Journal of
Food Chemistry & Nanotechnology

https://doi.org/10.17756/jfcn.2023-s1-046

Review Article

Open Access

The Impact of the Fermentation Process on Bioactive Compounds in Turmeric: A Review

Rahul Vinayak Salve[1], Ramesh Chavan[1], Prashant Pawase[2], Nilesh Kelapure[3], Rameshwar Jaju[3], Harshal Wadatkar[4*] and Mahesh Kadam[3]

[1]Department of Food Technology and Nutrition, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India
[2]Department of Food Technology, MIT-ADT University, Pune, Maharashtra, India
[3]MGM College of Food Technology, Gandheli Aurangabad, Maharashtra, India
[4]Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

***Correspondence to:**
Harshal Wadatkar
Department of Agronomy,
School of Agriculture,
Lovely Professional University,
Phagwara, Punjab, India.
E-mail: harshal.29551@lpu.co.in

Received: September 29, 2023
Accepted: November 02, 2023
Published: November 06, 2023

Citation: Salve RV, Chavan R, Pawase P, Kelapure N, Jaju R, et al. 2023. The Impact of the Fermentation Process on Bioactive Compounds in Turmeric: A Review. *J Food Chem Nanotechnol* 9(S1): S367-S374.

Copyright: © 2023 Salve et al. This is an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CCBY) (http://creativecommons.org/licenses/by/4.0/) which permits commercial use, including reproduction, adaptation, and distribution of the article provided the original author and source are credited.

Published by United Scientific Group

Abstract

Turmeric (*Curcuma longa* L.) is a plant that has been used for its medicinal properties for centuries. It is known to contain a wide range of bioactive compounds, such as curcumin, which has antioxidant and anti-inflammatory properties. The bioavailability of these compounds, however, can be limited by their poor solubility and low absorption rate. Fermentation is a process that can enhance the bioavailability and bioactivity of these compounds by breaking down complex compounds into simpler compounds. The fermentation of turmeric can be achieved using various strains of bacteria or yeast. The most used strains are Lactic acid bacteria, such as *Lactobacillus acidophilus*, *Lactobacillus fermentum*, and *Lactobacillus plantarum*, and yeast strains such as *Saccharomyces cerevisiae*. The fermentation process involves the addition of the starter culture to the turmeric rhizome powder, followed by incubation under specific conditions, including temperature and pH, to promote the growth of the bacteria or yeast. Fermentation of turmeric can result in changes to the bioactive compounds present in the rhizome. Studies have shown that fermentation can lead to increased levels of curcuminoids, the main bioactive compounds, production of other bioactive compounds such as γ-aminobutyric acid (GABA), a neurotransmitter that has been linked to various health benefits, including anxiety reduction and improved sleep quality. Additionally, fermentation can increase the antioxidant activity of turmeric, as measured by its ability to scavenge free radicals. This review delves into the fermentation process, emphasizing the use of starter cultures and precise conditions to foster microbial growth. It also highlights how fermentation boosts curcuminoids and generates beneficial compounds like GABA. Furthermore, it underscores the enhancement of turmeric's antioxidant abilities. The review aims to unveil fermentation's vital role in maximizing turmeric's therapeutic potential.

Keywords

Turmeric, Fermentation, Microbial cultures, Curcuminoid, Bioactivity, Bioactive component

Introduction

Turmeric (*C. longa*) is a spice that has a long and rich history of use. The use of turmeric dates to 2500 BC in ancient India, where it was first used as a dye for textiles [1]. Over the centuries, it was gradually introduced into Indian cuisine and traditional medicine. The spice was then spread to other parts of the world, including China, Southeast Asia, and the Middle East, where it became an important ingredient in food and medicine. In traditional Chinese medicine, turmeric is used to treat a variety of health conditions, including pain,

