Role of Garlic in Chronic Diseases: Focusing on Gut Microbiota Modulation

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Abstract: Garlic is a herb and has been used as a spice with a long history in different types of cuisine. Garlic and its components are believed to be able to bring benefits to the health of an individual. The gut microbiota is closely related to an individual's health, and garlic is shown to have an effect on the gut microbiota as well. Hence, this literature review aims to portray the uses of garlic and its bioactive constituents on human health, particularly looking at how it modulates the gut microbiota and subsequently affects an individual's health directly or indirectly. These studies have shown the ameliorative effects of garlic and its bioactive constituents on various chronic diseases, including hypertension, diabetes mellitus, hyperlipidaemia and liver diseases.

Keywords: Garlic; allicin; alliin; gut microbiome; metabolic diseases

1. Introduction

Chronic diseases, such as hypertension, diabetes mellitus, obesity, hyperlipidaemia, and complications, including myocardial infarction and cerebrovascular accidents, are the major health concerns surrounding people all the time. It takes time, effort, and money to manage the diseases from diagnosis to treatment. They appear as some form of burden to the people, and most of the time, uncontrolled diseases will lead to complications that may
severely affect the well-being of humans. Awareness regarding the diseases has been raised, and people started taking steps to prevent the diseases and their complications. Initiatives can be made in the simplest form, including lifestyle modifications (diet modification and exercise) and taking medications.

Regarding preventative methods, garlic has been used traditionally in improving health. Garlic as a spice has not only been used to improve the taste of food, but it also has the potential to regulate an individual's health. Recently, it has been believed that garlic helps to alter the gut microbiota in good ways and further improves health. Various chronic illnesses can be prevented by supplementing garlic into our diet. Garlic and its constituent allicin, diallyl disulphide, can act as anti-inflammatory and antioxidant agents to help cope with diseases.

Gut microbiota plays a vital role in maintaining human health. The gut microbiome consists of different types of bacteria. A balanced gut microbiome system helps maintain good health by forming a good immune system and defence against pathogens [1-7]. The components in the gut microbiota are largely affected by many factors, including inheritance, diet, and drugs [8-11]. As inheritance is a non-modifiable factor, diet and drugs are those we can take into account and modify accordingly to help improve our health [12-14]. The gut microbiota is in mutualism with the host, and they provide benefits to each other. The gut microbes feed on the food we consume, and on the other hand, they help to degrade and convert those complex substances to enable the gut to absorb the nutrients. Garlic has been part and parcel of our diet, and taking garlic can help to modulate the gut microbiota in a good way so that the beneficial microorganisms or the probiotics can be retained while the pathogenic species can be eliminated. Consumption of garlic in the long term will help to improve health indirectly.

This review aims to investigate recent studies to determine the benefits of taking garlic in daily life and the role of garlic and its constituents in modulating human health via gut microbiome modulation. Besides that, this review also provides an overview of how garlic prevents chronic diseases and explores the potential use of garlic as a therapeutic agent for diseases.

2. An overview of garlic and its constituents and their effect on gut microbiota

Garlic has been used widely in different cuisines. It can be consumed raw or crushed, depending on the consumers' preferences. Garlic is thought to be bringing a lot of benefits, especially towards the health of an individual. A person with a healthy gut microbiota will have a healthy immune system. Garlic and its constituents have been shown to modulate the gut microbiota composition by selectively stimulating beneficial microorganisms' growth and suppressing pathogenic species' growth. Gut microbiota is correlated to an individual's health because it affects the absorption and elimination of the food we eat. This is particularly more observed with patients with metabolic diseases as those chronic diseases are highly
dependent on diet and lifestyles [15]. In the literature review, the aim is to investigate the effect of garlic on gut microbiota, in turn, its impact on an individual's health.

