**Fermented Food Products: Their Potential Role in Managing Hypercholesterolemia**

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ABSTRACT

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| **Background and Objectives:** Hypercholesterolaemia, characterized by elevated cholesterol levels, poses a significant risk for various cardiovascular diseases. Fermentation has been a traditional method for food preservation and enhancement, leading to improved nutritional quality and the production of bioactive compounds with potential health benefits. This study explores the potential of fermented food products in managing hypercholesterolaemia as an alternative to synthetic drugs.  **Materials and Methods**: A randomized review of 36 eligible research was carried out, studies were screened based on their relevance to the research topic, non-fermented results were excluded. The study investigated various fermented condiments, drinks, and other food products, highlighting their impact on cholesterol levels based on documented database of PubMed, Scopus and Google scholar.  **Result:** Fermented condiments such as soy sauce, soy-daddawa, iru, ogiri, fermented garlic, and fermented red onion; drinks like soymilk, kombucha, and fermented milk are discussed, showcasing their potential in reducing hypercholesterolaemia by up to 80.5%. Furthermore, fermented red yeast rice, known for its cholesterol-lowering properties due to the presence of monacolin K, is explored. Korean staple, kimchi, and Nigerian fermented food, ogi, made from maize or sorghum, also demonstrate their hypocholesterolemic effects. The mechanisms underlying these effects involve the inhibition of HMG CoA reductase, reduction in cholesterol synthesis, and modulation of transcriptional factors in the liver.  **Conclusion:** In conclusion, fermented products emerge as promising natural alternatives for managing hypercholesterolaemia, offering cost-effective and potentially side-effect-free options. Their impact on cholesterol levels is attributed to the influence of specific microorganisms, secondary metabolites, and their ability to modulate key regulatory factors in cholesterol metabolism. It is recommended to incorporate fermented foods into a balanced diet for improved cardiovascular health. |

***Keywords:***Cholesterol, Hypercholesterolaemia, Fermentation, Condiments

1. INTRODUCTION

Hypercholesterolaemia is defined as high level of cholesterol in the blood. This is a condition where excess of fatty substances largely cholesterol and triglycerides are present in the blood. This condition could also be described in terms of fat-protein complexes called lipoproteins. A measure of the low-density lipoproteins which is greater than 190 mg/dL in blood is termed hypercholesterolaemia. Hypercholesterolaemia has been described as a health risk of some other illnesses including high blood pressure, heart attack and other cardiovascular linked problems such as atherosclerosis, atheroma, and others. The population of people living with this medical condition is increasing daily, and this inadvertently has put burden on the health system.

Food fermenting has a long history, with the aim of preserving the raw materials, produce varieties, enhance better quality and digestibility, improve the nutritional quality and degrading hazardous components of material food source (Atere *et al*., 2020a). However, as microorganisms’ ferments food samples, they tend to produce secondary metabolite which gives a measure of medicinal benefits to the consumers. Aderiye & Laleye (2003) reported using fermented *Parkia biglobosa* as a remedy for eyes problem, which is an example of medicinal benefits derived from fermented foods. Several research has been carried out on the benefit of different fermented food on human health. Examining the health benefit of fermented foods in the treatment of hypercholesterolaemia is an effort in the right direction.

To date, statins has been one of the most effective synthetic drugs used in reducing the level of cholesterol in the body. Other cholesterol lowering drugs may include: clofibrate, gemfibrozil, nicotinic acid resins, and fibric acid (De Jongh *et al*., 2002). However, statins being the most used drug and as synthetic drugs are expensive and tend to have some side effects in the patients. It has been documented that some of the side effect of statin may include abdominal pain, constipation, and abnormal liver function, among others (Harikumar *et al*., 2013). Hence the need to investigate natural means of controlling this condition with little or no side effects.

This study was aimed at exploring different fermented products which could serve as alternative for synthetic statin and examine the effectiveness of these fermented products in reducing cholesterol, this can therefore serve as a cheaper treatment for hypercholesterolaemia and an assessable natural product with little or no side effects.

2. material and methods

A review was conducted to explore the impact of fermented food products on cholesterol levels in the body. This review focused on published articles investigating specific fermented foods, condiment, and drinks with the potential of lowering cholesterol levels in hypercholesterolemic conditions.

Various search tools were utilized to identify relevant fermented products, including condiments, fermented drinks, and fermented staple foods. Searches were predominantly performed on databases such as PubMed, Scopus, and Google Scholar. Studies were screened based on their relevance to the research topic, with randomized trials being included while those not involving fermented products were excluded.