inflammation, and digestive disorders. It is considered to have cooling properties and is used to balance the body's yin and yang energies. In recent years, turmeric has gained attention from the scientific community due to its potential health benefit. Curcumin, the active ingredient in turmeric, has been studied for its anti-inflammatory and antioxidant properties. Studies have shown that curcumin may be helpful in treating a variety of health conditions, including arthritis, cancer, and Alzheimer's disease [2]. Turmeric is a widely cultivated spice that is grown in many parts of the world, with India being the largest producer and exporter of turmeric. In 2023, the global production of turmeric is expected to be around 1.5 million metric tons, with India accounting for more than 80% of the total production. The production of turmeric in India has been steadily increasing over the years, with the country producing over 1.25 million metric tons of turmeric in 2021. The major turmeric-producing states in India include Andhra Pradesh, Tamil Nadu, Telangana, Maharashtra, and Karnataka. Apart from India, other major producers of turmeric include China, Bangladesh, and Pakistan. In recent years, turmeric production has increased in other parts of the world, including Africa, Latin America, and the Caribbean. The demand for turmeric is expected to continue to grow, driven by its use in food, medicine, and cosmetics. The increasing awareness of the health benefits of turmeric, particularly its anti-inflammatory and antioxidant properties, is also expected to contribute to the growth in demand [3].

Fermentation is a traditional food processing technique that has been used for centuries to improve the taste, texture, and nutritional quality of food. Fermentation can also lead to the production of bioactive compounds that have health-promoting properties. Fermentation can enhance the bioavailability of bioactive compounds by increasing their solubility, stability, and bio accessibility. It also increases the diversity and abundance of beneficial microorganisms in food. The effect of fermentation on bioactive compounds can vary depending on the type of food, the fermentation conditions, and the microorganisms involved. The concentration of phenolic compounds in fermented products can vary depending on the type of fermentation starter used. Fermentation of turmeric is a common practice in some cultures, and it has been suggested that this process can enhance its bioactivity of bioactive compounds in turmeric [4]. Fermentation can increase the concentration of curcuminoids, the primary bioactive compounds in turmeric, and alter their chemical structure, leading to the production of new metabolites with distinct biological activities. Fermentation can also increase the solubility and bioavailability of curcuminoids, which are poorly absorbed by the body due to their low water solubility and rapid metabolism [5]. Fermented turmeric extract had higher antioxidant activity and greater bioavailability compared to unfermented extract. Fermented turmeric extract was more effective at reducing inflammation in rats compared to unfermented extract [6]. This review article aims to thoroughly investigate the transformative potential of fermentation in enhancing the therapeutic properties of turmeric (*C. longa*). By focusing on the optimization of bioavailability and bioactivity, it delves into the multifaceted impacts of this traditional food processing technique on the bioactive components found within turmeric. The review meticulously dissects the fermentation process, emphasizing the critical role of starter cultures and precise control of incubation conditions, which collectively foster the robust growth of selected microbial agents. These changes induce significant alterations in the profile of bioactive compounds, prominently elevating curcuminoids and yielding novel bioactive substances like GABA, all of which are examined in-depth. Furthermore, this review highlights the fundamental contribution of fermentation in augmenting turmeric's antioxidant capabilities, a pivotal facet in combating free radicals and advancing health outcomes. Through this comprehensive exploration, the review provides valuable insights into the profound impact of fermentation on turmeric, offering a foundation for comprehending and harnessing its health-enhancing attributes to their fullest potential.

The Nutritional and Bioactive Composition of Turmeric

Turmeric contains a variety of constituents, including essential oils, polysaccharides, proteins, vitamins, lipids, fibre, and minerals, as shown in table 1. Essential oils are one of the primary constituents in turmeric [7]. The major constituents of turmeric essential oil are turmerones, ar-turmerone, alpha-phellandrene, and zingiberene. Turmerones constitute 30-60% of the oil, ar-turmerone constitutes 12-35%, alpha-phellandrene constitutes 1.28%, and zingiberene constitutes 25-50%. Polysaccharides are another important constituent present in turmeric. Curdlan is the major polysaccharide present in turmeric, constituting 3-6% of the total weight. Starch is also present in significant amounts, comprising 30-40% of the total weight. Proteins are present in turmeric, and the major proteins present are turmerin and curcuminoids-binding protein. Turmerin constitutes 0.16-0.19% of the total weight, and curcuminoids-binding protein constitutes 0.06% [8]. Turmeric is a good source of vitamins, including vitamin C, vitamin E, and vitamin K. Vitamin C is present in amounts ranging from 5.5-6.5 mg/100 g, vitamin E is present in amounts ranging from 2.8-3.0 mg/100 g, and vitamin K is present in amounts of 13.3 µg/100 g (Table 1). Lipids are also present in turmeric. The major lipids present are fatty acids and phytosterols. Fatty acids constitute 5.8% of the total weight, and phytosterols constitute 0.29-0.32% of the total weight. Fiber is another important constituent present in turmeric. The total dietary fiber present in turmeric ranges from 21.1-22.7%. This includes both soluble and insoluble fiber, with insoluble fiber constituting 8.9-9.6% and soluble fiber constituting 11.2-12.1% of the total weight [4]. Turmeric is also a good source of minerals. The major minerals present in turmeric are potassium (2520-3150 mg/kg), calcium (183.5 mg/kg), iron (16.3 mg/kg), zinc (18.5 mg/kg), and copper 5.5 mg/kg [9].

