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Digestion Characteristics of Starch in Animal Feed and Application of Amylase: Postprint

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Abstract

Starch constitutes a crucial energy source for animals, and its utilization efficiency determines the overall energy utilization efficiency in animals. Starch accounts for a relatively high proportion in diets; however, young animals exhibit low starch utilization efficiency, which is further compromised by the deficiency of endogenous amylase in their intestinal tract, leading to energy wastage. Dietary supplementation with exogenous amylase can enhance starch utilization efficiency and improve animal production performance. This review comprehensively examines the classification of starch, its structural properties and their influence on nutrient digestion and metabolism, the interaction mechanisms between starch digestion/metabolism and those of other nutrients, and the application of exogenous amylase in animal production, with the aim of establishing a theoretical foundation for the widespread application of amylase.

Full Text

Digestive Characteristics of Dietary Starch in Animals and Application of Amylase

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Abstract

Starch is a crucial energy source for animals, and its utilization rate directly determines the efficiency of energy utilization. Starch constitutes a high proportion of animal diets, yet young animals exhibit low starch utilization efficiency. This inefficiency is compounded by insufficient endogenous amylase secretion in the intestinal tract of young animals, leading to reduced starch utilization and

energy waste. Dietary supplementation with amylase can improve starch utilization and enhance animal production performance to a certain extent. This review synthesizes current research on starch classification, structural properties and their effects on nutrient digestion and metabolism, the linkage mechanisms between starch digestion and other nutrient metabolic processes, and the application of exogenous amylase in animal production, aiming to establish a theoretical foundation for the broader adoption of amylase supplementation.

Keywords: starch; structural properties; digestive characteristics; amylase; regulatory mechanism

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Energy is a vital nutritional factor for animal health and nutrition, representing a key focus in feed nutritional value evaluation systems. Starch serves as the primary form and source of energy, and its utilization efficiency determines the animal's overall energy utilization rate. Starch digestion and utilization are closely related to its structural properties and the activity of starch-digesting enzymes in the animal's intestinal tract. Research has demonstrated that young animals exhibit low starch utilization efficiency, with low ileal digestibility that does not increase with age. Microscopic examination of digesta reveals numerous undigested starch particles that enter the hindgut for fermentation, resulting in energy loss. Numerous studies have also shown that the activity of intestinal amylase is very low in young livestock and poultry, even showing a declining trend, which reduces energy utilization efficiency and limits early growth. Supplementing young animal diets with appropriate amounts of exogenous amylase can compensate for insufficient endogenous enzyme secretion, assist in starch digestion and utilization, and promote growth. Therefore, adding exogenous amylase to early-stage animal diets is of significant importance.

1 Classification of Starch

Starch exists widely in plant tissues and cells in granular form and serves as an important energy source for animals. Based on different glucose polymerization patterns, starch can be divided into amylose and amylopectin. From a nutritional perspective, starch is classified into rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS). RS is further categorized into four types based on source and enzyme resistance: RS1 refers to physically enclosed starch formed mainly through mechanical processing; RS2 comprises native starch granules with high enzyme resistance due to their special conformation; RS3 represents retrograded starch formed after gelatinization and cooling; and RS4 denotes modified starch with altered molecular structure obtained through chemical methods or genetic modification. Based on crystalline patterns, starch is classified as A-type, B-type, or C-type. A-type starch granules are relatively large, generally 10-38 μ m in diameter, lens-shaped, accounting for 70%-80% of total endosperm starch weight but less than 10% of

total granule number. B-type granules are smaller than 10 μm , spherical or irregular polyhedral, comprising less than 30% of total endosperm starch weight but over 90% of total granule number. C-type starch is a mixture of A-type and B-type granules. Starch granules consist of crystalline and amorphous regions, with the crystalline regions formed by amylopectin and amorphous regions composed of amylose, alternating to create the granular structure. Some researchers have found that crystalline regions are actually formed by both amylose and amylopectin, connected by hydrogen bonds between them.