3. results and discussion

A total of 287 articles were searched with only 36 eligible by giving a link between fermented samples and hypercholesterolaemia. The findings were grouped into fermented condiments, fermented drinks and other food products.

**3.1 Fermented Condiments**

Finding showed that condiments have capacity to reduce cholesterol level. Documented studies find fermented soybeans (*Glycine max*) (Marrelli *et al*., 2016), fermented *Parkia biglobosa* seed (iru) (Atere *et al*., 2020c), fermented melon seed (*Citrullus vulgaris*) (ogiri) (Ayo-Lawal *et al*., 2015), Garlic (*Allium sativum*) (Irfan *et al*., 2019), and red onion (*Allium cepa*) (Rohani *et al*., 2020).

Condiments are substances added to food to enhance the organoleptic characteristic of the food. They are sometimes added to the meal at the end of the cooking or toward the end of the cooking. Fermented condiments have played an important role in many culinary traditions around the world by bringing distinct flavours and textures to foods. Some of these condiments are made by a fermentation process, which not only improves the taste but also contributes to their nutritional properties and potential health advantages (Tang *et al*., 2022).

In this section, we'll look at some classic fermented condiments, highlighting their manufacturing methods and addressing their nutritional benefits. Much attention has been given to fermented condiments in recent years because of their possible health benefits, particularly in the case of hypocholesterolemia (low levels of cholesterol in the blood). These fermented condiments provide a unique blend of flavours, textures, and health-promoting ingredients that can contribute to the maintenance of good cholesterol levels. Table 1 showed the list of condiment reported with the potential of reducing body cholesterol, the type of organisms involved in their fermentation and common name of the fermented products.

**Table 1:** **Common bacteria associated with fermented condiments with reported Hypocholesterolaemic potential.**

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| **Condiments** | **Fermenting organisms** | **References** |
| Fermented *Parkia biglobosa* (iru) | *Bacillus subtilis*  *Lactobacillus plantarum*  *Leuconostoc mesenteroidis*  *Staphylococcus saprophyticus* | Omafuvbe *et al*., 2004; Aderibigbe *et al*., 2011;  Atere *et al*., 2019;  Atere *et al*., 2020a;  Enujiugha, 2009. |
| Fermented Soybean (*Glycine max*) to Soy-daddawa | *Bacillus subtilis,*  *B. licheniformis*  *B. pumilus*  *Bifidobacterium,*  *Streptococcus,*  *Lactobacillus,*  *and Saccharomyces* | Omafuvbe *et al*., 2002;  Yang *et al*., 2017. |
| Fermented melon seed *Citrullus vulgaris* to ogiri | *Bacillus subtilis,*  *Lactobacillus fermenti, Micrococus varians* | Falegan, 2012;  Enujiugha, 2009. |
| Fermented garlic (*Allium sativum*) | Bacillus subtilis Leuconostoc spp.,  Weissella spp., and Lactobacillus spp. | Jung *et al*., 2012;  Lee *et al*., 2019; |
| Fermented red onion (*Allium cepa*) | *Lactobacillus zymae,*  *L. malefermentans,*  *L. plantarum* | Cheng *et al*., 2014. |

**3.1.1 Fermented Soybeans (*Glycine max*)**

Soy sauce, a mainstay in Asian cuisine, is one of the most well-known fermented condiments. Soy sauce is created by fermenting soybeans, wheat, salt, and water. The method often entails the employment of specialised moulds (such as *Aspergillus oryzae*) and bacteria (including lactic acid bacteria), which break down the proteins, carbohydrates, and lipids found in soybeans and wheat, resulting in the development of distinct flavours and chemicals (Wang *et al*., 2014). Soy sauce is well-known for its umami flavour and high in amino acids, antioxidants, and bioactive peptides (Li *et al*., 2017). Fermented Soybean (*Glycine max*) to Soy-daddawa is indigenous to Western Africa, being produced as a soup condiment which enhances the tastes and aroma of traditional soups. This fermentation process has been initiated by bacteria like *Bacillus subtilis,* *B. licheniformis and B. pumilus*. This processs has also resulted in an improved nutritional content of the product (Omafuvbe *et al*., 2002). Cheonggukjang is a traditional Korean soy food derived from the fermentation of soybeans with chance inoculum most of the time *Bacillus* spp as the main fermentation organism. It was reported that fermentation increased the phytochemicals of the product (Kim *et al*., 2014). Fermented soybean foods contain high level of bioactive components like isoflavones, daidzein and genistein which helps in the regulation process in lipid generation and bioactivity (do Prado *et al*., 2022).