Curcuminoids: the major bioactive constituent in turmeric

Curcuminoids are the group of natural polyphenols found in turmeric. Turmeric (*C. longa* L.) contains three main curcuminoids, namely curcumin, demethoxycurcumin, and bisdemethoxycurcumin, which are the main active components that have been studied for their medicinal properties [10]. Curcum-

Table 1: Nutritional and bioactive composition of turmeric.

Constituent type	Constituent	Amount (%)	Ref.
Essential oils	Turmerones	30 - 60%	[6, 7]
	Ar-turmerone	12 - 35%	
	Alpha-phellandrene	1.28%	
	Zingiberene	25 - 50%	
Polysaccharides	Curdlan	3 - 6%	[7]
	Starch	30 - 40%	
Proteins	Turmerin	0.16 - 0.19%	[8]
	Curcuminoids-binding protein	0.06%	
Vitamins	Vitamin C	5.5 - 6.5 mg/100 g	[9]
	Vitamin E	2.8 - 3.0 mg/100 g	
	Vitamin K	13.3 µg/100 g	
Lipids	Fatty acids	5.8%	[4]
	Phytosterols	0.29 - 0.32%	
Fiber	Total dietary fiber	21.1 - 22.7%	[4]
	Insoluble fiber	8.9 - 9.6%	
	Soluble fiber	11.2 - 12.1%	
Minerals	Potassium	2520 - 3150 mg/kg	[9]
	Calcium	183.5 mg/kg	
	Iron	16.3 mg/kg	
	Zinc	18.5 mg/kg	
	Copper	5.5 mg/kg	

in is the most abundant and most widely studied curcuminoid and has been shown to have a wide range of pharmacological activities, including antioxidant, anti-inflammatory, anticancer, and neuroprotective effects [11]. Curcumin, demethoxycurcumin, and bisdemethoxycurcumin are all yellow pigments that give turmeric its distinctive colour. As shown in figure 1, these curcuminoids are structurally similar, but they differ in the number of methoxy groups attached to the phenolic rings of the molecule. Curcumin has two methoxy groups, demethoxycurcumin has one, and bisdemethoxycurcumin has none [12]. Curcuminoids have a variety of beneficial effects on human health. Curcumin has been extensively studied for its anti-inflammatory and antioxidant properties. It has been shown to inhibit the production of pro-inflammatory cytokines and enzymes, such as cyclooxygenase-2, lipoxygenase, and nitric oxide synthase, which are involved in the inflammatory response. In addition to its anti-inflammatory properties, curcumin has been found to have anticancer effects. Studies have shown that curcumin can inhibit the growth of cancer cells and induce cell death in various types of cancer, including breast, lung, and colon cancer [13]. Furthermore, curcumin has been found to have neuroprotective effects and may be beneficial in the treatment of neurodegenerative diseases, such as Alzheimer's and Parkinson's disease. Demethoxycurcumin and bisdemethoxycurcumin have also been found to have medicinal properties. Demethoxycurcumin has been shown to have antioxidant and anti-inflammatory effects, as well as anticancer properties. It has been found to inhibit the growth of cancer cells and induce cell death in various types of cancer. Bisdemethoxycurcumin has been found to have antioxidant and anti-inflammatory effects and may also have potential as a therapeutic agent for the treatment of various diseases [14].