2.1 Structural Properties of Starch

Starch structure changes with increasing amylose content, altering its properties accordingly. Zhang et al. found that as amylose content increased, the molecular weight of corn starch gradually decreased, along with its root-mean-square radius of gyration. Li et al. reported that with increasing amylose content, A-type granules transformed from full, smooth, waxy spheres or polyhedrons into shrunken, dull, irregular polyhedrons, while B-type granules changed from full, smooth small spheres to non-waxy oval shapes, eventually distorting into irregular particles. Zhang et al. discovered that waxy and normal corn starches belong to A-type, while high-amylose corn starches (Hylon V and Hylon VII) are B-type. Normal and waxy corn starches contain higher SDS content, whereas high-amylose corn starch contains significantly higher RS content than high-amylopectin starch. Yin et al. found that both A-type and B-type starches contain more amylopectin than amylose, though this difference is greater in A-type than in B-type starch. Amylose content in starch granules affects gelatinization temperature and viscosity properties due to the restraining effect of amylose molecules on the granule surface against amylopectin molecules. Amylose and amylopectin molecules intertwine and bind together throughout the starch molecule, inhibiting gelatinization and swelling. When amylose content is low, this restraining effect is relatively small, allowing starch to swell and gelatinize at lower temperatures while amylopectin molecules easily extend, resulting in higher viscosity. As amylose content increases, this restraining effect becomes more pronounced, and the crystalline structure formed by amylopectin raises gelatinization temperature. Additionally, amylose-lipid complexes exhibit enzyme resistance, making starch granules difficult to gelatinize.

2.2.1 Digestive Characteristics of Starch

Starch structure influences its properties and affects animal digestion. Huang et al. measured the *in vitro* digestive characteristics of cooked corn starch and found that as amylose content increased, RDS content gradually decreased. Except for normal corn with relatively high SDS content, overall SDS content decreased progressively, while high-amylose corn starch showed higher RS content. Zhang et al. reported that native cereal starch hydrolysis begins with the enlargement of surface pores and channels, hydrolyzing from the pore region outward in a so-called “inside-out” digestion pattern. This pattern results from

the uneven distribution of starch granules from a low-density center to a denser matrix and applies only to porous A-type starches. For non-porous B-type starches, enzymes digest from the resistant surface in an “outside-in” pattern, which is one reason for the difficulty in digesting B-type starches.

2.2.2 Effects of Different Amylose/Amylopectin Ratios on Nutrient Digestion and Metabolism

The amylose/amylopectin ratio affects animal nutrient digestion and metabolism. *In vitro* experiments show that the amylose/amylopectin ratio in corn is extremely significantly positively correlated with RS content and extremely significantly negatively correlated with digestible starch (DS) content. *In vivo* experiments demonstrate that this ratio significantly affects ileal starch digestibility, digestible energy, and energy digestibility in piglets. Dai et al. found that different dietary amylose/amylopectin ratios significantly affect amino acid digestibility and energy utilization in broilers, thereby influencing production performance, with 0.23 identified as the optimal ratio. Subsequent research revealed that when broilers consumed diets with a 0.11 amylose/amylopectin ratio, blood glucose and insulin concentrations fluctuated dramatically, reducing carcass quality. As the dietary amylose/amylopectin ratio increased, blood glucose and insulin concentrations remained more stable, significantly increasing beneficial microorganisms such as lactobacilli, bifidobacteria, and enterococci in the hindgut. This may occur because increased amylose/amylopectin ratio slows starch digestion and glucose release, resulting in smaller blood glucose fluctuations while increasing fermentable carbohydrates reaching the hindgut, promoting beneficial microbial growth. The increased abdominal fat rate in broilers may be related to glucose regulation of fatty acid synthase expression.

Different starch sources and compositions in diets affect the amylose/amylopectin ratio, leading to varying degrees of digestion and energy utilization efficiency in animals, consequently affecting production performance. Using corn, brown rice, glutinous rice, and RS as starch sources, experimental results showed that the RS group reduced pig performance, while the corn group achieved the best performance. The RS diet group exhibited relatively stable blood glucose, insulin concentrations, and insulin/glucose ratios compared to other groups, but also showed lower protein deposition rates.