In a comparative study to determine the level of hypocholesterolaemic effects of fermented soybeans, it was found that, fermented soybeans reduced both the total cholesterol and triglyceride in rats, the observed data indicated that the fermented condiment is more effective at a higher concentration (Yang *et al*., 2017). It was argued that supplementing saponin with the fermented seed further enhances the hypocholesterolaemic capacity of the fermented condiment (Marrelli *et al*., 2016). Naturally, fermentation increased the nutritional quality of soybeans (do Prado *et al*., 2022). The observed reduction in the total cholesterol may have resulted from the inhibition of adipogenesis, when AMP-activated protein kinase (AMPK) is activated, it serves as a potential strategy in regulating the metabolism of fat and therefore leads to control in synthesis of fatty acid as well as its uptake (Kim *et al*., 2014; Marrelli *et al*., 2016).

**3.1.2 Iru (*Parkia biglobosa)***

Iru is a fermented product of the seed of *Parkia biglobosa*, it is generally consumed in Western Africa as soup condiments which accompany traditional dishes like egusi and okra soups. This fermented product is known by different names across regions as dawadawa, ugba or iru (Atere & Aderibigbe, 2015). It is obtained from the chance inoculation of the seeds after boiling and dehulling. However, some researchers have subjected it to pure culture fermentation with the aim of a consistent product (Atere *et al*., 2019). Fermenting seeds of *Parkia biglobosa* has resulted in improved mineral, proximate, antioxidant, fatty acid, and amino acid components of iru. The fatty acids were said to contain more unsaturated fatty acids compared to the raw seeds (Atere *et al*., 2020a; Atere *et al*., 2020b). There are lots of fermenting microorganisms associated with the naturally fermented *P. biglobosa* seeds, these include, *Bacillus subtilis*, *Lactobacillus plantarum*, *Leuconostoc mesenteroidis* among others (Omafuvbe *et al*., 2004; Enujiugha, 2009; Aderibigbe *et al*., 2011).

Several research has been designed to investigate the effect of treating high level of cholesterol with the fermented product (Ayo-Lawal *et al*., 2014; Atere *et al*., 2020c).Reports showed that iru had hypocholesterolaemic effect when used in the treatment of rats induced into hypercholesterolaemia. The data showed reduction in the level of both the LDL and VLDL while the HDL was increased compared to the control group (Ayo-Lawal *et al*., 2014). When the seeds of *Parkia biglobosa* were subjected to natural fermentations, the observed result indicated the ability of the fermented seed of *P biglobosa* to reduce both the cholesterol level (43.2%) and triglyceride (42.3%) and even showed a better result when compared to fluvastatin (41%; 40.4% respectively) treatment (Atere *et al*., 2020c). A better insight was gained to the ability of this fermented condiment when compared the result obtained during chance inoculation to iru fermented with starter culture. Atere *et al*., (2020c) reportedly used different starter culture for the fermentation *P. biglobosa* and compared the hypocholesteroalaemic effect. It was observed that samples fermented with *Lactobacillus plantarum* showed the highest level of reduction of hypercholesterolaemia. Linking this observation to the fatty acid and antioxidant capacity of the fermented sample, Linoleic acid (C18:2) was reportedly found to be the most abundant fatty acid in iru (Aremu *et al*., 2015; Atere *et al*., 2019). High level of this saturated fatty acid has been allegedly responsible for a decrease in serum lipids (Aremu *et al*., 2015). Atere *et al* (2020c) gave insight to another reason for reduction in the total cholesterol LDL and triglyceride by looking into the ability of *Lactobacillus plantarum* to have produce a (some) secondary metabolite, which helps in the conversion of LDL to HDL. And therefore, concluded that using *L. plantarum* as starter culture might be an asset to the treatment of hypercholesterolaemia mediated through fermented seeds of *Parkia biglobosa*.

