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益生菌对宠物健康的影响研究进展

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摘　要

随着生活水平的提高，伴侣动物(主要是犬和猫)在人们日常生活中扮演着越来越重要的角色，其健康状态也越来越受到宠物主人的关注。在人类和养殖动物上的研究均发现，消化道微生物对于宿主健康需要重要的调控作用，而消化道微生物群落的紊乱或失调则与多种疾病的发生有关。目前，益生菌已被广泛用于人类食品和动物饲料添加剂当中，通过调控消化道微生物群落起到促进宿主健康的作用。近年来，益生菌也开始在宠物粮食中被添加应用，来源于犬和猫肠道的益生菌菌株也被不断地分离和鉴定，但大部分试验仍以体外研究为主，缺乏对益生菌作用机制的研究。本文综述了宠物消化道微生物组成和功能、来源于宠物消化道的益生菌，以及益生菌对宠物消化道健康影响的最新研究进展，并提出了目前研究的局限性和未来研究方面，以期为益生菌在宠物中的开发和合理应用提供参考。

关键词

益生菌，消化道微生物，肠道健康，犬，猫

Research Progress on the Impact of Probiotics on Pet Health

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Abstract

With the improvement of living standards, companion animals (mainly dogs and cats) play an increasingly important role in people's daily lives, and their health status has attracted more and more attention from pet owners. Studies on humans and farmed animals have found that digestive tract microorganisms play an important regulatory role in host health, and the disorder or imbalance of the digestive tract microbial community is related to the occurrence of a variety of diseases.

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At present, probiotics have been widely used in human food and animal feed additives to promote host health by regulating the microbial community in the digestive tract. In recent years, probiotics have also begun to be added to pet food, and probiotic strains originating from the intestines of dogs and cats have been continuously isolated and identified. However, most of the experiments are still based on in vitro studies and lack the effect on probiotics. Research on mechanisms. This article reviews the composition and function of pet digestive tract microorganisms, probiotics derived from pet digestive tracts, and the latest research progress on the impact of probiotics on pet digestive tract health. It also proposes the limitations of current research and future research aspects, with a view to providing probiotics. Provide reference for the development and rational application of bacteria in pets.

Keywords

Probiotics, Gastrointestinal Microbiota, Gut Health, Dogs, Cats

1. 引言

益生菌是指对人类或动物有益的一类活性微生物[1]，主要包括细菌和酵母等。大量研究表明，益生菌具有改善动物生长性能、促进肠道健康和提高抗感染的作用，在动物生产中具有替代抗生素的应用前景[2] [3]。近年来，益生菌也开始普遍应用于伴侣动物粮食中，在对犬猫等宠物的健康和疾病预防方面具有积极作用，但其机制研究并不深入相对于人类和养殖动物而言并不深入[4]-[6]。本文综述了益生菌对于调控宠物健康和消化道微生物方面的最新进展，为益生菌在宠物粮食中的合理应用和研发提供参考。

2. 宠物消化道微生物组成和功能

2.1. 微生物组成

相对于人类和养殖动物，犬猫等宠物的消化道微生物研究较少，但现有研究表明犬和猫的消化道微生物群组成通常相似[7] [8]，这可能是因为犬和猫都已经进化成肉食动物，具有一些共同的解剖和代谢特征，以高蛋白粮食为主，与人和养殖动物相比胃肠道相对较短[9]。健康的犬猫胃中的微生物以螺杆菌和乳酸菌为主[5] [10]，厚壁菌门、变形菌门、拟杆菌门、梭杆菌门和放线菌门是肠道中的主要菌门，但各菌门的具体丰度在不同研究间存在差异[5] [10]-[12]；粪便微生物以厚壁菌门、变形菌门、拟杆菌门、梭杆菌门和放线菌门为主[4] [10]。在属水平上，乳酸杆菌、双歧杆菌、肠球菌、链球菌和片球菌在犬类粪便中占主导地位[13] [14]；梭杆菌、普氏菌和拟杆菌是犬和猫的核心肠道微生物群[15]。相对来说，猫更加依赖于高蛋白粮食，而犬偏杂食并可消化和吸收大量的碳水化合物[9]。这可能是有些研究发现两者消化道微生物存在差异的原因，有研究表明，犬的粪便中肠球菌属、梭杆菌属和巨型单胞菌属的丰度较高，而双歧杆菌属、粪杆菌属、等在猫粪便中更为丰富[16]，另一项研究还发现猫肠道中的双歧杆菌更加丰富和普遍[15]。