Fermentation of Turmeric

Fermentation is a process that involves the use of microorganisms to convert the curcuminoids and other compounds in turmeric into more bioavailable and potentially beneficial forms. The fermentation of turmeric can be done using different microorganisms, such as bacteria or yeast, and can be carried out in different ways, including solid-state and submerged fermentation. The optimal conditions for fermentation can be determined through experimentation and can vary depending on the desired product. Fermented turmeric has been shown to have higher levels of antioxidant activity, total phenolic content, and bioavailability of curcuminoids than unfermented turmeric, making it a promising source of functional compounds with potential health benefits. In solid-state fermentation, the microorganisms grow on the surface of a solid substrate, such as rice bran or wheat bran, which has been inoculated with the microorganisms. The turmeric is added to the substrate and then left to ferment [15]. Solid-state fermentation has been shown to enhance the production of curcuminoids, including tetrahydrocurcumin, demethoxycurcumin, and bisdemethoxycurcumin, which are believed to contribute to the antioxidant and anti-inflammatory properties of fermented turmeric. In submerged fermentation, the turmeric is added to a liquid medium that has been inoculated with the microorganisms. The fermentation is carried out in a bioreactor, which provides the ideal conditions for the growth of the microorganisms. Submerged fermentation has been shown to increase the bioavailability of the curcuminoids in turmeric and to enhance the production of ferulic acid, which is another compound with antioxidant and anti-inflammatory properties [16]. The duration of fermentation can vary depending on the microorganisms used, the substrate or medium, and the desired product. The optimal conditions for fermentation include factors such as temperature, pH, and oxygen levels. Different fermentation conditions have been shown to affect the production of curcuminoids and other compounds in turmeric, as well as the overall antioxidant activity and total phenolic content of the fermented turmeric [17].

The process of producing fermented turmeric powder involves several steps which are represented in figure 1. First, the turmeric rhizome is cleaned, boiled, dried, and ground into powder. The powder is then inoculated with a strain of bacteria or yeast and mixed with a starter culture. The mixture is then incubated at a specific temperature to initiate fermentation, during which the complex compounds in the turmeric powder are broken down into simpler compounds, resulting in the characteristic flavour and aroma of fermented turmeric. After fermentation, the powder is dried again to remove any remaining moisture, and then stored in airtight containers away from moisture and light to maintain freshness.

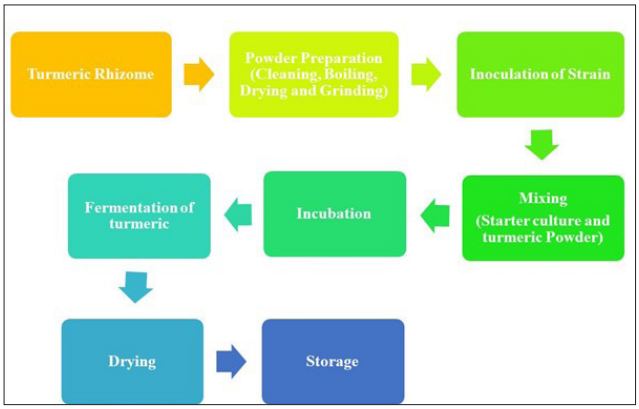


Figure 1: Process flow chart for fermentation of turmeric.

Fermentation of turmeric by *Lactobacillus plantarum*

L. plantarum is a common member of the genus *Lactiplantibacillus* that can be found in a variety of fermented foods and anaerobic plant debris. *L. plantarum* can create antimicrobial compounds that aid in their survival in human gastrointestinal tracts. Gram-positive and Gram-negative bacteria have been significantly impacted by the antibacterial compounds generated [18]. Fermented turmeric was prepared using *L. plantarum* showed that fermentation of turmeric with *L. plantarum* for 24 h at 30 °C resulted in a significant increase in the levels of curcuminoids. The concentration of curcumin increased by 10.6-fold, demethoxycurcumin by 11.4-fold, and bisdemethoxycurcumin by 12.6-fold. Fermentation increases the ability of *L. plantarum* to produce lipase, which can hydrolyse the lipids in turmeric and release the essential oils. In addition to enhancing the bioavailability of the bioactive compounds, fermentation of turmeric with *L. plantarum* strains has also been reported to improve its antioxidant and anti-inflammatory properties [19]. A study by reported that fermented turmeric with *L. plantarum* BCC 9546 had higher antioxidant activity and total phenolic content compared to unfermented turmeric. Similarly, fermentation of turmeric with *L. plantarum* for 72 h led to a significant reduction in the levels of pro-inflammatory cytokines like IL-1β and TNF-α, indicating its anti-inflammatory effect [20].