**3.1.3 Ogiri (*Citrullus vulgaris*)**

Ogiri is a fermented product of melon seed (*Citrullus vulgaris*). It is one of the soup condiments indigenous to Nigeria, it is often a result of uncontrolled fermentation of the processed melon seed. The presence of bacteria such as *Bacillus subtilis, Lactobacillus fermenti, Micrococus varians* has been reported (Enujiugha, 2009; Falegan, 2012). Being prepared by native people with chance inoculum, there are slight variation in the organoleptic properties (Falegan 2012). As a general principle for most fermented food and condiments, the nutritional composition of fermented melon improves with fermentation which resulted in increased phenolic contents, flavonoids and saponin (Lee *et al*., 2019; Arukwe & Onyeneke, 2020).

Hypocholesterolaemic effect of ogiri has been reported in laboratory animal. The observed data showed that HDL-cholesterol increased because of the fermented condiment (ogiri) complement and reduction in the LDL- cholesterol. Comparing the result to the standard statin, the fermented condiment tends to be more effective in reducing the total cholesterol level (69.38%), triglyceride (80.58%), and LDL (7.8%) (Ayo-Lawal *et al*., 2015). The observed capacity of the fermented product in mitigating hypercholesterolaemia might be linked to high level of saponin content of the fermented product (Arukwe & Onyeneke, 2020). This observed decrease may have resulted from the activation of AMP-activated protein kinase (AMPK) by saponin which in effect regulates the cells activity to control fatty acid synthesis and uptake uptake (Kim *et al*., 2014a; Marrelli *et al*., 2016).

**3.1.4 Garlic (*Allium sativum*)**

Garlic (*Allium sativum*) are members of onion family, often used in many parts of the world for cooking due to its strong smell and delicious taste. *Allium sativum* is native to Mediterranean area and popular for its medicinal properties. Bacteria reported to be in association with garlic fermentation include Bacillus subtilis Leuconostoc spp., Weissella spp., and Lactobacillus spp (Jung *et al*., 2012; Lee *et al*., 2019). The nutritional composition of the fermented garlic increases as a result of the activities of the fermenting organisms. An increase in the protein composition, antioxidants and phytochemicals of fermented garlic compared to the unfermented has been documented (Tahir *et al*., 2023).

Research carried out to determine the hypocholesterolaemic effect of fermented garlic showed a significant increase in the fermented product when compared with the unfermented. Irfan *et al*. (2019) documented an increase in the hypocholesteroalmic effect of fermented. The observed hypocholesteroalmic capacity was attributed to the effect of fermenting bacteria. These bacteria used in the research are known for production of antioxidants and phytochemicals which are responsible for the observed result (Lee *et al*., 2019). Low density lipoproteins, total cholesterol and triglycerides were significantly reduced in rats fed with fermented garlic compared to other groups. *Bacillus sublilis* has been documented to increase the phenolic and flavonoid content of fermented samples (Lee *et al*., 2019). Phenols and phenolic compounds could inhibit the production of cholesterol in the liver by inactivating the action of HMG-CoA reductase, this process may have contributed to the observed reduction in total cholesterol when rats were fed with fermented garlic (Ademosun *et al*., 2015).

**3.1.5 Red Onion (*Allium cepa*)**

Red onion (*Allium cepa*) and its products are known in many countries. The flavour onion produces in food makes it favourites of so many. Raw onions have been reported with high level of antioxidants, vitamins and fibre (Colina-Coca *et al*., 2017; Dinkecha & Muniye, 2017). The fermented product of red onion is often derived from chance inoculation of the organisms. Generally, lactic acid bacteria have been reportedly found as the major fermenter, these include *Lactobacillus zymae, L. malefermentans, L. plantarum* (Cheng *et al*., 2014). The fermentation process changes the physicochemical properties of the products. Cheng *et al*. (2014) reported that the effect of fermentation on red onion leads to a unique flavour which resulted from the accumulation of esters, alcohols, and aldehydes. The observed changes also enhance not only the organoleptic parameters, but also the nutritional and medicinal properties.

Extract from fermented red onion has been experimented to determine the effect on cholesterol level. It was found that the extract of the fermented red onion had potentials of reducing the cholesterol level in hypercholesterolaemic rat (Rohani *et al*., 2020). However, the hypocholesterolaemic effect of the fermented onions seems to be dosage dependent, the result obtained showed that rats fed with 200 mg of the extract had a better cholesterol profile compared to those with 100 mg and 300 mg (Rohani *et al*., 2020). It is interesting to know that this potential could be an asset in combatting hypercholesterolaemia.

