

Health Benefit of Plant-base Fermented Food and Beverage on Type 2 Diabetes Mellitus

Jialin Lian*

United World College, Changshu, China

*Corresponding author: jllian21@uwccchina.org

Abstract. Fermentation has been a significant food processing and storage method in human dietary culture since ancient times. Nowadays, an increasing number of research studies are intensely focusing on the health advantages that fermented beverages and foods have. Type 2 diabetes mellitus, known as the metabolic disorder with high blood glucose level, is prevailing in modern society and seriously harms publics' well-being. However, several studies showcased the benefits of fermented food in the potential treatment and prevention of type 2 diabetes. Effect of animal-based fermented food, such as yogurt, on type 2 diabetes has been greatly explored, but insufficient studies specifically explored the relationship between plant-based fermented food and type 2 diabetes. This article investigated the health benefits of plant-based fermented beverage and food, including vegetables, tea, fruits, legumes, and grains, on type 2 diabetes. In conclusion, the fermentation process enhanced the nutritional value of the raw material. Fermented food and beverage are potentially diabetes-friendly and desirable, but they must be consumed in moderation.

Keywords: Plant-based Food, Fermented Food, Type 2 Diabetes Mellitus.

1. Introduction

Fermentation is the most affordable and oldest food preservation method enjoyed by humans in worldwide, and fermented food is an integral part of human culture [1, 2]. A wide range of food can be fermented, for example, dairy products, meat, legumes, grains, vegetables, and fruits [3]. In the fermentation process, microorganisms and molecules such as enzymes, bacteria, or fungi will be involved, implementing biochemical reactions and improving the taste and nutrition value of food [1]. Many studies revealed the health benefits of fermented food, such as reducing cardiovascular disease risks, potential enhancement in gut microbiota composition, antihypertension, anti-inflammatory, and enhancing insulin secretion [1, 4, 5]. Hence, investigating the health benefits of fermented food became a focus of study.

As a metabolic disorder prevailing in modern days, type 2 diabetes mellitus is associated with a large portion of global death [5]. To be more specific, the non-communicable disease, type 2 diabetes, can be identified by high blood glucose level caused by insulin resistance and inadequate secretion of insulin [6]. The mechanism and risk factors of this disease are substantially explored, and in which the family history of diabetes, high-calorie intake diet, deficiency in physical activity, dyslipidemia, hormone factors, and obesity are the risk factors for the onset of type 2 diabetes [5, 6]. Adjusting to a healthier lifestyle, including decreasing calorie intake, preventing trans fatty acid intake, and selecting food with low glycemic index, will be helpful in treating or preventing type 2 diabetes [4].

According to studies, several fermented foods, such as kimchi, have been validated with potential health benefits in preventing type 2 diabetes [5]. Additionally, food fermentation had shown with hypoglycemic effect by decreasing soluble carbohydrate content, increasing resistant starch, and increasing dietary fiber concentration [4].

The studies focusing on specific health benefits to type 2 diabetes of plant-based fermented food are relatively less than that of animal-based fermented food. However, plant-based foods are healthy and compose a large portion of the human diet with its increased popularity. This article aimed to investigate and discuss the health benefits of plant-based fermented beverages and food for type 2 diabetes.

2. Fermentation

Fermented food, a historically essential food type in the human diet, is the product manufactured by changing nutrients such as carbohydrates, fat, and protein by reactions of microbial organisms and enzymes in food [3, 7]. Fermentation, as a major process in producing fermented food, involves the breakdown of carbohydrates or similar substances in either aerobic or anaerobic reactions [7].

2.1. Health Benefits

Several health benefits can be achieved by fermenting food. Firstly, fermented food can improve food digestibility. By breaking down macronutrients, enzymes and microorganisms involved during fermentation can digest large organic molecules in advance [8, 9]. Second, fermentation can implement detoxification as well as degradation of anti-nutrients. Poisonous substances or toxins, such as mycotoxin and cyanide content in cassava, and anti-nutrient, such as phytic acid, will be inhibited from absorption or reduced in concentration during fermentation, indirectly improving nutritional value [7, 8]. Additionally, fermentation enhances the nutrition content of food. Microorganisms in fermentation can synthesize and increase the availability of vitamin B-12, niacin, folic acid, and thiamine [8, 10].