2.2. 微生物失衡与疾病

肠道菌群失调与犬和猫的各种肠道疾病有关，如慢性肠道疾病、急性单纯性腹泻、急性出血性腹泻

综合征和肠癌[8] [17]-[19]等。患有肠道炎症的犬和猫肠道微生物群结构和/或代谢物会发生显著改变[8] [12] [19]-[21]。例如，在患有慢性肠病的犬粪便中观察到微生物群多样性下降、潜在有益细菌(例如梭杆菌和粪杆菌)减少以及产气荚膜梭菌过度生长[4] [21]。急性和慢性肠病的犬粪便中观察到瘤胃球菌科、布劳氏菌属、粪杆菌属和图里奇杆菌属的减少[22]。据报道，患有 IBD 的猫体内双歧杆菌减少，但大肠杆菌增加[11]。犬 IBD 肠道微生物群的紊乱与人类 IBD 相似，其特征是多样性减少、厚壁菌门减少、变形菌增加以及短链脂肪酸和次级胆汁酸的产生减少[12] [23]。

3. 益生菌对宠物肠道健康的影响

3.1. 宠物来源的益生菌

在犬和猫上研究最多的益生菌是乳酸杆菌、双歧杆菌和肠球菌[21] [24]。由于宿主特异性，肠道微生物是益生菌的重要来源，包括从犬和猫肠道中分离出的几种菌株，已表现出益生菌特性[5] [24]。这些益生菌已被证明具有改善肠道微生物群平衡、调节炎症、增强免疫功能的作用，并且能够防止肠道病原体引起的感染[5] [25]-[27]。双歧杆菌和其他产乳酸菌主要存在于健康猫的粪便中，为筛选益生菌提供了潜在来源[28]。最近研究表明，从健康猫的不同生境中分离出的植物乳杆菌、鼠李糖乳杆菌、嗜酸乳杆菌和青春双歧杆菌菌株表现出体外益生菌特性，包括对术后感染病原体的粘附活性和抗菌活性等[25]。另一项研究从犬和猫的粪便中鉴定出罗伊氏乳杆菌、发酵乳杆菌、屎肠球菌和戊糖片球菌的几种菌株，但其安全性和有效性需要进一步研究[29]。基于功能基因组的研究表明，从猫粪便中分离出的 CACC737 菌株具有潜在的益生菌特性[30]；从健康幼猫粪便中分离出的冻干 *E. hirae* 能够降低腹泻率，但不影响其他主要细菌的组成[31]。

3.2. 益生菌对犬和猫肠道健康的研究

在健康成年猫的猫粮中补充嗜酸乳杆菌 CECT4529 可改善粪便质量，并减少粪便大肠菌群计数[32]；由布拉氏链球菌和乳酸片球菌组成的多菌株益生菌增加了丁酸和总短链脂肪酸的产生，降低了炎症标记物髓过氧化物酶和钙卫蛋白的浓度，并提高了健康短毛猫粪便中抗氧化酶超氧化物歧化酶和谷胱甘肽的活性，但并没有改变猫的粪便微生物群结构[33]；饲喂屎肠球菌 SF68 降低了收容所猫的腹泻率，但不影响收容所犬的腹泻率[34]；膳食补充嗜酸乳杆菌 DSM13241 增加了乳杆菌和嗜酸乳杆菌的数量，并减少了梭状芽胞杆菌的数量，健康成年猫粪便中的粪肠球菌[35]；口服地衣芽孢杆菌发酵产品可缓解腹泻，丰富属于梭状芽胞杆菌 XIVa 簇的细菌，并减少慢性腹泻猫粪便中的产气荚膜梭菌[36]。一项初步研究表明，口服由八种乳酸菌菌株组成的多菌株益生菌可改善患有慢性便秘和特发性巨结肠的猫的临床症状，并增加粪便中乳酸菌和链球菌的丰度[37]。饲喂屎肠球菌菌株 SF68 可以改善接受阿莫西林克拉维酸治疗的猫的粪便质量，阿莫西林克拉维酸可导致呕吐或腹泻[38]。