3. Composition of garlic

Garlic (*Allium sativum* L.) is mainly comprised of water, followed by carbohydrates, protein, and organosulfur compounds. Fructans are the main component of carbohydrates, and they can provoke the growth of probiotic bacteria in the gut and subsequently improve the immune system [1]. Organosulfur compounds (OSC) are available in most plants, but garlic's amount is higher than the other plants. The primary OSC from garlic are γ-glutamyl-S-allyl-l-cysteines (G-SAC). G-SAC is a metabolite that will later be converted to alliin and is thought to be responsible for antimicrobial activity in the gut [1]. Alliinase will be activated during the crushing process of garlic, and it converts alliin into allicin. Allicin has a variety of actions on the gut, including antimicrobial, anticancer, antioxidant, and immune-modulating activities. Allicin will be absorbed in the intestines through the villi, and it can bypass the stomach without being affected by the low pH of the gastric acid. Allicin is then metabolised into diallyl disulphide in the bloodstream and transported to various organs. Allicin and its metabolites can be interconverted by the liver cells. This keeps allicin readily available as it can only be transported in the form of diallyl disulphide. The metabolites formed from allicin include diallyl disulphide, S-allylmercaptocysteine, S-allyl cysteine, and so on, and they are those responsible for bringing benefits to the health [16]. Apart from that, garlic also contains a variety of minerals and vitamins, including potassium, zinc, iron, sodium, and water-soluble vitamins [17].

4. The effect of garlic and its constituents on gut microbiota

Gut microbiota consists of the bacteria grown in the intestines and have a mutualistic relationship with the human host. Bacteroidetes and Firmicutes are the significant part of the gut microbiota, and other bacteria reside in the human gut [18]. Numerous studies have investigated the relationship between garlic and its effect on gut microbiota and health [1, 19-22]. Through these studies, garlic has been shown to be able to modulate gut microbiota [1, 19, 21]. One of the studies by Chen *et al.* [23] has demonstrated that garlic supplementation in the diet increases *Lachnospiraceae* and decreases *Prevotella* [1]. *Lachnospiraceae* is the normal flora found in the gut, and it plays a role in producing short-chain fatty acid (SCFA). SCFAs are the primary source of nutrients for colonic epithelial cells, and they exert an anti-inflammatory effect in the gut [24]. Another study by Filocamo *et al.* [19] suggested that using garlic powder can inhibit the growth of microorganisms in the gut. However, Lactobacilli (lactic acid bacteria) have shown resistance towards garlic powder, and these bacterial species can grow and replicate despite consuming garlic regularly. Lactobacilli are the probiotics that have an essential role in forming the barrier in the gastrointestinal system [25]. Apart from that, they act as anti-inflammatory agents and help to prevent cancer and inflammation in the intestines [26-30]. Studies also showed that the components present in garlic have bactericidal effects on some bacteria species, including *Escherichia coli*, *Salmonella typhimurium* and *Neisseria gonorrhoeae* [20, 31, 32]. Those bacteria are the
pathogen that predisposes the host to infections [33, 34]. A study by Maeda et al. [35] investigated the effect of taking aged garlic extracts on the gut microbiota profile. After seven weeks of consuming aged garlic extracts, there is an increase in the Lactobacillus and a decrease in several bacteria species, including Clostridium cluster XVIII and Prevotella. The use of garlic has been shown to be beneficial to the host. Garlic supplementation in the diet can expand the diversity and richness of the gut microbiome and, at the same time, help lower the pathogenic species in the gut [36].

The ratio of Firmicutes to Bacteroidetes is closely related to obesity, and obese patients tend to have a higher Firmicutes/Bacteroidetes ratio compared to a healthy individual [21]. The Firmicutes/Bacteroidetes ratio will increase with ageing and implementing a high-fat diet [23]. Allicin, the main OSC present in crushed garlic, has an antibacterial effect on the gut. Consumption of garlic has been shown to reduce the ratio, and this indirectly deals with gut dysbiosis caused by a prolonged high-fat diet [23].

A study from Zhang et al. [22] demonstrates that alliin (an active component in garlic) consumption can modify the gut microbiota, especially Allobaculum sp. The role of Allobaculum spp. in the gut is to utilise glucose [37], which helps to weight loss for obese individuals [38]. Another study finds that alliin can induce the modulation of components in the gut microbiota. The study shows that alliin supplementation results in a decrease in the abundance of Lachnospiraceae and an increase in the abundance of Ruminococcaceae [39]. Those are the common normal flora found in the gut, and they assist the host in degrading the complex materials from plants, such as cellulose and hemicellulose, and further aid in the absorption of the substrate to yield energy for the hosts [40]. Those substrates cannot be digested and broken down by the host as there is no enzyme specifically targeting those substrates, and the host must rely on the gut microorganisms. Besides, the study suggested that alliin consumption helps to improve lipid and glucose profiles in the long term [39]. This result is consistent with the increase in Ruminococcaceae as it has been proved that Ruminococcaceae has a protective function against long-term weight gain in the host [41].