These are only a few examples of the many fermented condiments available around the world. The fermentation process not only improves the flavours and fragrances of the condiments, but it also improves their nutritional value. Fermented condiments are frequently high in beneficial bacteria, enzymes, vitamins, minerals, and bioactive compounds, all of which have potential health benefits such as improved digestion, increased immunological function, and antioxidant characteristics (Lee *et al*., 2016). The fermented condiments reportedly lower plasma cholesterol, the mechanism of action of these fermented condiments may be linked to the increase in phenolic content of the fermented products which may have influence cholesterol metabolism (Ademilua *et al*., 2019; Atere *et al*., 2020a). Plasma cholesterol level is often regulated by the factors that affects the production, metabolism, and excretion in the body, with 3-hydroxyl3-methylglutaryl CoA reductase being primary to the production of lipids in the liver (Zhang *et al*., 2002).However, phenolic compounds have been reportedly indicated as an inhibitor of HMG-CoA reductase, thereby reducing the rate of production of cholesterol (Ademosun *et al*., 2015).

While fermented condiments may have a favourable effect on cholesterol levels, their benefits can vary depending on a variety of factors such as individual metabolism, total diet, and lifestyle choices. For best effects, incorporate fermented condiments into a balanced diet alongside other cholesterol-lowering techniques such as regular physical activity and a diet rich in fruits, vegetables, healthy grains, and lean proteins.

**3.2 Fermented Drinks**

Fermented drinks have been reported with the potential of reducing cholesterol level some of which include fermented soymilk (Tsai *et al*., 2014), kombucha (Alaei *et al*., 2020), and fermented milk (Yadav *et al*., 2019).

Fermented drinks are liquid that are produced from fermentation process, this process usually involve microorganisms which makes use of the available sugar in the dink to produce a byproduct. Generally, bacteria and yeast are often encounter in the fermentation process of drinks. Fermented drinks have been reported as nutritional, source of variety and medicinal (Tsai *et al*., 2014).

**3.2.1 Fermented soymilk**

Soymilk is derived from the processed soybeans. The process of extraction includes clean soybeans being blanched, wet milled and sieve with muslin cloth, extract boiled, flavouring could be then added (Sowonola *et al*., 2005). Soy milk is one of the traditional foods consumed in Asia. It is seen as a source of protein and carbohydrate. Because of its nutritional composition, it serves as a replacement for animal milk in individuals with lactose intolerance, and vegetarians. This product is also relatively cheap which makes good nutrient accessible to poor families (Liu & Lin, 2000). When the milks extracted from the soybeans were fermented, the resulting fermented soymilk product has high levels of β-glucosidase, this tends to improve the nutrition and bioactivity value of the fermented product (Tsai *et al*., 2014). Basically, lactic acid bacteria such as, Lactobacillus spp., Bacteroides spp., and Bifidobacterium spp are used in the fermentation process, this eventually result in a fermented product which has the capacity to hydrolyse isoflavone glycosides through the enzyme β-glucosidases in a process called endogenous β-glucosidases (Tsai *et al*., 2014).

The effect of fermented soymilk on hypercholesterolaemia has been documented. Tsai *et al*.(2014) reported the effect of the fermented soymilk in hamsters, it was found that the fermented product reduces the level of atherosclerotic plaques which is often caused by high level of cholesterol. This potential is attributed to the effect of the fermenting organisms used in the fermentation of the soymilk (Tsai *et al*., 2014; do Prado *et al*., 2022). Fermenting soymilk with *Lactobacillus plantarum* has been reported to have been a successful measure of reducing hypercholesterolaemia (Kim *et al*., 2014b). The fermented product inhibits the expression of the cholesterol receptor gene. This eventually leads to a decrease in the hepatic and serum cholesterol level. The fermented soymilk had a greater hypocholesterolaemic effect than the unfermented soymilk. It was observed that only rats fed with fermented soymilk had reduced hepatic triglyceride and serum free fatty acids with an increased serum HDL and faecal cholesterol. This is an indication of the effect of the fermented product on the hypercholesterol level. Reis *et al*.(2017) described the effect these microorganisms use in fermentation could have as probiotic which act on the metabolism of cholesterol in the consumer by converting cholesterol in the intestine to coprostanol, and inhibition of Niemann–Pick C1 like 1 (NPC1L1) in the enterocytes which is a cholesterol transporting mechanism in the intestine. This will eventually lead to the reduction in the level of both serum and liver cholesterol.