3.3. 目前研究的局限性和未来研究方向

益生菌的功效可能受到物种、疾病状况、年龄和性别等许多因素的影响[27] [34] [39]-[41]。最近的一项研究表明，由于内分泌和中枢神经系统的差异，益生菌的生物活性可能具有性别特异性[41]。益生菌通过与宿主细胞和常驻微生物群的直接相互作用，或通过微生物代谢物间接发挥促进健康的作用。肠道拥有最大、最复杂的微生物群落，更精确和准确地评估微生物群组成并进一步表征肠道微生物功能将扩大犬和猫益生菌筛选的范围[39]。尽管已从犬和猫身上分离出多种具有益生特性的菌株，但它们的健康促进作用在体内很大程度上尚未得到证实，需要进一步研究。由于消化道微生物组成和功能也会受到物种、年龄、性别、品种、饲料、抗生素[11] [19] [20] [42]-[46]等因素的影响，因此体内试验评估益生菌有效性

时需要充分考虑上述因素的影响。已有研究表明，发酵乳杆菌的饲喂剂量或饲喂时间不会影响其在犬上发挥健康益处[29]，但这一发现是否适用于其他益生菌还需要进一步研究。此外，益生菌活性可能具有异质性和菌株特异性，因此需要明确菌株水平上的作用机理。

在加工层面，稳定性是益生菌应用需要关注的主要问题。大部分益生菌如乳杆菌、双歧杆菌、*A. muciniphila* 和 *F. prausnitzii* 等均对温度、氧含量、pH、酶和胆汁盐等条件存在不同的敏感，这些条件会影响上述益生菌在加工、储存、分配和通过胃肠道过程中的功效[47]。通过包被制成胶囊的方式已成为增强益生菌活力、稳定性和功效的有效策略[47] [48]，其中乳液、凝胶、粉末颗粒、纳米纤维、电喷雾胶囊和纳米涂层是常用的益生菌包被材料或方法[48]。这些方法都有各自的优点和缺点，例如与传统的封装方法相比，纳米封装技术能够为益生菌提供更高的保护和递送功效[49] [50]，此外，单细胞纳米涂层封装策略被认为是比纳米纤维和纳米粒子等纳米材料的整体封装方法更先进的技术[49]，但先进技术方法所需要的成本较高，因此目前在犬和猫益生菌中仍未大规模地使用包被技术。此外，最近的一项在猫上的研究表明，不同微囊包被技术在维持益生菌储存和通过胃肠道期间的活力方面的效率不同[51]，基于此，还需要进一步通过研究来评估不同包被技术未来在犬和猫消化道中作用效果。

4. 小结

随着人们越来越关注宠物的健康尤其是肠道健康，使用益生菌增强犬和猫的肠道健康水平变得越来越重要。研究已证实了益生菌可通过改善犬和猫肠道菌群平衡，从而发挥抑制炎症、增强免疫功能、缓解肠道疾病的作用效果。但目前开展的研究仍相当有限，且针对犬和猫的益生菌菌株研究基本以体外试验为主，尚未在动物体内通过验证或证实，其作用机制也并不明确。此外，随着包被等加工工艺的进一步优化以及成本的降低，有望在犬和猫益生菌产品生产时应用该技术，从而充分发挥益生菌的作用效果。

参考文献

[1] Hill, C., Guarner, F., Reid, G., Gibson, G.R., Merenstein, D.J., Pot, B., *et al*. (2014) The International Scientific Association for Probiotics and Prebiotics Consensus Statement on the Scope and Appropriate Use of the Term Probiotic. *Nature Reviews Gastroenterology & Hepatology*, **11**, 506-514. https://doi.org/10.1038/nrgastro.2014.66

[2] Lambo, M.T., Chang, X. and Liu, D. (2021) The Recent Trend in the Use of Multistrain Probiotics in Livestock Production: An Overview. *Animals*, **11**, Article 2805. https://doi.org/10.3390/ani11102805

[3] Su, W., Gong, T., Jiang, Z., Lu, Z. and Wang, Y. (2022) The Role of Probiotics in Alleviating Postweaning Diarrhea in Piglets from the Perspective of Intestinal Barriers. *Frontiers in Cellular and Infection Microbiology*, **12**, Article 883107. https://doi.org/10.3389/fcimb.2022.883107