Fermentation of turmeric by *L. fermentum*

L. fermentum is a Gram-positive bacterium of the *Lactobacillus* genus. Numerous and effective antimicrobial peptides are produced by *L. fermentum* strains, which can be used as antibiotic substitutes or as food preservatives [21]. Bacteriocins, which are ribosomal synthesised peptides produced by both Gram-negative and Gram-positive bacteria, are antimicrobial peptides that *Lactobacillus* fermented strains produce. Fermentation of turmeric with *L. fermentum* for 48 h at 37 °C led to a significant increase in the levels of curcuminoids, including curcumin, demethoxycurcumin, and bisdemethoxycurcumin. The researchers attributed this increase to the ability of *L. fermentum* CECT to produce esterase, which can hydrolyse the ester bonds of the curcuminoids and increase their bioavailability. Fermentation for 24 h at 37 °C led to a significant increase in the levels of volatile compounds, including ar-turmerone, turmerone, and zingiberene and increase their bioavailability [22]. It also enhances the antioxidant and anti-inflammatory properties of turmeric. The fermented turmeric with *L. fermentum* NCDC 414 showed higher antioxidant activity and total phenolic content compared to unfermented turmeric.

Fermentation of turmeric by *Lactobacillus johnsonii*

L. johnsonii is a probiotic bacterium that has been used to ferment turmeric, and several studies have investigated the effect of this fermentation on the bioactive compounds. Fermentation of turmeric with *L. johnsonii* for 24 h at 37 °C led to an increase in the levels of curcuminoids, including curcumin, demethoxycurcumin, and bisdemethoxycurcumin. This increase was due to the ability of *L. johnsonii* to produce β-glucuronidase, which can hydrolyse the glucuronide conjugates of the curcuminoids and increase their bioavailability [23]. Fermented turmeric showed higher anti-inflammatory activity, as demonstrated by a significant reduction in the levels of pro-inflammatory cytokines like TNF-α and IL-6. This also showed higher anticancer activity, as demonstrated by a significant reduction in the viability of human colon cancer cells. There is growing interest in the use of fermentation to enhance the bioactive compounds in turmeric. Fermentation can help to increase the bioavailability and functionality of these compounds. *L. johnsonii* is a probiotic bacterium that has been used to ferment turmeric, and several studies have investigated the effect of this fermentation on the bioactive compounds. In comparison to unfermented turmeric, the fermented turmeric with *L. johnsonii* showed higher antioxidant activity. The researchers attributed this increase to the ability of *L. johnsonii* to produce exopolysaccharides, which can scavenge free radicals and increase the antioxidant activity of the fermented turmeric [24].

Fermentation of turmeric by *Aspergillus oryzae*

A. oryzae is a filamentous fungus or mould mostly found in East Asian food production (especially in Japanese and Chinese), such as soybean fermentation. *A. oryzae* is used in solid-state culture a type of fermentation that takes place in a solid rather than a liquid condition. This fungus is necessary for the fermentation processes because it can secrete significant numbers of different enzymes that break down different starch and proteins into sugars and amino acids. As a result, it can break down the proteins of different starches into these simpler compounds. Fermentation of turmeric with *A. oryzae* is a traditional method of processing turmeric in some countries, and it has been shown to have an impact on the bioactive compounds. Several studies have examined the effect of *A. oryzae*

fermentation on the bioactive compounds in turmeric [25]. Fermentation of turmeric with *A. oryzae* for 48 h led to an increase in the levels of total phenolic compounds, including ferulic acid and vanillic acid. The researchers suggested that this increase was due to the hydrolysis of feruloyl glycosides by the enzymatic activity of *A. oryzae*. Fermentation for 96 h led to an increase in the levels of curcuminoids, including curcumin, demethoxycurcumin, and bisdemethoxycurcumin. The researchers suggested that this increase was due to the enzymatic hydrolysis of the glucuronide conjugates of the curcuminoids. In addition to increasing the levels of bioactive compounds, it also enhances the antioxidant and anti-inflammatory properties of turmeric [26]. Thus, fermented turmeric with *A. oryzae* showed higher antioxidant activity as compared to unfermented turmeric.