3 Linkage Mechanisms Between Starch Digestion/Metabolism and Other Nutrient Digestion/Metabolism

After dietary starch enters the intestine, amylase degrades it into glucose. A small portion of glucose enters the bloodstream through glucose transporters—sodium-dependent glucose transporter 1 (SGLT1) and facilitative glucose transporter 2 (GLUT2)—while most is converted to lactate. Lactate content is related to starch digestion speed. Elevated blood glucose stimulates pancreatic insulin

secretion, which regulates cells to increase glucose and amino acid absorption, promoting protein synthesis and reducing blood glucose and amino acid concentrations. When blood glucose is low, pancreatic glucagon secretion is stimulated. The body first mobilizes hepatic glycogen for energy, but glycogen reserves are limited. When hepatic glycogen is insufficient, glucagon promotes protein conversion to glucose and fat conversion to glycerol and fatty acids. This functional mode requires a series of synthesis and decomposition processes far less efficient than direct intestinal glucose absorption. Therefore, efficient energy supply requires continuous glucose delivery from the intestine to achieve amino acid sparing.

Starch structure and digestive properties affect glucose absorption and utilization, thereby influencing energy efficiency. RDS releases large amounts of glucose rapidly, causing dramatic increases in blood glucose and insulin concentrations with short insulin peak duration, leading to blood glucose dropping below normal ranges, which is unfavorable for glucose utilization and promotes fat production. SDS releases glucose slowly, maintaining blood glucose and insulin concentrations within normal ranges, allowing continuous glucose utilization, reducing fat conversion, decreasing amino acid use for energy supply and gluconeogenesis, and increasing protein deposition. Starch digestive properties also affect amino acid absorption. Glucose and amino acid absorption in the intestine share similar mechanisms, both requiring Na⁺-coupled transport, so their absorption may compete. Consequently, high intestinal glucose absorption can inhibit amino acid absorption.

4 Application of Exogenous Amylase in Animals

Young animals have underdeveloped digestive tracts and pancreases, resulting in insufficient intestinal amylase secretion, reduced starch utilization efficiency, and considerable starch entering the hindgut for fermentation, causing energy waste. Exogenous amylase supplementation can compensate for this deficiency, promote endogenous amylase secretion, assist starch digestion, increase apparent metabolizable energy and nutrient digestibility, reduce digestive organ indices, and improve animal production performance.

4.1 Classification and Function of Exogenous Amylase

Amylases are active substances secreted by animals to aid digestion, representing a class of enzymes that act on various starch glycosidic bonds. Major starch-degrading enzymes include α -amylase, β -amylase, glucoamylase, pullulanase, and isoamylase. α -Amylase acts on α -1,4-glycosidic bonds, hydrolyzing starch into disaccharides, oligosaccharides, and dextrans, and can only decompose the linear portions of amylose and amylopectin. β -Amylase acts on β -1,4-glycosidic bonds (branch points in amylopectin), hydrolyzing starch into disaccharides, oligosaccharides, and dextrans. Glucoamylase hydrolyzes linear disaccharides, oligosaccharides, and dextrans to produce glucose and fructose, sequentially hydrolyzing

-1,4-glycosidic bonds from the non-reducing end of starch to generate glucose. Isoamylase acts on -1,6-glycosidic bonds, producing amylose and dextrins.

4.2 Effects of Exogenous Amylase on Nutrient Digestibility and Production Performance

Supplementing early-stage animal diets with exogenous amylase can improve energy utilization efficiency, apparent metabolizable energy, and nutrient digestibility. Gracia et al. demonstrated that adding 47.5 U/kg α -amylase to broiler diets significantly improved performance in 1-4-day-old broilers and increased intestinal villus height, consistent with earlier findings that α -amylase supplementation improved nutrient digestibility and performance in corn-soybean meal diets. Tang et al. also reported that adding 2,500 U/kg α -amylase to cassava-based diets promoted average daily feed intake and average daily gain in broilers aged 1-21 days, improved apparent starch digestibility and nitrogen retention, and enhanced dietary energy utilization. Gencoglu et al. found in dairy cows that feeding low-starch diets supplemented with amylase improved feed conversion efficiency and potential economic benefits, with an optimal amylase level of 300 U/kg. Li et al. showed in pigs that adding compound amylase to corn-based or corn-wheat diets extremely significantly improved dry matter and organic matter digestibility, and significantly increased nitrogen apparent digestibility, biological value, and net utilization.