Furthermore, the gastrointestinal tract health can be improved by intaking fermented food. A large number of microorganisms being delivered to the gastrointestinal tract are supported by fermented food, which is beneficial to human gut microbiota [11]. The prebiotic and probiotic components in fermented food, such as probiotic lactic acid bacteria, also exert benefits on health [11]. For example, probiotic bacteria have been demonstrated to enhance antioxidant and lipid profile status in type 2 diabetes patients [12]. Study elucidated that type 2 diabetes is related to the composition and alteration in gut microbiota, while probiotics can positively and promisingly change gastrointestinal [6]. However, the specific pathway and diabetes-probiotic relationship are unconfirmed [4].

2.2. Categorization of Fermented Food

2.2.1 Mechanism of Fermentation

Fermentation can be categorized in distinct ways. Based on the mechanism or pathway aspect, food can be fermented in a controlled or uncontrolled way [1]. The former method refers to fermenting substances with microorganisms naturally existing in food or environment, also known as natural or spontaneous fermentation, dominating the vast majority of fermented products [1, 13]. The latter uncontrolled approach relates to supplementing starter culture to initiate fermentation, known as culture-dependent fermentation [13].

2.2.2 Classify Fermentation According to Microorganisms or Molecules Contained

According to the microorganisms involved in fermentation, lactic acid fermentation, alcoholic fermentation, and the acetic acid fermentation are commonly utilized among food industries.

2.2.2.1 Lactic Acid Fermentation

The lactic acid fermentation refers to utilizing lactic acid bacteria (LAB) during the fermenting process [14]. This fermentation method is regarded as the contributor of beneficial traits in fermented products due to the LAB, the dominant microorganism existed in a wide range of fermented products [14]. By breaking down carbohydrate into lactate, an acidic substance that can decrease the pH of product to approximately 4.0, lactic acid fermentation can hamper the development of pathogenic microbes [15, 16]. By extension, oxidation of carbohydrates into carbon dioxide and alcohol is involved in lactic acid fermentation, as well as the conversion of the intermediate, pyruvate, into acetoin, acetaldehyde, diacetyl, or acetic acid [15]. Fruits and vegetables are commonly fermented by natural probiotic--lactic acid bacteria such as *Lactobacter plantarum*, *Lb. gasseri*, *Lb. rhamnosus* and *Lb. acidophilus*, enhancing bioavailability and antioxidant by removing hazardous free radicals [16, 17]. Study illustrated that low glycemic index diet can decrease glucose and insulin response, prevent weight gain, and alleviate type 2 diabetes risk [18]. Reduction in soluble carbohydrate concentration

and starch availability in fermentation results in the low glycemic index of food and partially contributes to a lower risk of type 2 diabetes [1].

2.2.2.2 Alcoholic Fermentation

In alcoholic fermentation, also called ethanol fermentation, yeast performed a profound role. Yeasts are eukaryotes colonized in various niches, including plant and fruit surfaces [19]. By converting carbohydrates into ethanol and carbon dioxide, yeast can ferment both alcoholic beverages, wine and beer, and non-alcoholic food, such as bread and chocolate [19].

2.2.2.3 Acetic Acid Fermentation

Acetic acid fermentation involves the utilization of acetic acid bacteria (AAB) aerobically in food fermenting. AAB can be found in flowers, fruits, and plants and is capable in oxidizing alcohol, sugar, or aldehydes [20]. With the conversion of acetic acid from fructose and of gluconic acid from glucose, this fermentation method can provide sour taste and is essential in the vinegar industry [20, 21].

3. Plant-Base Fermented Food and Health Benefit to Type 2 Diabetes

A wide range of food can be fermented and relished, for instance, vegetables, fruits, dairy, and meat [13]. Fermented food can be classified into animal-based and plant-based food. Compared to animal-based fermented food, such as yogurt, plant-based fermented food is underexplored in overall [22]. However, the impact of plant-based fermented food on health is significant and worth exploring.

3.1. Legume

Many cultures throughout the world eat legumes as a staple meal. Legumes are rich in carbohydrates, protein, and dietary fiber, while low in fat [23]. A study reported that fermented legumes can modify enzymes such as acetylcholinesterase, amylase, and glucosidase, exerting anti-diabetic quality [24].