**3.2.2 Kombucha (*Clitoria ternatea*)**

Kombucha is a drink made from butterfly pea (*Clitoria ternatea*) (Majid *et al*., 2023). It could also be produced from the unconventional parts of the *Hibiscus sabdariffa* (Mendonca *et al*., 2023). This drink is a sweetened tea derived from cofermentation of yeasts and acetic acid bacteria. It is known by many consumers around the world for its sour taste which comes from organic acid. Yeasts involved in the fermentation produces enough citric acid which leads to a decrease in the pH and the development of the sour taste (Wang *et al*., 2023). Some of the organisms present in the fermentation process may include *Lactobacillus, acetobacter, saccharomyces and candida (*Arıkan *et al*., 2020; Majid *et al*., 2023). Fermentation brings a lot of physiological changes to the fermented product; this includes an increase in the phenolic content of the fermented drink (kombucha) (Aung & Eun, 2021).

Research has been carried out to determine the effect of this kombucha on the hypercholesterol level. It was found that feeding laboratory animals with the drink reduces the level of their serum cholesterol (Alaei *et al*., 2020). The observed decrease in the total cholesterol and triglyceride was attributed to the effect of fermenting microorganisms which leads to changes in the composition of the product (Alaei *et al*., 2020).Jayabalan *et al*.(2007)reported an increase in the polyphenol content of fermented kombucha. The increase in phenol and its content might have been responsible for the reduction in cholesterol level when used in the treatment of hypercholesterolaemia as reported by Yang *et al*.(2009) Cholesterol production by the liver is coordinated by the enzyme called HMG-CoA reductase, however, phenols and phenolic compounds could inhibit this enzyme thereby inactivate the liver production of cholesterol and eventually leading to observable drop in the serum cholesterol level (Ademosun *et al*., 2015). The level of probiotic composition of the drink may have also contributed to the observed decrease in the cholesterol level. It has been reported that *Lactobacillus* spp are responsible for the conversion of LDL to HDL by producing secondary metabolites which helps in the conversion, they can aid the metabolism of cholesterol in the intestine thereby reducing the assimilation of cholesterol molecule. This also resulted in the reduction of body cholesterol (Atere *et al*., 2020c). Reis *et al*.(2017) concluded that the effect of bacteria probiotics on hypercholesterolaemia is due to co-precipitation of intestinal cholesterol and bacteria cell may assimilate cholesterol into their cell membrane thereby reducing the absorption into the system.

**3.2.3 Fermented milk**

Milks are products from mammary gland of mammals. This liquid has been described as a complete diet which gives baby mammals all the needed nutrient without the addition of any further supplement. Generally, most mammals tend to feed their younger ones with the milk. However, human has developed interest in tarping from those and producing it in large quantity for human nutritional requirements. Irrespective of the source of milk, they are generally considered as a complete nutritional drink for the infants (Smith *et al*., 2022).

Milk has been reportedly fermented with *Lactobacillus* spp to give yoghurt which is tolerated by most people who cannot tolerate lactose in milk. However, this process of fermentation assists to improve the nutritional quality of the product as well as give a level of medicinal characteristics on the product. It has been observed that microorganisms used in the fermentation procedure confer a level of medicinal properties on the fermented product. Yadav *et al.* (2019) reported the hypocholesteraemia effect of fermented milk on rats. It was observed that the hypercholesterolaemic rats were fed with milk fermented with *Lactobacillus rhamnosus*, this resulted in the decrease in the level of total cholesterol, LDL as well as triglycerides of the rats. Alharibi *et al*. (2022) reportedly used the milk from both camel and cow as source of milk for fermentation. Both milks fermented showed potentials of reducing the cholesterol level in the laboratory animals used in the study. Using *Streptococcus thermophilus* and *Lactobacillus bulgaricus* combined, *Streptococcus thermophilus*, *Lactobacillus acidophilus* and *Bifidobacterium bifidum*, as starter culture, the bacteria produced a level of medicinal benefit on the products. This has resulted in the observed decrease in the cholesterol level reported in these cases. Lactobacillus tends to have the ability to assimilate cholesterol into the cell membrane(Xiao *et al*., 2003) this explained the observed reduction in total cholesterol when fermented milk is used in the treatment of hypercholesterolaemia. The logical conclusion was based on the ability of fermenting bacteria in assimilating and binding of cholesterol as well as bile acids, this assimilation reduces the rate of cholesterol absorption in the intestine, thereby leading to a drastic reduction in the serum cholesterol.

