn on its nutritional value for pigs. Livestock Science, 2007, 109(1/2/3): 166－169.

[68] Wang Z H, Fang L H, Zhao X J, *et al*. Silage corn seeds affect performance, egg quality and intestinal environment in laying hens. Chinese Journal of Animal Nutrition, 2012, 24(8): 1571－1576.
王中华, 方磊涵, 赵香菊, 等. 青贮玉米籽实对蛋鸡生产性能、蛋品质和肠道内环境的影响. 动物营养学报, 2012, 24(8): 1571－1576.

[69] Fang L H, Yang J Y, Wang Z H. Effects of silage maize on production performance and non specific immunity of laying hens. Cereal & Feed Industry, 2012, 12(12): 54－56.
方磊涵, 杨继远, 王中华. 青贮玉米籽实对蛋鸡生产性能和非特异性免疫的影响. 粮食与饲料工业, 2012, 12(12): 54－56.

[70] Kunishige K, Koda Y, Hara S. Effect of high moisture ear corn and high moisture shelled corn feeds on laying hen performance. The Journal of Poultry Science, 2016, 53(4): 284－290.

[71] Barcellos L C G, Furlan A C, Murakami A E, *et al*. Nutritional evaluation of high moisture sorghum silage grain with high or low tannin content for broilers. Revista Brasileira de Zootecnia, 2006, 35(1): 104－112.

[72] Konieczka P, Mikulski D, Ognik K, *et al*. Chemically preserved high-moisture corn in the turkey diet does not compromise performance and maintains the functional status of the gut. Animal Feed Science and Technology, 2020, 263: 114483.

[73] Cruz-Polycarpo V C, Sartori J R, Gonçalves J C, *et al*. Feeding high-moisture corn grain silage to broilers fed alternative diets and maintained at different environmental temperatures. Brazilian Journal of Poultry Science, 2014, 16(4): 449－457.

[74] Li Y P. Effect of wet storage of grain corn on dairy cows. Modern Animal Husbandry Science & Technology, 2000(2): 9－10.
李玉萍. 籽粒玉米湿贮饲喂奶牛的效果观察. 现代畜牧科技, 2000(2): 9－10.

[75] Stock R A, Sindt M H, Cleale R M, *et al*. High-moisture corn utilization in finishing cattle. Journal of Animal Science, 1991, 69(4): 1645－1656.

[76] San Emeterio F, Reis R B, Campos W E, *et al*. Effect of coarse or fine grinding on utilization of dry or ensiled corn by lactating dairy cows. Journal of Dairy Science, 2000, 83(12): 2839－2848.

[77] He L W, Wu H, Wang G G, *et al*. The effects of including corn silage, corn stalk silage, and corn grain in finishing ration of beef steers on meat quality and oxidative stability. Meat Science, 2018, 139(5): 142－148.

[78] Arcari M A, Martins C M M R, Tomazi T, *et al*. Effect of substituting dry corn with rehydrated ensiled corn on dairy cow milk yield and nutrient digestibility. Animal Feed Science and Technology, 2016, 221(11): 167－173.

[79] Clark J H, Croom W J, Harshbarger K E. Feeding value of dry, ensiled, and acid treated high moisture corn fed whole or rolled to lactating cows. Journal of Dairy Science, 1975, 58(6): 907－916.

[80] Oba M, Allen M S. Effects of corn grain conservation method on feeding behavior and productivity of lactating dairy cows at two dietary starch concentrations. Journal of Dairy Science, 2003, 86(1): 174－183.

[**81**] Gómez-Vázquez A, Pinos-Rodríguez J M, García-López J C, *et al*. Nutritional value of sugarcane silage enriched with corn grain, urea, and minerals as feed supplement on growth performance of beef steers grazing stargrass. Tropical Animal Health and Production, 2011, 43(1): 215－220.

[**82**] Podversich F, Roskopf S, Abdelhadi L. Effects of sorghum silage kernel processing on intake and apparent total tract digestibility of beef heifers. Journal of Animal Science, 2020, 98(4): 153－154.

[**83**] Forsyth J G, Mowat D N, Stone J B. Feeding value for beef and dairy cattle of high moisture corn preserved with propionic acid. Journal of Animal Science, 1972, 52(1): 73－79.

[**84**] Peng S Y. Effects of feeding different levels of high-moisture corn on rumen fermentation, production performance and rumen microbial diversity in dairy. Daqing: Heilongjiang Bayi Agricultural University, 2023.
彭述宇. 饲喂不同水平湿贮玉米对奶牛瘤胃发酵、生产性能及瘤胃菌群多样性的影响. 大庆: 黑龙江八一农垦大学, 2023.

[**85**] Cardoso-Gutiérrez E, Narváez-López A C, Robles-Jiménez L E, *et al*. Production performance, nutrient digestibility, and milk composition of dairy ewes supplemented with crushed sunflower seeds and sunflower seed silage in corn silage-based diets. Animals, 2020, 10(12): 2354.

[**86**] Ítavo C C, Morais M G, Ítavo L, *et al*. Intake and digestibility of nutrients in sheep diets based on corn and sorghum grain high moisture silages. Arquivo Brasileiro De Medicina Veterinaria E Zootecnia, 2009, 61(2): 452－459.

[**87**] Hara S. Effect of grinding, sodium hydroxide and anhydrous ammonia treatments on digestibility of soft rice grain silage in cow. Nihon Chikusan Gakkaiho, 2010, 81(2): 153－159.