3.1.1 Soybeans

Containing exceptional quality and variety of proteins and phytochemicals among the plants, soybeans are known as one of the healthiest foods in worldwide, with abundant nutrients and health benefits [25]. Soybeans are within the traditional diet in Asian countries with relatively lower type 2 diabetes incidents, such as China, Korea, Vietnam, and Japan, and the association between type 2 diabetes and soybeans had been widely studied [11, 25]. Despite the abundance of nutrients and components, two major components, isoflavonoids, including daidzein and genistein, and soy protein, are investigated worldwide the most [4, 25]. Figure 1 presents the isoflavone content in different soybean products.

The isoflavonoids possess structural similarity with endogenous estrogen, which is supportive in treating and preventing type 2 diabetes by escalating the secretion of insulin and reducing insulin resistance, and thus isoflavonoids can weakly bind to estrogen receptors and may enhance glucose homeostasis and prevent type 2 diabetes via estrogenic activity [11, 25]. According to research, fermented soybeans are unlike to boost absorption of isoflavonoid directly. However, the probiotics and metabolites generated during fermentation may construct the gastrointestinal microbiota that can assist hydrolysis and absorption of isoflavonoids, contributing to diminishing insulin resistance and type 2 diabetes risks [25]. Soybean protein, especially bioactive oligopeptides, is a prospective research scope, and had been reported with a great amount of health benefits to human, such as enhancement in insulin secretion [26].

However, the detailed impact of fermented soybean on type 2 diabetes in particular groups of people is still unveiled due to the lack of specified data. For example, populations with different ages and food matrices will maintain diverse gut microbiota, and thus the effect of fermented soybeans isoflavonoids' metabolism will be distinct [25]. Nevertheless, the ample nutrients and benefits of fermented soybean products are unignorable.

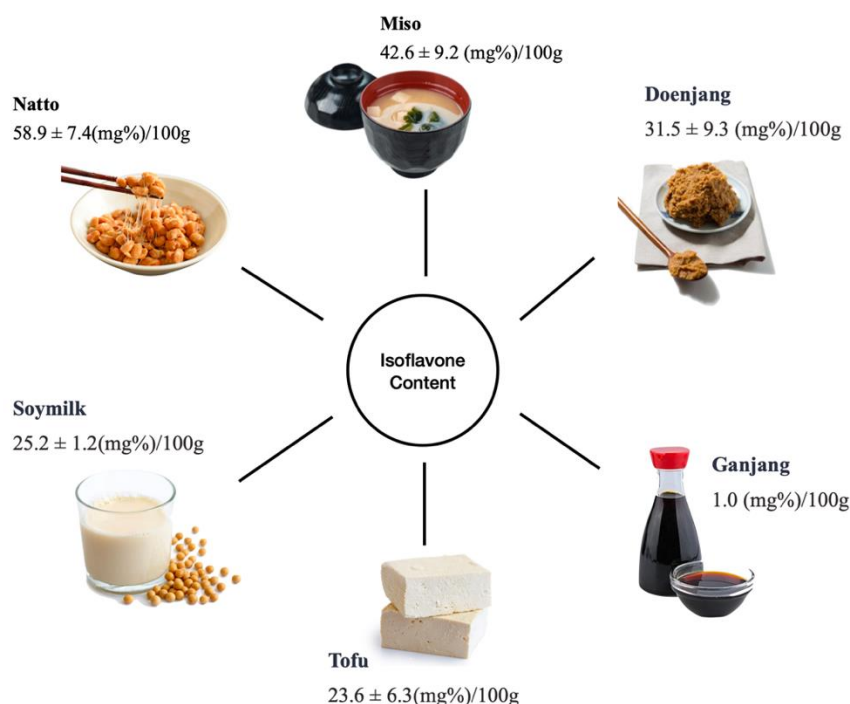


Figure 1. Isoflavone Content in Different Soybean Products [25]

3.2. Vegetable and Plant

Regarding the high nutritional value of vegetables and plants, though the non-fermented vegetables had an overall weak association with reduced risks of type 2 diabetes, they are still a desirable food group to intake and further research [27]. Meanwhile, the spontaneous fermentation of plants by lactic acid bacteria can enhance food nutrition values and elongate their storage time to prevent plants from being easily spoiled [11]. Fermented vegetables and plants such as kimchi and tea are popular among the public, significant to certain cultures, and promising in controlling or preventing type 2 diabetes.

3.2.1 Kimchi

Kimchi is a traditional Korean cuisine which mixed Chinese cabbages, spices, radishes, garlic, ginger, and salt together to ferment naturally. It is recognized as beneficial in mitigating prediabetes risks due to the function of reducing insulin resistance and increasing insulin sensitivity [11, 28].