4.3 Effects of Exogenous Amylase on Digestive Organ Indices

Research has found that appropriate dietary amylase levels can promote starch digestion, reduce digestive burden, and lower digestive organ indices. Zhang et al. discovered that adding 1,500 U/kg amylase to corn-soybean meal diets significantly reduced jejunal and pancreatic organ indices. Zhu et al. also reported that adding enzyme preparations containing amylase to corn-soybean meal diets reduced the relative weight of the pancreas in 7-21-day-old broilers, indirectly decreasing digestive organ indices, consistent with findings by Jiang et al. However, some studies have reported that dietary amylase supplementation does not significantly affect digestive organ indices.

4.4 Mechanisms of Exogenous Amylase Regulating Endogenous Amylase Secretion

Insufficient endogenous amylase secretion in young animals impedes starch digestion and absorption, reduces energy utilization efficiency, and decreases production performance. Exogenous amylase can synergistically act with endogenous amylase to degrade dietary starch, increasing substrate concentration in the digestive tract. This signal is transmitted to the pancreas via the digestive tract, regulating endogenous amylase secretion. Additionally, exogenous amylase acts at slightly different sites than endogenous amylase, altering dietary structure and transmitting this signal to regulate pancreatic secretion. Furthermore, exogenous amylase can accelerate glucose release, affecting blood glucose

and insulin concentrations, which stimulates the pancreas through blood glucose levels to regulate pancreatic amylase mRNA expression and influence protein deposition. Jiang et al. found that adding exogenous amylase to corn-soybean meal diets increased intestinal amylase activity, but high doses downregulated pancreatic amylase mRNA expression, suggesting possible negative feedback regulation. Shen et al. reported that amylase supplementation in corn-cooked full-fat soybean meal diets promoted pancreatic and jejunal amylase activity in piglets. Yu et al. demonstrated that adding amylase to weaned piglet diets increased jejunal pancreatic amylase activity after two weeks. However, some scholars have reported that amylase supplementation had no significant effect on small intestinal pancreatic amylase activity in silky fowl.

5 Summary

As understanding of starch and amylase deepens, amylase has been widely applied in animal diets. Research indicates that appropriate dietary amylase supplementation can improve animal starch utilization and production performance to some extent. However, excessive amylase supplementation may inhibit endogenous amylase secretion, impair starch utilization, and reduce energy efficiency, suggesting a quadratic relationship between starch utilization efficiency and amylase supplementation level. Further research is needed to determine whether amylase supplementation is necessary when animal digestive function is fully developed.

References

- [1] MORAN E T, Jr. Starch digestion in fowl[J]. Poultry Science, 1982, 61(7): 1257-1267.
- [2] NOY Y, SKLAN D. Digestion and absorption in the young chick[J]. Poultry Science, 1995, 74(2): 366-373.
- [3] BEDFORD M R, AUTIO K. Microscopic examination of feed and digesta from wheat-fed broiler chickens and its relation to bird performance[J]. Poultry Science, 1996, 75: 1-14.
- [4] 林厦菁, 蒋守群, 洪平, 等. 黄羽肉鸡与白羽肉鸡胃肠道消化酶活性比较研究 [J]. 中国家禽, 2017, 39(13): 26-30.
- [5] 王艳玲, 杨雪峰, 李宏基, 等. 仔猪断奶前后消化酶活性变化的初步探讨 [J]. 中国畜牧杂志, 2005, 41(8): 14-17.
- [6] 张耕, 曾子建, 李竞. 荣昌猪仔断乳前后几种消化酶活性变化 [J]. 四川畜牧兽医学院学报, 2002, 16(2): 9-12.
- [7] 李昂, 郑腾, 王宏, 等. 雏番鸭胰腺和肠道消化酶活性变化规律研究 [J]. 中国畜牧杂志, 2004, 40(7): 14-17.
- [8] 蒋正宇, 周岩民, 王恬, 等. 外源 α -淀粉酶对肉鸡生产性能的影响 [J]. 家畜生态学报, 2007, 28(4): 13-16, 22.
- [9] ENGLYST H N, KINGMAN S M, CUMMINGS J H. Classification and measurement of nutritionally important starch fractions[J]. European Journal of Clinical Nutrition, 1992, 46 Suppl 2: S33-S50.
- [10] LEHMANN U, ROBIN F. Slowly digestible starch-its structure and health implications: a review[J]. Trends in Food Science & Technology, 2007, 18(7): 346-355.
- [11] 康萍. 抗性淀粉的营养研究进展 [J]. 中国饲料, 2007(12): 15-16, 20.
- [12] 银永安, 齐军仓, 李卫华, 等. 小麦胚乳 A、B 型淀粉粒理化特性研究 [J]. 中国农业科学, 2010, 43(11): 2372-2379.
- [13] 杨景峰, 罗志刚, 罗发兴. 淀粉晶体结构研究进展 [J]. 食品工业科技, 2007(7): 240-243.
- [14] 张攀峰, 陈玲, 李晓玺, 等. 不同直链/支链比的玉米淀粉分子质量及其构象 [J]. 食品科学,