Besides alliin, fructan is also the main component found in garlic. Supplementation of garlic fructan (GF) can promote the growth of Bifidobacterium in the gut [42]. Bifidobacterium is the beneficial normal flora in the gut, and it is linked to many health benefits, including preventing colon cancer and reducing the symptoms of inflammatory bowel disease [43]. Bifidobacterium probiotic has been used to treat diarrhoea and necrotising enterocolitis in preterm neonates [43, 44]. Another study by Zhang et al. [45] focuses on the effect of inulin-type fructan on the gut microbiota. After treatment with inulin, a rise in the number of short-chain fatty acid-producing bacteria and Lactobacillus is evidenced [45]. Apart from that, a drop in Desulfovibrio is also present in the study. Desulfovibrio bacteria is considered a pathogen in the human host, and it is often associated with ulcerative colitis and intra-abdominal infections [46, 47]. Inulin-type fructan can affect the gut microbiota. It is noted that those receiving inulin-type fructan have softer stools, which actually improves the hosts' constipation issues [48].
Organosulfur compounds in garlic are the hydrogen sulphide (H₂S) donors in the body\(^{[49]}\). Study shows that H₂S can prevent the dysbiosis of gut microbiota caused by non-steroidal anti-inflammatory drugs (NSAIDs) and alcohol\(^{[50]}\). This helps balance the system after the host is exposed to external factors like alcohol and drugs. Besides that, H₂S has been shown to prevent inflammation and foster the restoration of the damaged tissues in the gut\(^{[50]}\). Propyl-propane thiosulfonate (PTSO) from garlic also exerts anti-inflammatory effects and helps restore the epithelial tissues’ barrier function in the intestines\(^{[51]}\). This suggests that garlic may help with inflammatory bowel diseases in the future.

**5. The effect of garlic on chronic diseases**

Many studies have shown that garlic can directly or indirectly improve the health of an individual, which may link to the modulation of gut microbiota (Figure 1). Supplementation of garlic in diet can affect health in a good way. The human gut microbiota helps to degrade complex substances, produce short-chain fatty acids, and maintain homeostasis in the intestines. When there is microbial dysbiosis, problems start in the host, such as metabolic syndromes, allergies, and neurological and gastrointestinal diseases\(^{[52-55]}\).

Figure 1. Summary of garlic’s gut microbiome modulation effect in improving overall health and metabolic syndromes.

**5.1 Hyperlipidaemia**

Practising a diet high in fat content in the long term affects gut microbiota composition. The high-fat diet increases the number of pathogenic bacteria such as Proteobacteria, *Desulfovibrio*, and Actinobacteria in the gut. These pathogenic bacteria tend to be pro-inflammatory and affect energy uptake, leading to obesity\(^{[56]}\). In previous studies, garlic has been shown beneficial in lowering cholesterol levels and ameliorating the lipid profile. One shows that consuming garlic can improve dyslipidaemia caused by a high-fat diet\(^{[23]}\). Another study found that intake of aged garlic extract may help decrease fat uptake
from the intestines and thus suppressing the deposition of triglycerides in the liver \[35\]. Black garlic melanoids (MLD) can target obesity issues as they effectively slow down the weight gain process caused by the high-fat diet. Besides, MLD can also inhibit lipid accumulation in the liver and assist the lipid metabolism process, improving the lipid profile among patients with dyslipidaemia \[57\]. A high-fat diet usually leads to a change in the gut microbiota, and a study reveals that implementing low molecular and high molecular melanoids can reverse the changes and eventually relieve the disrupted rhythm of gut microorganisms \[58\]. Allicin from garlic helps the browning of white adipose tissue and further prevents the gaining of weight caused by a high-fat diet \[59\]. Allicin can stimulate lipolysis in the body as well as contribute to thermogenesis, and these are ways to burn fat and relieve obesity issues \[59\]. Inulin, as a substrate found in garlic, is also able to promote weight loss in patients with obesity. After 3 months of an inulin-rich diet, the participants experienced a drop in their BMI and had better blood pressure and sugar profile \[60\].