The raw ingredient cabbage was verified with antidiabetic properties. Cabbaged contained antidiabetic-related and bioactive compounds such as vitamin K and vitamin C, fibers, phenolic acid, and flavonoids. Prediabetic and diabetic patients have low vitamin C level due to the cellular oxide reduction imbalance which necessitates extra extrinsic antioxidant molecules as vitamin C. Additionally, vitamin C competed with glucose in cellular absorption due to their similar structures, aiding in treating and preventing Type 2 Diabetes [5]. Also, another molecule vitamin K can influence insulin sensitivity since it reduces pro-inflammatory cytokine production [29]. Phenolic acids, such as vanillic, ferulic, synaptic, syringic, and caffeic, can potentially regulate glucose absorption and carbohydrate metabolism by inhibiting α -glucose enzymes, protecting pancreas beta-cells, and promoting insulin action, thus beneficial in treating and preventing type 2 diabetes [5]. Quercetin, one of the flavonoids, can spur glucose uptake by stimulate GLUT 3 gene expression and increase insulin sensitivity by promoting pancreatic beta-cell generation and thus raising insulin production [5].

Compounds such as organic acid, functional phytochemicals, and volatile compounds are produced during fermentation by microorganisms, which means that the original nutrition content in

cabbages will be enhanced and promoted, partially contributing to the diabetes-friendly property of kimchi [5].

3.2.2 Kombucha Beverage

Kombucha is a fermented sugared black tea drink with the use of glutinous starter, bacteria, and yeast [13]. Figure 2 shows the overall and general process of fermenting black tea into kombucha. Fermentation increases the flavonoid and polyphenol content, and the compounds are shown to have associations with type 2 diabetes prevention or treatment through intervening in insulin secretion pathway and glucose metabolism.

Study had demonstrated that providing kombucha to diabetic experiment rats for 45 days can increase their insulin and tissue glycogen level [30]. This hypoglycemic effect is achieved by strengthening glycolytic enzymes and gluconeogenic functions by kombucha [30]. However, insufficient studies investigated the mechanism of kombucha on gastrointestinal microbiota health of animals or humans to provide a more specific pathway [13].

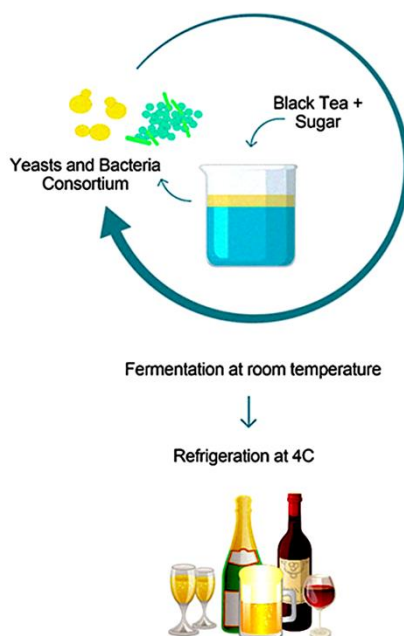


Figure 2. General Production Process of Kombucha [21]

3.3. Fruit

Correspondingly to vegetable and plant-based fermented food, fruit as raw material is perishable, and fermentation can enhance nutrition quality and storage ability. Nevertheless, fruits have a higher and closer association with lowering type 2 diabetes risk than plants and vegetables [24, 27].

3.3.1 Red wine

Red wine was produced from alcoholic fermentation of grapes. The raw material, grape, contained antioxidants classified as polyphenols, the molecule had shown beneficial effect on reducing cardiovascular diseases and diabetes [31]. One of the polyphenols in both grapes and wine, resveratrol, is shown to have protection functionality in vitro and in vivo vessels and can be utilized in preventing diabetic angiopathy [31]. Although wine is beneficial in reducing the risks of diabetes, hypertension, and hyperlipidemia, excessive intake will ultimately bring negative effects [1]. Therefore, drinking red wine in moderation is necessary.

3.3.2 Coffee

As a popular beverage in worldwide, coffee was fermented through both aerobically and anaerobically fermentation during the preparation stage [32]. Study had shown the inverse association

between long term coffee intake and type 2 diabetes risks, and the anti-diabetic effect was primarily from the compounds and molecules in coffee, such as phenolic compound and magnesium [33, 34].