2010, 31(19): 157-160. [15] 李志伟, 钟雨越, 吴权明, 等. 高直链玉米淀粉的理化特性研究 [J]. 西北农林科技大学学报 (自然科学版), 2014, 42(7): 53-60. [16] 张斌, 罗发兴, 黄强, 等. 不同直链含量玉米淀粉结晶结构及其消化性研究 [J]. 食品与发酵工业, 2010(8): 26-30. [17] SINGH N, SINGH S, ISONO N, et al. Diversity in amylopectin structure, thermal and pasting properties of starches from wheat varieties/lines[J]. International Journal of Biological Macromolecules, 2009, 45(3): 298-304. [18] JANE J L. Current understanding on starch granule structures[J]. Journal of Applied Glycoscience, 2006, 53(3): 205-213. [19] 黄强, 王婵, 罗发兴, 等. 玉米淀粉的热力学性质与消化性 [J]. 华南理工大学学报 (自然科学版), 2011, 39(9): 7-11. [20] ZHANG G Y, AO Z H, HAMAKER B R. Slow digestion property of native cereal starches[J]. Biomacromolecules, 2006, 7(11): 3252-3258. [21] 张遨然. 玉米中淀粉支/直比及膨化加工对淀粉和能量消化率影响的研究 [D]. 硕士学位论文. 武汉: 华中农业大学, 2010. [22] 戴求仲, 李湘, 张石蕊, 等. 日粮直/支链淀粉比对黄羽肉仔鸡生产性能和养分利用率的影响 [J]. 动物营养学报, 2008, 20(3): 249-255. [23] 戴求仲, 刘绍伟, 李湘, 等. 饲料直/支链淀粉比对黄羽肉鸡血液生化指标和后肠微生物菌群的影响 [J]. 动物营养学报, 2010, 22(4): 904-910. [24] 江诚, 谢俊, 陈海峰. 葡萄糖转运蛋白的转运机制研究 [J]. 基因组学与应用生物学, 2015, 34(7): 1372-1377. [25] 王修启, 谭会泽, 束刚, 等. 鸡肠道 SGLT1 和 GLUT2 mRNA 表达的组织特异性研究 [J]. 畜牧兽医学报, 2006, 37(1): 12-17. [26] MITHIEUX G. New data and concepts on glutamine and glucose metabolism in the gut[J]. Current Opinion in Clinical Nutrition and Metabolic Care, 2001, 4(4): 267-271. [27] RIESENFELD G, GEVA A, HURWITZ S. Glucose homeostasis in the chicken[J]. The Journal of Nutrition, 1982, 112(12): 2261-2266. [28] 宾石玉. 日粮淀粉来源对断奶仔猪生产性能、小肠淀粉消化和内脏组织蛋白质合成的影响 [D]. 博士学位论文. 雅安: 四川农业大学, 2005. [29] 戴求仲. 日粮淀粉来源对生长猪氨基酸消化率、门静脉净吸收量和组成模式的影响 [D]. 博士学位. 雅安: 四川农业大学, 2004. [30] WOLEVER T M. Dietary carbohydrates and insulin action in humans[J]. British Journal of Nutrition, 2000, 83 Suppl 1: S97-S102. [31] 杨秀平, 肖向红. 动物生理学 [M]. 2 版. 北京: 高等教育出版社, 2009. [32] 唐小懿, 马杰, 陈清华, 等. 淀粉酶在畜禽饲料中的应用研究进展 [J]. 饲料研究, 2017(11): 4-7. [33] 缪可嘉, 王正祥. 淀粉酶系中淀粉结合域的结构和功能的研究进展 [J]. 食品工业科技, 2007, 28(3): 242-245. [34] BEATTY M K, RAHMAN A, CAO H P, et al. Purification and molecular genetic characterization of ZPU1, a pullulanase-type starch-debranching enzyme from maize[J]. Plant Physiology, 1999, 119(1): 255-266. [35] GRACIA M I, LÁZARO R, LATORRE M A, et al. Influence of enzyme supplementation of diets and cooking-flaking of maize on digestive traits and growth performance of broilers from 1 to 21 days of age[J]. Animal Feed Science and Technology, 2009, 150(3/4): 303-315. [36] GRACIA M I, ARANIBAR M J, LAZARO R, et al. Alpha-amylase supplementation of broiler diets based on corn[J]. Poultry Science, 2003, 82(3): 436-442. [37] 唐德富, 史兆国, 汝应俊, 等. 木薯日粮中添加 α -淀粉酶对肉仔鸡生产性能和养分消化利用的影响 [J]. 国外畜牧学 (猪与禽), 2014, 34(6): 62-64. [38] GENCOGLU H, SHAVER R D, STEINBERG W, et al. Effect of feeding a reduced-starch diet with or without amylase addition on lactation performance in dairy cows[J]. Journal of Dairy Science, 2010, 93(2): 723-732. [39] 李建沅, 姜建阳, 宋春阳. 不同淀粉来源饲料中添加复合淀粉酶对鲁烟白猪养分消化率及氮平衡的影响 [J]. 养猪, 2015(5): 13-16. [40] 张仕琦, 热合木塔依·吾布力卡斯木, 陈跃平, 等. 低温 α -淀粉酶对青脚麻鸡生长性能和消化功能的影响 [J]. 粮食与饲料工业, 2016, 12(8): 57-60. [41] ZHU H L, HU L L, HOU Y Q, et al. The