5.2 Liver diseases

A high-fat diet causes metabolic syndrome such as obesity, eventually leading to liver diseases. Dysbiosis of gut microbiota can lead to liver inflammation and fibrosis. This occurs through the change in the yielding of energy from the diet, an increase in intestinal permeability that leads to the presence of bacterial products in the bloodstream, the formation of ethanol and changes in the metabolism of choline, bile acid, and lipid \[61\]. Choline deficiency predisposes an individual to non-alcoholic fatty liver disease by increasing lipid deposition in the liver \[62\]. Not only does garlic target dyslipidaemia, but garlic also helps with liver inflammation. Garlic supplementation in the diet can relieve inflammation in the liver by reducing alanine transaminase (ALT) and aspartate transaminase (AST) and normalising the lipid profile. This suggests that garlic may potentially treat alcoholic liver fibrosis \[63\]. Diallyl disulphide was used to address the issue of liver inflammation, and it was found that diallyl disulphide can suppress inflammation, lipid metabolism, and peroxidation \[64\]. Non-alcoholic steatohepatitis (NASH) can be targeted using garlic as a therapeutic agent. Another study has used garlic essential oil and diallyl disulphide, and the result shows that they can prevent non-alcoholic fatty liver disease (NAFLD) by suppressing inflammation and lipid accumulation \[65\]. A study from Shunming et al. \[66\] revealed that high amounts of raw garlic could help lower the prevalence of NAFLD among men but not women. This can be due to allicin's bioactivity, which exhibits anti-inflammatory and antioxidant effects that stop the progression of NAFLD \[66\]. On the other hand, a study by Yang et al. \[67\] shows that diallyl disulphide (DADS) can modulate the gut microbiota by lowering the number of Bacteroides and raising the number of Firmicutes. These have been seen in patients with obesity and those on a high-fat diet. DADS alters the expression of genes responsible for lipid metabolism, and a low dose of DADS, along with a high-fat diet, increases fat deposition in the liver \[67\]. The results from this study are different from the other studies where garlic has consistently shown to have the ability to target obesity and liver diseases. More studies need to be done to explore garlic's effect on patients' lipid profiles.
5.3 Hypertension

Gut microbiota plays a vital role in regulating blood pressure as well. They modulate the uses of the energy, metabolism of catecholamines in the gut, and transportation of ions through the gastrointestinal system [68]. Production of short-chain fatty acids switches on receptors such as G-protein coupled receptors and olfactory receptors, which work to balance blood pressure [68]. A rise in Firmicutes to Bacteroidetes ratio puts an individual at a higher risk of developing hypertension, and garlic can help to lower the ratio. On the other hand, Lactobacilli helps to inhibit angiotensin-converting enzymes and subsequently lowers blood pressure [68]. This works similarly to the drugs ACE inhibitors used for hypertensive patients. Garlic can lower blood pressure among hypertensive patients. Kyolic aged garlic supplementation prevents the stiffening of arteries caused by ageing via lessening the pulse wave velocity and thinning the blood to lower the risk of thrombosis [69]. This overall improves the cardiovascular health of an individual.

Allicin found in garlic is able to inhibit the formation of trimethylamine-N-oxide (TMAO) [70]. The gut microbiota forms TMAO through the metabolism of carnitine, and it acts to promote atherosclerosis [70]. Hence, we can deduce that consumption of garlic in the long term will decrease the risk of atherosclerosis.

Furthermore, garlic-derived organic polysulfides have been shown to exhibit vasoactivity. A study showed that several garlic-derived organic polysulfides acted as an H₂S donors and boosted endogenous H₂S production in blood and tissues. H₂S can promote vasorelaxation of the vessels and indirectly help promote the health of the cardiovascular system [71]. A more recent animal study by Hsu et al. [72] revealed that garlic oil supplementation protected adult male offspring from hypertension induced by a perinatal high-fat diet given to the mother during pregnancy and lactation. Interestingly, garlic oil was shown to mediate the hypertension preventive effect with modulations of gut microbiota composition, microbiota-derived metabolite SCFAs, H₂S-generating pathway, and NO bioavailability. Genus Lactobacillus was found to be increased in abundance, while Tunicibacter and Staphylococcus were decreased in the garlic oil supplementation group [72].

5.4 Diabetes mellitus

Patients with diabetes mellitus tend to show some changes in the gut microbiota to some extent. There is an increase in the pathogens and a decrease in the butyrate-producing bacteria in the intestines [73]. Diabetic patients have a higher number of Lactobacillus species in the gut, and those species have a positive correlation with fasting glucose and HbA1c levels [74]. Garlic has a beneficial effect on the blood glucose profile of diabetic patients as well. Aged garlic extract used in the study has been demonstrated to improve insulin insensitivity [35]. Another study focused on the effect of alliin and found that the use of alliin increased the sensitivity to insulin and augmented glucose homeostasis in the body [39]. This will prevent fluctuation of glucose levels after meals and help diabetic patients better control
their serum glucose levels. A study by Zhang et al. [75] also found that allicin from garlic maintained glucose homeostasis, suggesting that it could be used to treat metabolic disorders.