The phenolic compound such as CGA can inhibit the glucose-6-phosphate, alpha-glucosidase, and GLUT4 to absorb glucose and thus reduce plasma glucose level, hepatic glucose production and damaging hyperglycemia symptoms [4].

Magnesium, another molecule abundant in coffee, is significant in glucose homeostasis regulation and glucose metabolism as a cofactor for enzymes [4]. Deficiency in magnesium can be a biomarker for type 2 diabetes since diabetic patients may exhibit hypomagnesemia [4]. Coffee intake in long-term impressively escalates serum magnesium level, thus can decrease the type 2 diabetes risk by enhancing insulin sensitivity and improving glycemic regulation [4, 34].

3.3.3 Fruit Vinegar

Vinegar can be derived from fermentation of either fruit or grain by using double fermentation method, which is alcoholic fermentation (anaerobic) and acetic fermentation (aerobic) [35]. Fruit based vinegar can be made from the juice of apple, coconut, and grape [32]. By containing a high concentration of phenolic acid, including syringic acid, gallic acid, ferulic acid, epicatechin, catechin, and chlorogenic acid, fruit-based vinegar was recognized to have reduction effect on diabetes [32, 36]. Furthermore, the acidity of vinegar can potentially inhibit the alpha-amylase, thus hindering the carbohydrate digestion and preventing increment of blood glucose level [35]. Figure 3 showcased a brief illustration of hypoglycemic effect of vinegar. However, an acute intake of vinegar may cause high urinary excretion of sodium, bicarbonate, and potassium and may cause injury to esophagus as well as to oropharynx [35]. Still, cautiousness and moderation to the amount in consuming vinegar are noteworthy.

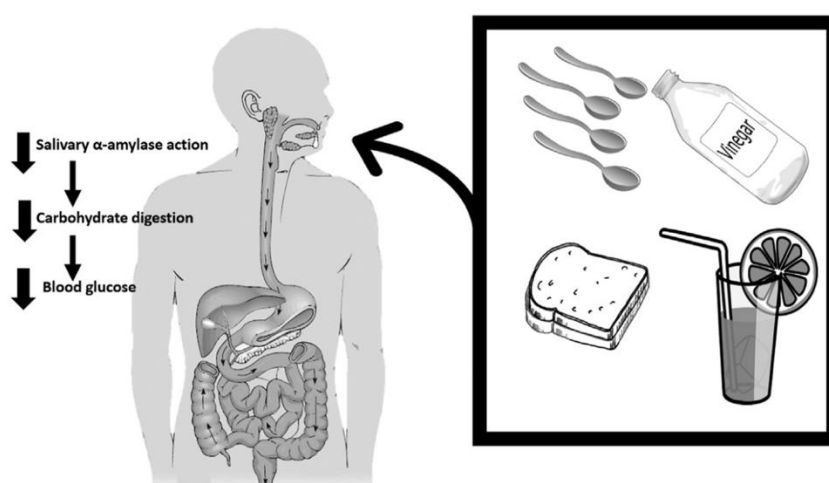


Figure 3. Hypothesis of Lowering Blood Glucose Level Via Vinegar Inhibiting Alpha-Amylase [35]

3.4. Grain

Grains comprise a large portion of staple food in worldwide, yet they are considered to be nutritionally deficient due to a lack of fundamental elements such as essential amino acids [1]. Nonetheless, grains' functional qualities and nutritional values can be enhanced through fermentation. For example, the bioavailability of vitamin B group can be increased, and particular amino acids can be newly synthesized [1].

3.4.1 Red mold rice

The traditional Chinese food, red mold rice, is a fermented grain product made by inoculating steamed rice with the mold *Monascus*, demonstrating with anti-diabetic effect [37, 38]. The mold *Monascus* will produce some health-benefiting secondary metabolites during fermentation. Few studies have shown intake of red mold rice for eight weeks can help to augment insulin secretion and

improve antioxidant properties also lipid profile in diabetic rats [38]. For a more precise conclusion, further long-term studies tested on human is expected.

3.4.2 Beer

Beer is a highly consumed alcohol-based beverage in worldwide that fermented through yeast and alcohol. As a high antioxidant capacity beverage, beer was shown to have various health benefits due to its molecular content, such as phenol, melanoidin, and vitamin. Ethanol, one of the significant parts of beer, may reduce the risks of diabetes and cardiovascular diseases [39]. Additionally, non-alcoholic elements, mostly polyphenol, can provide protective effect, and the prevention of type 2 diabetes is promising and expected due to its anti-diabetic property [1]. However, healthy beer intake requires a moderate consumption volume. Moderation intake of beer is beneficial to humans, including benefiting gastrointestinal tract and lowering diabetes risk [1]. Similar to red wine, excessive consumption will trigger undesirable outcomes for body and health.