[4] Pilla, R. and Suchodolski, J.S. (2021) The Gut Microbiome of Dogs and Cats, and the Influence of Diet. *Veterinary Clinics of North America: Small Animal Practice*, **51**, 605-621. https://doi.org/10.1016/j.cvsm.2021.01.002

[5] Grześkowiak, Ł., Endo, A., Beasley, S. and Salminen, S. (2015) Microbiota and Probiotics in Canine and Feline Welfare. *Anaerobe*, **34**, 14-23. https://doi.org/10.1016/j.anaerobe.2015.04.002

[6] Schmitz, S., Werling, D. and Allenspach, K. (2015) Effects of *ex-vivo* and *in-vivo* Treatment with Probiotics on the Inflammasome in Dogs with Chronic Enteropathy. *PLOS ONE*, **10**, e0120779. https://doi.org/10.1371/journal.pone.0120779

[7] Hoffmann, A.R., Proctor, L.M., Surette, M.G. and Suchodolski, J.S. (2015) The Microbiome: The Trillions of Microorganisms That Maintain Health and Cause Disease in Humans and Companion Animals. *Veterinary Pathology*, **53**, 10-21. https://doi.org/10.1177/0300985815595517

[8] Hashimoto-Hill, S. and Alenghat, T. (2021) Inflammation-Associated Microbiota Composition across Domestic Animals. *Frontiers in Genetics*, **12**, Article 649599. https://doi.org/10.3389/fgene.2021.649599

[9] Deng, P. and Swanson, K.S. (2014) Gut Microbiota of Humans, Dogs and Cats: Current Knowledge and Future Opportunities and Challenges. *British Journal of Nutrition*, **113**, S6-S17. https://doi.org/10.1017/s0007114514002943

[10] Lee, D., Goh, T.W., Kang, M.G., Choi, H.J., Yeo, S.Y., Yang, J., *et al*. (2022) Perspectives and Advances in Probiotics

and the Gut Microbiome in Companion Animals. *Journal of Animal Science and Technology*, **64**, 197-217. https://doi.org/10.5187/jast.2022.e8

[11] Ziese, A. and Suchodolski, J.S. (2021) Impact of Changes in Gastrointestinal Microbiota in Canine and Feline Digestive Diseases. *Veterinary Clinics of North America: Small Animal Practice*, **51**, 155-169. https://doi.org/10.1016/j.cvsm.2020.09.004

[12] Schmitz, S. and Suchodolski, J. (2016) Understanding the Canine Intestinal Microbiota and Its Modification by Pro-, Pre- and Synbiotics—What Is the Evidence? *Veterinary Medicine and Science*, **2**, 71-94. https://doi.org/10.1002/vms3.17

[13] Suchodolski, J.S., Camacho, J. and Steiner, J.M. (2008) Analysis of Bacterial Diversity in the Canine Duodenum, Jejunum, Ileum, and Colon by Comparative 16S rRNA Gene Analysis. *FEMS Microbiology Ecology*, **66**, 567-578. https://doi.org/10.1111/j.1574-6941.2008.00521.x

[14] Kim, S. and Adachi, Y. (2007) Biological and Genetic Classification of Canine Intestinal Lactic Acid Bacteria and Bifidobacteria. *Microbiology and Immunology*, **51**, 919-928. https://doi.org/10.1111/j.1348-0421.2007.tb03983.x

[15] Alessandri, G., Milani, C., Mancabelli, L., Longhi, G., Anzalone, R., Lugli, G.A., *et al*. (2020) Deciphering the Bifidobacterial Populations within the Canine and Feline Gut Microbiota. *Applied and Environmental Microbiology*, **86**, e02875-19. https://doi.org/10.1128/aem.02875-19

[16] Jha, A.R., Shmalberg, J., Tanprasertsuk, J., Perry, L., Massey, D. and Honaker, R.W. (2020) Characterization of Gut Microbiomes of Household Pets in the United States Using a Direct-to-Consumer Approach. *PLOS ONE*, **15**, e0227289. https://doi.org/10.1371/journal.pone.0227289