6. Conclusion

Consumption of garlic has been demonstrated in many studies that it can modulate the gut microbiota by enhancing probiotics' growth and suppressing pathogenic microorganisms' growth. Studies showed that garlic has the potential to become a complementary alternative medicine to a lot of diseases. Thus, garlic is a great functional food containing bioactive constituents with immense potential to be developed as an anti-inflammatory, lipid-lowering, glucose-lowering, and antihypertensive agent.

Numerous studies have been conducted, and garlic has been portrayed as a beneficial agent for health conditions. It can modulate gene expression in the gut and the gut microbiota. Apart from that, garlic can be used to improve blood pressure, blood glucose profile, and lipid profile, and most importantly, garlic is a natural organic substance. It can effectively reduce the number of medications needed by a patient by substituting them with natural substances. However, most studies were done on the animal model. Future studies should be conducted on a large scale in humans to understand better the underlying mechanisms of garlic in conferring better health outcomes.

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References
1. Shreiner AB, Kao JY, and Young VB, The gut microbiome in health and in disease. Curr Opin Gastroenterol 2015; 31(1): 69-75.
2. Lau AWY, Tan LT-H, Ab Mutalib N-S, et al., The chemistry of gut microbiome in health and diseases. Prog Microbes Mol Biol 2021; 4(1).
3. Wang HJ, Battousse O, and Ramadas A, Modulation of gut microbiota by dietary macronutrients in type 2 diabetes: a review. Prog Microbes Mol Biol 2021; 4(1).
4. Goh JX-H, Tan LT-H, Law JW-F, et al., IDDF2022-ABS-0231 The effect of probiotic supplementation in newly diagnosed type-1 diabetes mellitus patient: a systematic review of randomized controlled trials. Gut 2022; 71(Suppl 2): A62-A63.
5. Thye AY-K, Bah Y-R, Law JW-F, et al., Gut-Skin Axis: Unravelling the Connection between the Gut Microbiome and Psoriasis. Biomedicines 2022; 10(5): 1037.
6. Thye AY-K, Law JW-F, Tan LT-H, et al., Exploring the Gut Microbiome in Myasthenia Gravis. Nutrients 2022; 14(8): 1647.
7. Lee L-H, Law JW-F, Tan LT-H, et al., IDDF2020-ABS-0113 Budding association between gut microbiome in the development of Myasthenia Gravis. Gut 2020; 69(Suppl 2): A17-A18.
8. Lim J-M, Letchumanan V, Tan LT-H, et al., Ketogenic Diet: A Dietary Intervention via Gut Microbiome Modulation for the Treatment of Neurological and Nutritional Disorders (a Narrative Review). Nutrients 2022; 14(17): 3566.
9. Chong H-Y, Tan LT-H, Law JW-F, et al., Exploring the Potential of Human Milk and Formula Milk on Infants' Gut and Health. Nutrients 2022; 14(17): 3554.
10. Letchumanan V, Thye AY-K, Tan LT-H, et al., IDDF2021-ABS-0164 Gut feelings in depression: microbiota dysbiosis in response to antidepressants. Gut 2021; 70(Suppl 2): A49-A50.
11. Lee JK-F, Hern Tan LT, Ramadas A, et al., Exploring the Role of Gut Bacteria in Health and Disease in Preterm Neonates. Int J Environ Res Public Health 2020; 17(19): 6963.
12. Valdes AM, Walter J, Segal E, et al., Role of the gut microbiota in nutrition and health. BMJ 2018; 361: k2179.
13. Durganaudu H, Kunasegaran T, and Ramadas A, Dietary Glycaemic Index and Type 2 Diabetes Mellitus: Potential Modulation of Gut Microbiota. Prog Microbes Mol Biol 2020; 3(1).
14. Tan LT-H, Letchumanan V, Law JW-F, et al., IDDF2021-ABS-0099 Exploring the effects of acupuncture therapy in restoring health via modulation of intestinal microbiota. Gut 2021; 70(Suppl 2): A37-A37.
15. Fan Y and Pedersen O, Gut microbiota in human metabolic health and disease. Nat Rev Microbiol 2021; 19(1): 55-71.
16. Rahman MS, Allicin and Other Functional Active Components in Garlic: Health Benefits and Bioavailability. International Journal of Food Properties 2007; 10(2): 245-268.
17. Ansary J, Forbes-Hernández TY, Gil E, et al., Potential Health Benefit of Garlic Based on Human Intervention Studies: A Brief Overview. Antioxidants 2020; 9(7).
18. Scassozzio B, Minghetti L, and D’Archivio M, Interaction between Gut Microbiota and Curcumin: A New Key of Understanding for the Health Effects of Curcumin. Nutrients 2020; 12(9).
19. Filocamo A, Nueno-Palop C, Bisignano C, et al., Effect of garlic powder on the growth of commensal bacteria from the gastrointestinal tract. Phytomedicine 2012; 19(8): 707-711.
20. Ruiz R, García MP, Lara A, et al., Garlic derivatives (PTS and PTS-O) differently affect the ecology of swine faecal microbiota in vitro. Vet Microbiol 2010; 144(1): 110-117.
21. Magne F, Gotteland M, Gauthier L, et al., The Firmicutes/Bacteroidetes Ratio: A Relevant Marker of Gut Dysbiosis in Obese Patients? Nutrients 2020; 12(5): 1474.
22. Zhang C, Xie J, Li X, et al., Alliin alters gut microbiota and gene expression of colonic epithelial tissues. J Food Biochem 2019; 43(4): e12795.
23. Chen K, Nakasone Y, Xie K, et al., Modulation of Allicin-Free Garlic on Gut Microbiome. Molecules 2020; 25(3).
24. Vacca M, Celano G, Calabrese FM, et al., The Controversial Role of Human Gut Lachnospiraceae Microorganisms 2020; 8(4): 573.
25. Law JW-F, Thye AY-K, Letchumanan V, et al., IDDF2022-ABS-0200 Probiotics to improve preterm babies’ health outcomes: research in recent 10 years (2012–2022). Gut 2022; 71(Suppl 2): A52-A53.
26. Azad MAK, Sarker M, Li T, et al., Probiotic Species in the Modulation of Gut Microbiota: An Overview. BioMed Res Int 2018; 2018: 9478630-9478630.
27. Selvaraj S, Wong S, Ser HL, et al., Role of Low FODMAP Diet and Probiotics on Gut Microbiome in Irritable Bowel Disease (IBS). Prog Microbes Mol Biol 2020; 3(1).
28. Thye AY-K, Tan LT-H, Law JW-F, et al., Long COVID-19: Psychological symptoms in COVID-19 and probiotics as an adjunct therapy. Prog Microbes Mol Biol 2022; 5(1).