3.4.3 Grain vinegar

The grain-based vinegar is produced by fermenting grains such as wheat, barley, and rice. Gallic acid, synaptic acid, salicylic acid, ferulic acid, protocatechuic acid, and vitamin B group were plentiful in grain-based vinegar [36]. Likewise, the fermented grain vinegar is also shown with anti-diabetic properties as fruit-based vinegar, contributing to the high phenolic content [36]. Figure 4 represents the production process of both grain and fruit vinegar. One notable notification is that consuming grain vinegar in moderation is also requisite for health and safety.

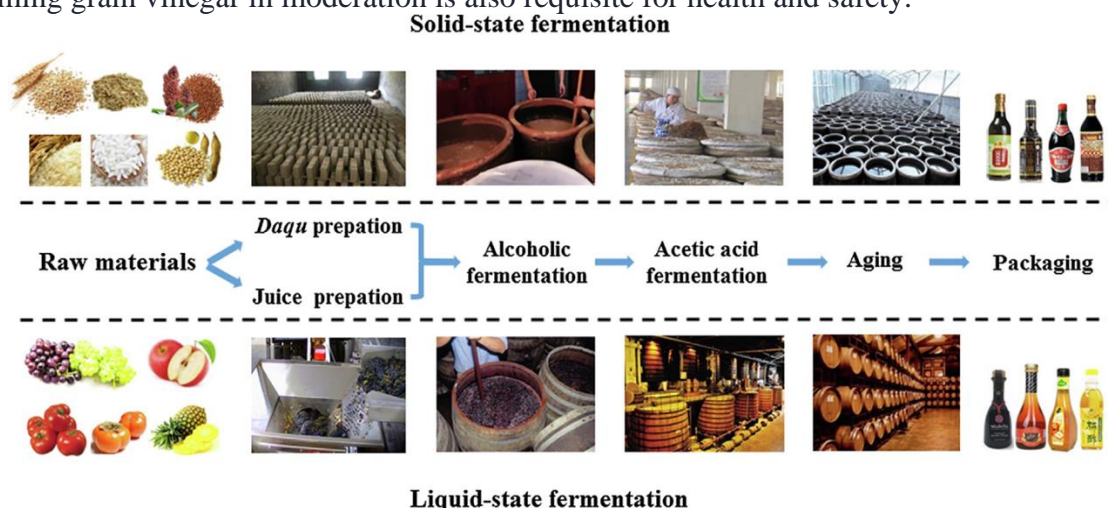


Figure 4 Fermentation Process of Grain and Fruit Vinegar [36]

4. Conclusion

In conclusion, fermented plant-based food has abundant health benefits to type 2 diabetes. The bioavailability of certain nutrients can be increased, and some nutrients can be newly synthesized or after fermentation. Additionally, some harmful substances can be inhibited from absorption or reduced in concentration by fermentation.

Several raw materials of fermented food, such as soybeans and cabbage, are type 2 diabetes-friendly already, and fermentation can further enhance their nutrition value. Some fermented foods or beverages, such as red wine, are beneficial in preventing or treating type 2 diabetes. However, the intake amount each time should be cautiously concerned during consumption.

Overall, consumption of fermented plant-based food in moderation and with a balanced diet can partially help prevent type 2 diabetes. Additionally, improving general dietary habits, enhancing lifestyle, and increasing physical activities are also crucial for maintaining health and preventing type 2 diabetes.

Fermented food was closely related to humans, and further human-based long-term experiments are necessary for a more precise validation of fermented food's health benefits. Additionally, future exploration of fermented food from multi-perspectives such as potential risks and industrial fermentation technology will be promising and desirable.