Fermentation of turmeric by *Trichoderma spp.*

Trichoderma species is a fungus commonly found in soil and other different environments. They are frequently employed in the textile and food sectors. Fermentation of turmeric with *Trichoderma* species is a traditional method of processing turmeric in some countries. It has been shown to have an impact on the bioactive compounds of turmeric. Several studies have examined the effect of *Trichoderma* spp. fermentation on the bioactive compounds [4]. Fermentation for 48 h led to an increase in the levels of total phenolic compounds, including ferulic acid, caffeic acid, and cinnamic acid, this increase was due to the enzymatic activity of *Trichoderma* species. Fermentation of turmeric with *Trichoderma* for 6 days led to an increase in the levels of curcuminoids, including curcumin, demethoxycurcumin, and bisdemethoxycurcumin, this increase was due to the activation of curcumin synthase, a key enzyme in the curcumin biosynthesis pathway, by the enzymatic activity of *Trichoderma*.

Fermentation of turmeric by *Rhizopus oligoporous*

R. oligoporous is considered to be a domesticated form of *R. microsporus*. *R. oligosporus* is a fungus that belongs to the class Zygomycetes. *R. oligosporus* is a common fungus used in the fermentation of soy tempeh. Fermentation of turmeric with *R. oligosporus* is a traditional method of processing turmeric in some Southeast Asian countries. It has been reported to have an impact on the bioactive compounds of turmeric. The fermentation of turmeric with *R. oligosporus* for 72 h led to an increase in the levels of curcuminoids, including curcumin, demethoxycurcumin, and bisdemethoxycurcumin. This increase was due to the activation of curcumin synthase by the enzymatic activity of *R. oligosporus*. The fermentation of turmeric with *R. oligosporus* for 48 h led to an increase in the levels of total phenolic compounds and flavonoids, this increase was due to the production of secondary metabolites during the fermentation process. In addition to increasing the levels of bioactive compounds, fermentation of turmeric with *R. oligosporus* has been shown to enhance the antioxidant and antimicrobial properties of turmeric [4]. This fermented turmeric showed higher antioxidant activity and antimicrobial activity against several pathogenic bacteria compared to unfermented turmeric.

Fermentation of turmeric by *S. cerevisiae*

S. cerevisiae, a yeast commonly used in food fermentation, is known to have potential to improve the bioactive compounds in turmeric. Several studies have investigated the effect of *S. cerevisiae* fermentation on the bioactive compounds in turmeric. In a study, *S. cerevisiae* was used to ferment turmeric for up to 72 h. The fermentation increased the concentration of curcumin by up to 6-fold compared to non-fermented turmeric. Fermentation also resulted in a significant increase in antioxidant activity, which was attributed to the increased concentration of curcumin. The enzymatic activities of *S. cerevisiae* contributed to the increase in bioactive compounds in turmeric. The Fermentation for 72 h resulted in significant increase in the concentration of curcumin and several phenolic compounds including ferulic acid, vanillic acid, and p-coumaric acid. The increase in bioactive compounds was attributed to the increased activity of enzymes produced during fermentation, which converted the inactive forms of the bioactive compounds to their active forms [27].

Effect of Fermentation on Bioactivity of Turmeric

Fermentation is known to have significant effects on the bioactive compounds of various foods. Many studies have shown that fermentation can enhance the bioavailability and bioactivity of various bioactive compounds, such as polyphenols, flavonoids, carotenoids, and vitamins. Fermentation enhances the bioavailability of polyphenols, which provides antioxidant, anti-inflammatory and various other health benefits as represented in figure 2. Fermentation with *A. oryzae* can increase the total phenolic content of turmeric, while fermentation with *L. fermentum* and *L. plantarum* can increase its antioxidant activity.