29. Lee L-H, Letchumanan V, Law JW-F, et al., IDDF2022-ABS-0241 Exploring the potential role of probiotics in alleviating insomnia. Gut 2022; 71(Suppl 2): A65-A66.

30. Letchumanan V, Thye AY-K, Law JW-F, et al., IDDF2022-ABS-0207 The potential use of probiotics in alleviating psychological symptoms of long covid-19. Gut 2022; 71(Suppl 2): A57-A57.

31. Ruddock PS, Liao M, Foster BC, et al., Garlic natural health products exhibit variable constituent levels and antimicrobial activity against Neisseria gonorrhoeae, Staphylococcus aureus and Enterococcus faecalis. Phytother Res 2005; 19(4): 327-334.

32. Cho JH, Liu SD, and Kim IH, Effects of dietary Korean garlic extract aged by Leuconostoc mesenteroides KCCM35046 on growth performance, digestibility, blood profiles, gas emissions, and microbiota in weanling pigs. Canadian Journal of Animal Science 2020; 100(3): 462-469.

33. Lee L-H, Loo K-Y, Tan LT-H, et al., IDDF2021-ABS-0126 Exploring the gut microbiota variation in response to vibrio infection. Gut 2021; 70(Suppl 2): A45-A46.

34. Law JW-F, Letchumanan V, Ser H-L, et al., IDDF2021-ABS-0108 Enterobacteriaceae – deciphering the culprit gut bacteria causing necrotizing enterocolitis in infants. Gut 2021; 70(Suppl 2): A40-A40.

35. Maeda T, Miki S, Morihara N, et al., Aged garlic extract ameliorates fatty liver and insulin resistance and improves the gut microbiota profile in a mouse model of insulin resistance. Exp Ther Med 2019; 18(1): 857-866.