References

- [1] Scazzino Francesca, Del Rio Daniele, Pellegrini Nicoletta, et al. Sourdough bread: Starch digestibility and postprandial glycemic response [J]. *Journal of Cereal Science*, 2009, 49(3): 419-421.
- [2] Kabak Bulent, Dobson Alan DW. An Introduction to the Traditional Fermented Foods and Beverages of Turkey [J]. *Critical Reviews in Food Science and Nutrition*, 2011, 51(3): 248-260.
- [3] Doreen Gille Alexandra Schmid, Barbara Walther, Guy Vergères. Fermented Food and Non-Communicable Chronic Diseases: A Review [J]. *Nutrients*, 2018, 10(4): 448.
- [4] Negrete-Romero Berenice, Valencia-Olivares Claudia, Baños-Dossetti Gloria Andrea, et al. Nutritional Contributions and Health Associations of Traditional Fermented Foods [J]. *Fermentation*, 2021, 7(4): 289.
- [5] Uuh - Narvaez Jonatan Jafet, Segura - Campos Maira Rubí. Cabbage (*Brassica oleracea* var. capitata): A food with functional properties aimed to type 2 diabetes prevention and management [J]. *Journal of Food Science*, 2021, 86(11): 4775-4798.
- [6] Salgaço Mateus Kawata, Oliveira Liliane Garcia Segura, Costa Giselle Nobre, et al. Relationship between gut microbiota, probiotics, and type 2 diabetes mellitus [J]. *Applied Microbiology and Biotechnology*, 2019, 103(23): 9229-9238.
- [7] M. N. Hasan M. Z. Sultan, M. Mar-E-Um. Significance of Fermented Food in Nutrition and Food Science [J]. *Journal of Scientific Research*, 2014, 6(2): 373-386.
- [8] Sharma Ranjana, Garg Prakrati, Kumar Pradeep, et al. Microbial Fermentation and Its Role in Quality Improvement of Fermented Foods [J]. *Fermentation*, 2020, 6(4): 106.
- [9] Xiang Huan, Sun-Waterhouse Dongxiao, Waterhouse Geoffrey IN, et al. Fermentation-enabled wellness foods: A fresh perspective [J]. *Food Science and Human Wellness*, 2019, 8(3): 203-243.
- [10] Kennedy David O. B vitamins and the brain: mechanisms, dose and efficacy—a review [J]. *Nutrients*, 2016, 8(2): 68.
- [11] Marco Maria L, Heeney Dustin, Binda Sylvie, et al. Health benefits of fermented foods: microbiota and beyond [J]. *Current Opinion in Biotechnology*, 2017, 44: 94-102.
- [12] Khan Hassan, Kunutsor Setor, Franco Oscar H, et al. Vitamin D, type 2 diabetes and other metabolic outcomes: a systematic review and meta-analysis of prospective studies [J]. *Proceedings of the Nutrition Society*, 2013, 72(1): 89-97.
- [13] Dimidi Eirini, Cox Selina Rose, Rossi Megan, et al. Fermented foods: Definitions and Characteristics, Impact on the Gut Microbiota and Effects on Gastrointestinal Health and Disease [J]. *Nutrients*, 2019, 11(8): 1806.
- [14] Mokoena Mduduzi Paul. Lactic Acid Bacteria and Their Bacteriocins: Classification, Biosynthesis and Applications against Uropathogens: A Mini-Review [J]. *Molecules*, 2017, 22(8): 1255.
- [15] Saeed A Hayek, Salam A Ibrahim. Current Limitations and Challenges with Lactic Acid Bacteria: A Review [J]. *Food and Nutrition Sciences*, 2013, 4(11A): 40133.
- [16] Montet Didier, Ray Ramesh C, Zakhia-Rozis Nadine. Lactic acid fermentation of vegetables and fruits [J]. *Microorganisms and fermentation of traditional foods*, 2014: 108-140.