[17] Alessandri, G., Argentini, C., Milani, C., Turroni, F., Cristina Ossiprandi, M., van Sinderen, D., *et al*. (2020) Catching a Glimpse of the Bacterial Gut Community of Companion Animals: A Canine and Feline Perspective. *Microbial Biotechnology*, **13**, 1708-1732. https://doi.org/10.1111/1751-7915.13656

[18] Rhimi, S., Kriaa, A., Mariaule, V., Saidi, A., Drut, A., Jablaoui, A., *et al*. (2022) The Nexus of Diet, Gut Microbiota and Inflammatory Bowel Diseases in Dogs. *Metabolites*, **12**, Article 1176. https://doi.org/10.3390/metabo12121176

[19] Huang, Z., Pan, Z., Yang, R., Bi, Y. and Xiong, X. (2020) The Canine Gastrointestinal Microbiota: Early Studies and Research Frontiers. *Gut Microbes*, **11**, 635-654. https://doi.org/10.1080/19490976.2019.1704142

[20] Wernimont, S.M., Radosevich, J., Jackson, M.I., Ephraim, E., Badri, D.V., MacLeay, J.M., *et al*. (2020) The Effects of Nutrition on the Gastrointestinal Microbiome of Cats and Dogs: Impact on Health and Disease. *Frontiers in Microbiology*, **11**, Article 1266. https://doi.org/10.3389/fmicb.2020.01266

[21] Gasaly, N., de Vos, P. and Hermoso, M.A. (2021) Impact of Bacterial Metabolites on Gut Barrier Function and Host Immunity: A Focus on Bacterial Metabolism and Its Relevance for Intestinal Inflammation. *Frontiers in Immunology*, **12**, Article 658354. https://doi.org/10.3389/fimmu.2021.658354

[22] Suchodolski, J.S., Markel, M.E., Garcia-Mazcorro, J.F., Unterer, S., Heilmann, R.M., Dowd, S.E., *et al*. (2012) The Fecal Microbiome in Dogs with Acute Diarrhea and Idiopathic Inflammatory Bowel Disease. *PLOS ONE*, **7**, e51907. https://doi.org/10.1371/journal.pone.0051907

[23] Hernandez, J., Rhimi, S., Kriaa, A., Mariaule, V., Boudaya, H., Drut, A., *et al*. (2022) Domestic Environment and Gut Microbiota: Lessons from Pet Dogs. *Microorganisms*, **10**, Article 949. https://doi.org/10.3390/microorganisms10050949

[24] Rudenko, P., Vatnikov, Y., Sachivkina, N., Rudenko, A., Kulikov, E., Lutsay, V., *et al*. (2021) Search for Promising Strains of Probiotic Microbiota Isolated from Different Biotopes of Healthy Cats for Use in the Control of Surgical Infections. *Pathogens*, **10**, Article 667. https://doi.org/10.3390/pathogens10060667

[25] Rossi, G., Pengo, G., Galosi, L., Berardi, S., Tambella, A.M., Attili, A.R., *et al*. (2020) Effects of the Probiotic Mixture Slab51® (SivoMixx®) as Food Supplement in Healthy Dogs: Evaluation of Fecal Microbiota, Clinical Parameters and Immune Function. *Frontiers in Veterinary Science*, **7**, Article 613. https://doi.org/10.3389/fvets.2020.00613

[26] Xu, H., Huang, W., Hou, Q., Kwok, L., Laga, W., Wang, Y., *et al*. (2019) Oral Administration of Compound Probiotics Improved Canine Feed Intake, Weight Gain, Immunity and Intestinal Microbiota. *Frontiers in Immunology*, **10**, Article 666. https://doi.org/10.3389/fimmu.2019.00666

[27] Strompfová, V., Kubašová, I. and Lauková, A. (2017) Health Benefits Observed after Probiotic *Lactobacillus fermentum* CCM 7421 Application in Dogs. *Applied Microbiology and Biotechnology*, **101**, 6309-6319. https://doi.org/10.1007/s00253-017-8425-z

[28] Handl, S., Dowd, S.E., Garcia-Mazcorro, J.F., Steiner, J.M. and Suchodolski, J.S. (2011) Massive Parallel 16S rRNA Gene Pyrosequencing Reveals Highly Diverse Fecal Bacterial and Fungal Communities in Healthy Dogs and Cats. *FEMS Microbiology Ecology*, **76**, 301-310. https://doi.org/10.1111/j.1574-6941.2011.01058.x