Fermented drinks of different sources have been seen as a useful tool in remediating hypercholesterolaemia, since the products are natural, they tend to be tolerated without any increased toxicity (Alaei *et al*., 2020). This might be a promising prospect for the treatment of high level of serum cholesterol.

**3.3 Other Fermented Food Products**

The study finds other fermented food products being reported with hypocholesterolaemic potential. Fermented red yeast rice produced from rice (Oryza sativa) (Cicero *et al*., 2019), Kimchi prepared from fermented vegetables (Choi *et al*., 2013), and ogi produced from (*Zea mays*), sorghum (Sorghum bicolor) (Banjoko *et al*., 2012).

Foods are referred to as substances consumed by living organism to provide nutrient needed for support and growth. They can be sourced from plants or animal. When these food materials are fermented, they were acted upon by microorganisms that uses some of the nutritional composition for their growth and eventually produce some of the needed medicinal properties which is so essential for either human or animal consumer (Atere *et al*., 2019). Some fermented food has been reported to provide hypocholesterolaemic effect on the consumers (Table 2).

**Table 2: Some fermented food and drinks displaying hypocholesterolaemic effect, and the microorganisms associated with the fermentation process.**

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| **Fermented food and Drinks** | **Fermented microorganisms** | **References** |
| Fermented soymilk  Source: soybeans | Lactobacillus spp.,  Bacteroides spp.,  Bifidobacterium spp | Kim *et al*., 2014b;  Reis *et al*., 2017;  Tsai *et al*., 2014. |
| Kombucha  Source: butterfly pea (*Clitoria ternatea*)  *Hibiscus sabdariffa* | *Lactobacillus,*  *Acetobacter,*  *Saccharomyces,*  *Candida* | Arıkan *et al*., 2020;  Majid *et al*., 2023. |
| Fermented milk  Source: cow milk, camel | *Streptococcus thermophilus,*  *Lactobacillus bulgaricus, Streptococcus thermophilus*,  *Lactobacillus acidophilus,*  *Bifidobacterium bifidum* | Yadav *et al*., 2019;  Xiao *et al*., 2003;  Alharibi *et al*., 2022. |
| Fermented red yeast rice.  Source: Rice (Oryza sativa) | Monascus pilosus,  M. floridanus,  M. ruber,  Pleurotus ostreatus | Cicero *et al*., 2019;  Ma *et al*., 2000. |
| Kimchi  Source: vegetable like cabbages (*Brassica rapa*) and radishes (*Raphanus raphanistrum*), cucumbers, spring onions | *Lactobacillus*,  *Leuconostoc*,  *Weissella.* | Surya & Lee, 2022;  Jung *et al*., 2011. |
| Ogi  Source: maize (*Zea mays)*, sorghum (Sorghum bicolor), guinea corn or millet | *Lactobacillus* spp, *Saccharomyces* spp. | Laleye *et al*., 2016;  Banjoko *et al*., 2012. |

**3.3.1 Fermented red yeast rice**

Rice (Oryza sativa) fermented with yeast are referred to as red yeast rice. One of the most common yeasts used in the fermentation process is called *Monascus purpureus* which gives a brilliant colouring in the fermented rice and popular in some part of Asia and China. Other yeasts that might be involved in the fermentation include Monascus pilosus, M. floridanus, M. ruber and Pleurotus ostreatus (Cicero *et al*., 2019).Ma *et al*.(2000) described the composition of red yeast rice as having up to about 30 % and 5 % of protein and fatty acid respectively, other composition may include isoflavones and polyketides. The fermentation process caused a build-up of components like monacolin which plays a significant role in the medicinal capacity of the product. It has been reported as one of the most effective cholesterols lowering food (Cicero *et al*., 2019). This claimed ability is based on the presence of monacolin K in the fermented food. This composition is claimed to be so effective to reduce the cholesterol level by up to 25 % within 6 weeks (Changling et al., 1998).

Previous research showed that red yeast rice has significant effect on the cholesterol level by reducing the LDL cholesterol in the consumers and claimed to be an alternative to the synthetic statin especially in statin intolerant patients (Gerards *et al*., 2015). Poli *et al* (2018) makes a clear indication of the effect of food micronutrient could have on the medicinal benefit of such food monacolin K in red yeast rice tends to inhibit the HMG CoA reductase in the liver, the mechanism of action is by inhibiting the enzymatic activities of HMG CoA reductase which is an enzyme responsible for synthesis of cholesterol. This process leads to a reduction in the production of body cholesterol by the liver, and an eventual reduction in the serum cholesterol.