Antioxidant activity

The antioxidant activity of turmeric is attributed to its high content of polyphenols, particularly curcuminoids, which are potent antioxidants that scavenge free radicals and protect against oxidative stress. The fermentation of turmeric involves the use of microorganisms to convert the curcuminoids and other compounds in turmeric into more bioavailable and potentially beneficial forms. The antioxidant activity of fermented turmeric was higher than that of unfermented turmeric due to the production of tetrahydrocurcumin, demethoxycurcumin

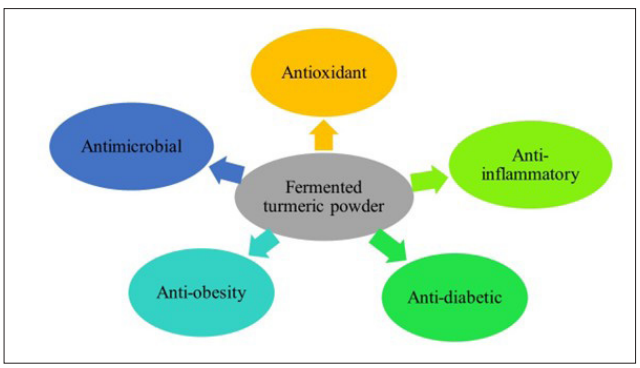


Figure 2: Therapeutic effects of fermented turmeric powder.

and bisdemethoxycurcumin during the fermentation process. The fermented turmeric had higher reduced power and scavenging ability than unfermented turmeric, which was attributed to the production of metabolites during the fermentation process. Fermentation process results in production of new compounds such as ferulic acid. The fermented turmeric had higher total phenolic content and antioxidant activity than unfermented turmeric due to the production of metabolites during the fermentation process [28].

Antimicrobial activity

Turmeric (*C. longa* L.) is a well-known spice and medicinal herb used in traditional medicine for its anti-inflammatory and antimicrobial properties [29]. The major bioactive compound in turmeric is curcumin, which has been reported to have various pharmacological properties, including antioxidant, anti-inflammatory, and antimicrobial activities. Turmeric has been reported to exhibit antimicrobial activity against a wide range of microorganisms, including bacteria, fungi, viruses, and parasites. The turmeric extract exhibited antifungal activity against several fungal species, including *Candida albicans* and *Aspergillus niger* and is a potential source of natural antifungal agents for the treatment of fungal infections. The fermented turmeric showed stronger antimicrobial activity against *C. albicans*, a common fungus responsible for various infections, compared to non-fermented turmeric. The increased antimicrobial activity of fermented turmeric can be attributed to the production of bioactive compounds, such as curcuminoids and volatile compounds, during the fermentation process [30]. Fermentation can increase the content of curcuminoids, especially curcumin, which has been reported to exhibit potent antimicrobial activity against various pathogenic bacteria and fungi. Volatile compounds, such as alcohols, esters, and ketones, are also produced during fermentation and can contribute to the antimicrobial activity of fermented turmeric.

Anti-inflammatory activity

Inflammation is a complex physiological response to tissue injury, infection, or other stimuli that can result in pain, swelling, redness, and heat. Chronic inflammation has been implicated in the pathogenesis of various diseases, including cancer, cardiovascular diseases, and neurodegenerative diseases. Turmeric has been traditionally used in Ayurvedic and Chinese medicine for its anti-inflammatory properties. Curcumin, the main bioactive component of turmeric, has been extensively studied for its anti-inflammatory activity. Curcumin modulates the activity of various enzymes, transcription factors, and signalling pathways that are involved in the inflammatory response [31]. Curcumin inhibits the activation of nuclear factor-kappa B (NF-κB), a key transcription factor that regulates the expression of pro-inflammatory cytokines, chemokines, and adhesion molecules. Curcumin also inhibits the activity of cyclooxygenase-2, an enzyme that is involved in the synthesis of prostaglandins, which are mediators of inflammation. In addition to curcumin, other bioactive components of turmeric, such as turmerones and polysaccharides, have also been found to exhibit anti-inflammatory properties. Turmerones, which are found in the essential oil of turmeric, have been shown to inhibit the production of pro-inflammatory cytokines and chemokines in vitro. Polysaccharides from turmeric have also been found to exhibit anti-inflammatory activity by modulating the activity of immune cells and inhibiting the production of pro-inflammatory cytokines [32].

Fermented turmeric exhibited greater anti-inflammatory activity than non-fermented turmeric in human monocytes. The increased anti-inflammatory activity of fermented turmeric has been attributed to the production of metabolites during fermentation. The fermentation process has been found to increase the bioavailability of curcumin and enhance its anti-inflammatory activity. The concentration of curcumin in fermented turmeric was more than three times higher than that in non-fermented turmeric. The fermentation process also increases the production of metabolites such as phenolic acids, which have been found to possess anti-inflammatory properties [4]. The synergistic effect of fermented turmeric and other natural compounds such as ginger, garlic, and green tea has been investigated in several studies, and has been found to have greater anti-inflammatory and anti-cancer activity than individual compounds alone. The fermented turmeric had a stronger inhibitory effect on inflammation in rats than non-fermented turmeric. Fermented turmeric was found to inhibit the production of pro-inflammatory cytokines and chemokines in rats, which are known to play a key role in the development of inflammatory diseases.