36. Satora M, Magdziarz M, Rząsa A, et al., Insight into the intestinal microbiome of farrowing sows following the administration of garlic (Allium sativum) extract and probiotic bacteria cultures under farming conditions. BMC Vet Res 2020; 16(1): 442.

37. Herrmann E, Young W, Rosendale D, et al., RNA-Based Stable Isotope Probing Suggests Allobaculum spp. as Particularly Active Glucose Assimilators in a Complex Murine Microbiota Cultured In Vitro. BioMed Res Int 2017; 2017: 1829685-1829685.

38. Ravussin Y, Koren O, Spor A, et al., Responses of gut microbiota to diet composition and weight loss in lean and obese mice. Obesity (Silver Spring, Md.) 2012; 20(4): 738-747.

39. Zhai B, Zhang C, Sheng Y, et al., Hypoglycemic and hypolipidemic effect of S-allyl-cysteine sulfoxide (alliin) in DIO mice. Sci Rep 2018; 8(1): 3527-3527.

40. Biddle A, Stewart L, Blanchard J, et al., Untangling the Genetic Basis of Fibrolytic Specialization by Lachnospiraceae and Ruminococcaceae in Diverse Gut Communities. Diversity 2013; 5(3).

41. Menni C, Jackson MA, Pallister T, et al., Gut microbiome diversity and high-fibre intake are related to lower long-term weight gain. Int J Obes 2017; 41(7): 1099-1105.

42. Zhang N, Huang X, Zeng Y, et al., Study on prebiotic effectiveness of neutral garlic fructan in vitro. Food Science and Human Wellness 2013; 2(3): 119-123.

43. O’Callaghan A and van Sinderen D, Bifidobacteria and Their Role as Members of the Human Gut Microbiota. Front Microbiol 2016; 7: 925-925.

44. Patole SK, Rao SC, Keil AD, et al., Benefits of Bifidobacterium breve M-16V Supplementation in Preterm Neonates - A Retrospective Cohort Study. PLoS One 2016; 11(3): e0150775-e0150775.

45. Zhang Q, Yu H, Xiao X, et al., Inulin-type fructan improves diabetic phenotype and gut microbiota profiles in rats. PeerJ 2018; 6: e4446-e4446.
46. Verstreken I, Laleman W, Wauters G, et al., Desulfovibrio desulfuricans bacteremia in an immunocompromised host with a liver graft and ulcerative colitis. J Clin Microbiol 2012; 50(1): 199-201.
47. Goldstein EJC, Citron DM, Peraino VA, et al., Desulfovibrio desulfuricans bacteremia and review of human Desulfovibrio infections. J Clin Microbiol 2003; 41(6): 2752-2754.
48. Vandeputte D, Falony G, Vieira-Silva S, et al., Prebiotic inulin-type fructans induce specific changes in the human gut microbiota. Gut 2017; 66(11): 1968.
49. Yagdi E, Cerella C, Dicato M, et al., Garlic-derived natural polysulfanes as hydrogen sulfide donors: Friend or foe? Food Chem Toxicol 2016; 95: 219-233.
50. Wallace JL, Motta J-P, and Buret AG, Hydrogen sulfide: an agent of stability at the microbiome-mucosa interface. Am J Physiol Gastrointest Liver Physiol 2017; 314(2): G143-G149.
51. Vezza T, Algieri F, Garrido-Mesa J, et al., The Immunomodulatory Properties of Propyl-Propane Thiosulfonate Contribute to its Intestinal Anti-Inflammatory Effect in Experimental Colitis. Mol Nutr Food Res 2019; 63(5): 1800653.
52. Seon-Kyun K, It, sup, et al., Role of Probiotics in Human Gut Microbiome-Associated Diseases. J Microbiol Biotechnol 2019; 29(9): 1335-1340.
53. Lee L-H, Letchumanan V, Tan LT-H, et al., IDDF2020-ABS-0112 Gut-skin axis: decoding the link between the gut microbiome and hives. Gut 2020; 69(Suppl 2): A16-A17.
54. Lee L-H, Tan LT-H, Letchumanan V, et al., IDDF2020-ABS-0115 A moulding game: the role of gut microbiome in osteoporosis. Gut 2020; 69(Suppl 2): A18-A19.
55. Tan LT-H, Letchumanan V, Law JW-F, et al., IDDF2022-ABS-0221 The roles of GUT microbiota in hand, foot and mouth disease. Gut 2022; 71(Suppl 2): A61-A61.
56. Li Y, Ma Q, Wang J, et al., Relationship between hyperlipidemia and the gut microbiome of rats, characterized using high-throughput sequencing. Journal of Traditional Chinese Medical Sciences 2020; 7(2): 154-161.
57. Wu J, Liu Y, Dou Z, et al., Black garlic melanoidins prevent obesity, reduce serum LPS levels and modulate the gut microbiota composition in high-fat diet-induced obese C57BL/6J mice. Food Funct 2020; 11(11): 9585-9598.
58. Wu J, Zhou X, Dou Z, et al., Different Molecular Weight Black Garlic Melanoidins Alleviate High Fat Diet Induced Circadian Intestinal Microbes Dysbiosis. J Agric Food Chem 2021.
59. Shi Xe, Zhou X, Chu X, et al., Allicin Improves Metabolism in High-Fat Diet-Induced Obese Mice by Modulating the Gut Microbiota. Nutrients 2019; 11(12).
60. Hiel S, Gianfrancesco MA, Rodriguez J, et al., Link between gut microbiota and health outcomes in inulin -treated obese patients: Lessons from the Food4Gut multicenter randomized placebo-controlled trial. Clin Nutr 2020; 39(12): 3618-3628.
61. Brenner DA, Paik Y-H, and Schnabl B, Role of Gut Microbiota in Liver Disease. J Clin Gastroenterol 2015; 49 Suppl 1(0 1): S25-S27.
62. Sherriff JL, O'Sullivan TA, Properzi C, et al., Choline, Its Potential Role in Nonalcoholic Fatty Liver Disease, and the Case for Human and Bacterial Genes. Adv Nutr 2016; 7(1): 5-13.
63. Wang Y, Guan M, Zhao X, et al., Effects of garlic polysaccharide on alcoholic liver fibrosis and intestinal microflora in mice. Pharm Biol 2018; 56(1): 325-332.
64. Zhang N, Wang Y, Zhang J, et al., Diallyl disulfide attenuates non-alcoholic steatohepatitis by suppressing key regulators of lipid metabolism, lipid peroxidation and inflammation in mice. Mol Med Report 2019; 20: 1363+.