effects of enzyme supplementation on performance and digestive parameters of broilers fed corn-soybean diets[J]. Poultry Science, 2014, 93(7): 1704-1712. [42] 蒋正宇, 周岩民, 王恬. 外源 α -淀粉酶对肉仔鸡消化器官发育及小肠消化酶活性影响的后续效应[J]. 中国农学通报, 2006, 22(10): 13-16. [43] 汪兴玉, 袁建敏. 添加淀粉酶对肉鸡玉米豆粕日粮能量利用效果的影响 [C]//中国畜牧兽医学动物营养学分会第七届中国饲料营养学术研讨会论文集. 郑州: 中国畜牧兽医学动物营养学分会, 2014. [44] 沈水宝, 冯定远. 外源酶对仔猪消化系统淀粉酶活性的影响 [C]//酶制剂在饲料工业中的应用. 北京: 中国畜牧兽医学, 2005. [45] OWSLEY W F, ORR O D, Jr, TRIBBLE L F. Effects of age and diet on the development of the pancreas and the synthesis and secretion of pancreatic enzymes in the young pig[J]. Journal of Animal Science, 1986, 63(2): 497-504. [46] CALL J L, MITCHELL G E, Jr., LITTLE C O. Response of ovine pancreatic amylase to elevated blood glucose[J]. Journal of Animal Science, 1975, 41(6): 1717-1721. [47] 蒋正宇, 周岩民, 王恬. 外源 α -淀粉酶对 21 日龄肉鸡消化器官发育、肠道内源酶活性的影响 [J]. 畜牧兽医学报, 2007, 38(1): 672-677. [48] 蒋正宇. 外源 α -淀粉酶对肉鸡消化器官发育、内源酶活性的影响及后续效应的研究 [D]. 硕士学位论文. 南京: 南京农业大学, 2006. [49] 于旭华. 外源酶对断奶仔猪消化系统酶活的影响 [D]. 硕士学位论文. 广州: 华南农业大学, 2001. [50] 奚刚, 许梓荣, 钱利纯, 等. 添加外源性酶对猪、鸡内源消化酶活性的影响 [J]. 中国兽医学报, 1999, 19(3): 286-289.

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