[29] Kim, K., Kim, J., Kim, S., Kim, S., Nguyen, T.H. and Kang, C. (2021) Antioxidant and Anti-Inflammatory Effect and Probiotic Properties of Lactic Acid Bacteria Isolated from Canine and Feline Feces. *Microorganisms*, **9**, Article 1971. https://doi.org/10.3390/microorganisms9091971

[30] Kim, J., Jung, M.Y., Kim, D. and Kim, Y. (2020) Genome Analysis of *Bacteroides* sp. CACC 737 Isolated from Feline for Its Potential Application. *Journal of Animal Science and Technology*, **62**, 952-955. https://doi.org/10.5187/jast.2020.62.6.952

[31] Gookin, J.L., Strong, S.J., Bruno-Bárcena, J.M., Stauffer, S.H., Williams, S., Wassack, E., *et al*. (2022) Randomized Placebo-Controlled Trial of Feline-Origin Enterococcus Hirae Probiotic Effects on Preventative Health and Fecal Microbiota Composition of Fostered Shelter Kittens. *Frontiers in Veterinary Science*, **9**, Article 923792. https://doi.org/10.3389/fvets.2022.923792

[32] Fusi, E., Rizzi, R., Polli, M., Cannas, S., Giardini, A., Bruni, N., *et al*. (2019) Effects of *Lactobacillus acidophilus* D2/CSL (CECT 4529) Supplementation on Healthy Cat Performance. *Veterinary Record Open*, **6**, e000368. https://doi.org/10.1136/vetreco-2019-000368

[33] Li, Y., Ali, I., Lei, Z., Li, Y., Yang, M., Yang, C., *et al*. (2023) Effect of a Multistrain Probiotic on Feline Gut Health through the Fecal Microbiota and Its Metabolite SCFAs. *Metabolites*, **13**, Article 228. https://doi.org/10.3390/metabo13020228

[34] Bybee, S.N., Scorza, A.V. and Lappin, M.R. (2011) Effect of the Probiotic *Enterococcus faecium* SF68 on Presence of Diarrhea in Cats and Dogs Housed in an Animal Shelter. *Journal of Veterinary Internal Medicine*, **25**, 856-860. https://doi.org/10.1111/j.1939-1676.2011.0738.x

[35] Marshall-Jones, Z.V., Baillon, M.A., Croft, J.M. and Butterwick, R.F. (2006) Effects of *Lactobacillus acidophilus* DSM13241 as a Probiotic in Healthy Adult Cats. *American Journal of Veterinary Research*, **67**, 1005-1012. https://doi.org/10.2460/ajvr.67.6.1005

[36] Lee, T., Chao, T., Chang, H., Cheng, Y., Wu, C. and Chang, Y. (2022) The Effects of *Bacillus licheniformis*—Fermented Products on the Microbiota and Clinical Presentation of Cats with Chronic Diarrhea. *Animals*, **12**, Article 2187. https://doi.org/10.3390/ani12172187

[37] Rossi, G., Jergens, A., Cerquetella, M., Berardi, S., Di Cicco, E., Bassotti, G., *et al*. (2018) Effects of a Probiotic (SLAB51™) on Clinical and Histologic Variables and Microbiota of Cats with Chronic Constipation/Megacolon: A Pilot Study. *Beneficial Microbes*, **9**, 101-110. https://doi.org/10.3920/bm2017.0023

[38] Torres-Henderson, C., Summers, S., Suchodolski, J. and Lappin, M.R. (2017) Effect of *Enterococcus faecium* Strain SF68 on Gastrointestinal Signs and Fecal Microbiome in Cats Administered Amoxicillin-Clavulanate. *Topics in Companion Animal Medicine*, **32**, 104-108. https://doi.org/10.1053/j.tcam.2017.11.002

[39] Sanders, M.E., Merenstein, D.J., Reid, G., Gibson, G.R. and Rastall, R.A. (2019) Probiotics and Prebiotics in Intestinal Health and Disease: From Biology to the Clinic. *Nature Reviews Gastroenterology & Hepatology*, **16**, 605-616. https://doi.org/10.1038/s41575-019-0173-3