**3.3.2 Kimchi**

Kimchi, a typical Korean side dish prepared from fermented vegetables, like baechu cabbages (*Brassica rapa*) and radishes (*Raphanus raphanistrum*), cucumbers, spring onions, and other plants. This gives variety of kimchi. Kimchi is made using a lacto-fermentation process in which naturally occurring lactic acid bacteria on the vegetables convert carbohydrates into lactic acid, resulting in a tangy and slightly sour flavour profile (Jung *et al*., 2011). Some of the lactic acid fermenters involved in the fermentation process include, *Lactobacillus*, *Leuconostoc*, and *Weissella* (Surya & Lee 2022). Kimchi is not only a diverse condiment, but it is also high in dietary fibre, vitamins, and good bacteria (probiotics), all of which have been linked to enhanced gut health (Park *et al*., 2014; Song *et al*., 2023).

It was reported by earlier researcher that Kimchi has hypocholesterolaemic effect on human subjects. In research carried out by Choi *et al*. (2013) it was reported that feeding on the fermented product resulted in a significant reduction in the serum total cholesterol and the low-density lipoprotein within a period of 7 days. This study gave an indication on the effect of the fermented product based on the presence of fermenting bacteria which may have been responsible for the observed decrease in the cholesterol level (Jo *et al* 2015).

The mechanism of action of the of this fermented food is based on its effect on transcriptional factors in the liver. The specific regulators of this lipid reduction are sterol regulatory element-binding proteins (SREBPs) and peroxisome proliferator-activated receptor alpha (PPAR-α) which tends to regulate the mechanism of cholesterol production (Reddy & Rao, 2006). Woo et al.(2017) reported that Kimchi tends to activate PPAR-α, this activation resulted in the downward regulation of SREBP-2. The downregulation of SREBP-2 eventually leads to the decrease in the cholesterol synthesis by the liver cell which translate to a decrease in both the hepatic and serum cholesterol level.

**3.3.3 Ogi**

Ogi is a Nigerian fermented food often made from maize (*Zea mays*), sorghum (Sorghum bicolor), guinea corn or millet. Ogi can be produced from each grain or in combination. The grains are soaked, milled, and allow to ferment. The fermentation is often carried out by the microflora of the grain. The analysis carried out on the product often showed the presence of *Lactobacillus* spp, *Saccharomyces* spp and other yeast forming a significant part of the fermentation. Banjoko *et al*. (2012) reported the effect of ogi made from maize had on the lipid profile of laboratory rats. It was observed that a decrease in the total serum cholesterol of the rats was reduced by the effect of the treatment. A reduction in the very low-density lipoprotein as well as the triglyceride was evident in the treated animal which is significantly different from the that of the other groups. The mechanism involved in this procedure is thought to be based on the inhibition of fat absorption and inhibition of the activity of HMG CoA reductase which decreased the production of lipids by the liver cells.

A similar report was given by Laleye *et al*.(2016) who reported a decrease in the serum cholesterol of rats treated with ogi made from the fermentation of the sorghum seeds. It was observed that the fermentation procedure was mediated by the presence of *Lactobacillus* spp. This production process gives a condition fairly acidic to the fermented product. This a however did not only gives a better taste, but also enhances the medicinal properties of the product. The presence of the *Lactobacillus* bacteria may have produced secondary metabolite. Laleye *et al*. (2016) concluded that the low level of cholesterol in the rats fed with ogi may have been the effect of the *Lactobacillus* spp present in the fermented sample to have bind the cholesterol molecules.

**4. CONCLUSION**

Based on documented evidences, fermented products such as ‘Iru’ ‘ogiri’ and others are essential natural product with great potentials in the management of hypercholesterolaemia. It is interesting to note that these products are readily available, natural, less expensive with no side effects. The cholesterol reduction is caused by modifications involved during fermentation process resulting from the activities of the fermenting bacteria or fungi. Sometimes, the products serve are a prebiotic by transporting the good bacteria like *Lactobacillus* which has affinity for the adsorption of cholesterol. The resulting mechanism include downward regulation of sterol regulatory element-binding proteins (SREBPs) or inhibition of HMG CoA reductase which eventually reduce the serum cholesterol by reduction in both absorption and synthesis of cholesterol by the intestine and liver cells respectively. This therefore necessitate the need to give more attention to the natural products in cholesterol management, as these products are readily available, effective, and less expensive.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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