- [17] Swain Manas Ranjan, Anandharaj Marimuthu, Ray Ramesh Chandra, et al. Fermented Fruits and Vegetables of Asia: A Potential Source of Probiotics [J]. *Biotechnology Research International*, 2014, 2014:1-19.
- [18] Demirkesen-Bicak Hilal, Arici Muhammet, Yaman Mustafa, et al. Effect of Different Fermentation Condition on Estimated Glycemic Index, In Vitro Starch Digestibility, and Textural and Sensory Properties of Sourdough Bread [J]. *Foods*, 2021, 10(3): 514.
- [19] Maicas Sergi. The Role of Yeasts in Fermentation Processes [J]. *Microorganisms*, 2020, 8(8): 1142.
- [20] De Roos Jonas, De Vuyst Luc. Acetic acid bacteria in fermented foods and beverages [J]. *Current Opinion in Biotechnology*, 2018, 49: 115-119.
- [21] de Almeida Souza Caroliny, de Oliveira Ícaro Alves Cavalcante Leite, de Oliveira Rolim Victoria Ananias, et al. Traditional Fermented Foods as an Adjuvant Treatment to Diabetes [J]. *Current Geriatrics Reports*, 2020, 9(4): 242-250.
- [22] Wuyts Sander, Van Beeck Wannes, Allonsius Camille Nina, et al. Applications of plant-based fermented foods and their microbes [J]. *Current opinion in biotechnology*, 2020, 61: 45-52.
- [23] Cichońska Patrycja, Ziarno Małgorzata. Legumes and legume-based beverages fermented with lactic acid bacteria as a potential carrier of probiotics and prebiotics [J]. *Microorganisms*, 2021, 10(1): 91.
- [24] Ademiluyi Adedayo O, Oboh Ganiyu, Boligon Aline A, et al. Dietary supplementation with fermented legumes modulate hyperglycemia and acetylcholinesterase activities in Streptozotocin-induced diabetes [J]. *Pathophysiology*, 2015, 22(4): 195-201.
- [25] Kwon Dae Young, Daily III James W, Kim Hyun Jin, et al. Antidiabetic effects of fermented soybean products on type 2 diabetes [J]. *Nutrition Research*, 2010, 30(1): 1-13.
- [26] Sites Cynthia K, Cooper Brian C, Toth Michael J, et al. Effect of a daily supplement of soy protein on body composition and insulin secretion in postmenopausal women [J]. *Fertility and Sterility*, 2007, 88(6): 1609-1617.
- [27] Jiang Zengliang, Sun Ting-yu, He Yan, et al. Dietary fruit and vegetable intake, gut microbiota, and type 2 diabetes: results from two large human cohort studies [J]. *BMC medicine*, 2020, 18(1): 1-11.
- [28] An So-Yeon, Lee Min Suk, Jeon Ja Young, et al. Beneficial effects of fresh and fermented kimchi in prediabetic individuals [J]. *Annals of Nutrition and Metabolism*, 2013, 63(1-2): 111-119.
- [29] Yan Mabel Kar-Wai, Khalil Hanan. Vitamin supplements in type 2 diabetes mellitus management: a review [J]. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews*, 2017, 11: S589-S595.
- [30] Srihari Thummala, Karthikesan Krishnamoorthy, Ashokkumar Natarajan, et al. Antihyperglycaemic efficacy of kombucha in streptozotocin-induced rats [J]. *Journal of Functional Foods*, 2013, 5(4): 1794-1802.
- [31] Snopek Lukas, Mlcek Jiri, Sochorova Lenka, et al. Contribution of red wine consumption to human health protection [J]. *Molecules*, 2018, 23(7): 1684.
- [32] Wilburn JR, Ryan EP. Fermented foods in health promotion and disease prevention: An overview [J]. *Fermented Foods in Health and Disease Prevention*, 2017: 3-19.
- [33] van Dam Rob M, Hu Frank B, Willett Walter C. Coffee, Caffeine, and Health [J]. *New England Journal of Medicine*, 2020, 383(4): 369-378.
- [34] Akash Muhammad Sajid Hamid, Rehman Kanwal, Chen Shuqing. Effects of coffee on type 2 diabetes mellitus [J]. *Nutrition*, 2014, 30(7-8): 755-763.

- [35] Santos Heitor O, de Moraes Wilson MAM, da Silva Guilherme AR, et al. Vinegar (acetic acid) intake on glucose metabolism: A narrative review [J]. *Clinical nutrition ESPEN*, 2019, 32: 1-7.
- [36] Xia Ting, Zhang Bo, Duan Wenhui, et al. Nutrients and bioactive components from vinegar: A fermented and functional food [J]. *Journal of Functional Foods*, 2020, 64: 103681.
- [37] Rajasekaran A, Kalaivani M. Protective effect of *Monascus* fermented rice against STZ-induced diabetic oxidative stress in kidney of rats [J]. *Journal of Food Science and Technology*, 2015, 52(3): 1434-1443.
- [38] Baruah Rwivoo, Ray Mousumi, Halami Prakash M. Preventive and therapeutic aspects of fermented foods [J]. *Journal of applied microbiology*, 2022, 132(5): 3476-3489.
- [39] Humia Bruno Vieira, Santos Klebson Silva, Barbosa Andrielle Mendonça, et al. Beer molecules and its sensory and biological properties: A review [J]. *Molecules*, 2019, 24(8): 1568.