[40] Yan, F. and Polk, D.B. (2020) Probiotics and Probiotic-Derived Functional Factors—Mechanistic Insights into Applications for Intestinal Homeostasis. *Frontiers in Immunology*, **11**, Article 1428. https://doi.org/10.3389/fimmu.2020.01428

[41] Snigdha, S., Ha, K., Tsai, P., Dinan, T.G., Bartos, J.D. and Shahid, M. (2022) Probiotics: Potential Novel Therapeutics for Microbiota-Gut-Brain Axis Dysfunction across Gender and Lifespan. *Pharmacology & Therapeutics*, **231**, Article 107978. https://doi.org/10.1016/j.pharmthera.2021.107978

[42] Rojo, D., Méndez-García, C., Raczkowska, B.A., Bargiela, R., Moya, A., Ferrer, M., *et al*. (2017) Exploring the Human Microbiome from Multiple Perspectives: Factors Altering Its Composition and Function. *FEMS Microbiology Reviews*, **41**, 453-478. https://doi.org/10.1093/femsre/fuw046

[43] You, I. and Kim, M.J. (2021) Comparison of Gut Microbiota of 96 Healthy Dogs by Individual Traits: Breed, Age, and Body Condition Score. *Animals*, **11**, Article 2432. https://doi.org/10.3390/ani11082432

[44] Garrigues, Q., Apper, E., Chastant, S. and Mila, H. (2022) Gut Microbiota Development in the Growing Dog: A Dynamic Process Influenced by Maternal, Environmental and Host Factors. *Frontiers in Veterinary Science*, **9**, Article 964649. https://doi.org/10.3389/fvets.2022.964649

[45] Whittemore, J.C., Stokes, J.E., Price, J.M. and Suchodolski, J.S. (2019) Effects of a Synbiotic on the Fecal Microbiome and Metabolomic Profiles of Healthy Research Cats Administered Clindamycin: A Randomized, Controlled Trial. *Gut Microbes*, **10**, 521-539. https://doi.org/10.1080/19490976.2018.1560754

[46] Rochegüe, T., Haenni, M., Mondot, S., Astruc, C., Cazeau, G., Ferry, T., *et al*. (2021) Impact of Antibiotic Therapies on Resistance Genes Dynamic and Composition of the Animal Gut Microbiota. *Animals*, **11**, Article 3280. https://doi.org/10.3390/ani11113280

[47] Yao, M., Xie, J., Du, H., McClements, D.J., Xiao, H. and Li, L. (2020) Progress in Microencapsulation of Probiotics: A Review. *Comprehensive Reviews in Food Science and Food Safety*, **19**, 857-874. https://doi.org/10.1111/1541-4337.12532

[48] Gu, Q., Yin, Y., Yan, X., Liu, X., Liu, F. and McClements, D.J. (2022) Encapsulation of Multiple Probiotics, Synbiotics, or Nutrabiotics for Improved Health Effects: A Review. *Advances in Colloid and Interface Science*, **309**, Article 102781.

https://doi.org/10.1016/j.cis.2022.102781

[49] Centurion, F., Basit, A.W., Liu, J., Gaisford, S., Rahim, M.A. and Kalantar-Zadeh, K. (2021) Nanoencapsulation for Probiotic Delivery. *ACS Nano*, **15**, 18653-18660. https://doi.org/10.1021/acsnano.1c09951

[50] Xu, C., Ban, Q., Wang, W., Hou, J. and Jiang, Z. (2022) Novel Nano-Encapsulated Probiotic Agents: Encapsulate Materials, Delivery, and Encapsulation Systems. *Journal of Controlled Release*, **349**, 184-205. https://doi.org/10.1016/j.jconrel.2022.06.061

[51] Rodrigues, B.M., Olivo, P.M., Osmari, M.P., Vasconcellos, R.S., Ribeiro, L.B., Bankuti, F.I., *et al*. (2020) Microencapsulation of Probiotic Strains by Lyophilization Is Efficient in Maintaining the Viability of Microorganisms and Modulation of Fecal Microbiota in Cats. *International Journal of Microbiology*, **2020**, Article 1293481. https://doi.org/10.1155/2020/1293481