65. Lai Y-S, Chen W-C, Ho C-T, et al., Garlic Essential Oil Protects against Obesity-Triggered Nonalcoholic Fatty Liver Disease through Modulation of Lipid Metabolism and Oxidative Stress. J Agric Food Chem 2014; 62(25): 5897-5906.

66. Shunming Z, Yeqing G, Liu W, et al., Association between dietary raw garlic intake and newly diagnosed nonalcoholic fatty liver disease: a population-based study. European Journal of Endocrinology 2019; 181(6): 591-602.

67. Yang Y, Yang F, Huang M, et al., Fatty liver and alteration of the gut microbiome induced by diallyl disulfide. Int J Mol Med 2019; 44(5): 1908-1920.

68. Jose PA and Raj D, Gut microbiota in hypertension. Curr Opin Nephrol Hypertens 2015; 24(5): 403-9.

69. Ried K, Garlic lowers blood pressure in hypertensive subjects, improves arterial stiffness and gut microbiota: A review and meta-analysis. Exp Ther Med 2020; 19(2): 1472-1478.

70. Wu W-K, Panyod S, Ho C-T, et al., Dietary allicin reduces transformation of L-carnitine to TMAO through impact on gut microbiota. J Funct Foods 2015; 15: 408-417.

71. Benavides GA, Squadrito GL, Mills RW, et al., Hydrogen sulfide mediates the vasoactivity of garlic. Proc Natl Acad Sci U S A 2007; 104(46): 17977-82.

72. Hsu C-N, Hou C-Y, Chang-Chien G-P, et al., Maternal Garlic Oil Supplementation Prevents High-Fat Diet-Induced Hypertension in Adult Rat Offspring: Implications of H2S-Generating Pathway in the Gut and Kidneys. Mol Nutr Food Res 2021; 65(11): 2001116.

73. Grigorescu I and Dumitrascu DL, Implication of gut microbiota in diabetes mellitus and obesity. Acta Endocrinol (Copenh) 2016; 12(2): 206-214.

74. Blandino G, Inturri R, Lazzara F, et al., Impact of gut microbiota on diabetes mellitus. Diabetes Metab 2016; 42(5): 303-315.

75. Zhang C, He X, Sheng Y, et al., Allicin-induced host-gut microbe interactions improves energy homeostasis. FASEB J 2020; 34(8): 10682-10698.

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