Antiallergic activity

Turmeric has been found to possess potent antiallergic properties, which have been attributed to its active ingredient curcumin. Curcumin has been shown to inhibit the activation of mast cells, which are responsible for the release of histamine and other mediators that cause allergic symptoms [33]. Curcumin has been found to inhibit the production of IgE, an antibody that plays a key role in allergic reactions. The curcumin was able to inhibit the release of histamine and other inflammatory mediators from mast cells in rats. The curcumin was able to inhibit the production of IgE in human peripheral blood mononuclear cells. The curcumin was effective in reducing the severity of symptoms in patients with allergic rhinitis. The curcumin was able to improve lung function and reduce the incidence of asthma attacks in patients with asthma. The fermented turmeric had a stronger inhibitory effect on allergic reactions in mice than non-fermented turmeric. Fermented turmeric was found to inhibit the production of IgE, an antibody that plays a key role in allergic reactions, and the activation of mast cells, which are responsible for the release of histamine and other mediators that cause allergic symptoms. The fermented turmeric exhibited greater anti-allergic activity than non-fermented turmeric in human mast cells. Fermented turmeric was found to inhibit the expression of inflammatory genes and the release of histamine and other mediators in human mast cells, which play a key role in the development of allergic reactions. The increased anti-allergic activity of fermented turmeric has been attributed to the production of metabolites during fermentation. The concentration of curcumin in fermented turmeric was more than three times higher than that in non-fermented turmeric [34]. It increases the production of metabolites such as phenolic acids, which have been found to possess anti-allergic properties. The synergistic effect

of fermented turmeric and other natural compounds such as ginger, garlic, and green tea has been investigated in several studies, and has been found to have greater anti-allergic activity than individual compounds alone.

Antidiabetic activity

The active ingredient in turmeric, curcumin, has been shown to improve insulin sensitivity, reduce blood glucose levels, and inhibit inflammation associated with diabetes. The curcumin was able to improve insulin sensitivity in mice fed a high-fat diet and able to reduce blood glucose levels in rats with streptozotocin-induced diabetes [35]. The curcumin was effective in improving insulin sensitivity and reducing blood glucose levels in patients with type 2 diabetes. The fermented turmeric is more effective than non-fermented turmeric in reducing blood glucose levels and improving insulin sensitivity in the diabetic rats and able to improve insulin sensitivity and reduce inflammation associated with insulin resistance more effectively than non-fermented turmeric. The increased bioavailability and potency of curcumin in fermented turmeric may have contributed to the enhanced antidiabetic effects.

Anti-obese activity

The active ingredient in turmeric, curcumin, has been shown to inhibit the growth and differentiation of fat cells, reduce inflammation associated with obesity, and improve insulin sensitivity. Several studies have investigated the anti-obesity effects of curcumin The fermented turmeric extract was able to reduce body weight gain and fat accumulation in mice fed a high-fat diet and able to reduce body weight, body fat, and inflammation in rats fed a high-fat diet [36]. The curcumin was able to suppress the growth and differentiation of fat cells in mice fed a high-fat diet, resulting in a reduction in body weight gain and fat accumulation and able to reduce inflammation associated with obesity in rats fed a high-fat diet. In addition to its direct effects on fat cells and inflammation, turmeric has been found to possess other properties that may be beneficial for the prevention and treatment of obesity. Curcumin has also been found to possess anti-cancer properties, which may be important for the prevention and treatment of cancers associated with obesity. A combination of curcumin and piperine, a compound found in black pepper, was able to reduce body weight, body mass index, and waist circumference in overweight individuals. Fermentation increases the bioavailability and activity of curcumin, the active ingredient in turmeric that is responsible for its anti-obesity properties. It also increases the antioxidant and anti-inflammatory properties of turmeric, which may help to reduce oxidative stress and inflammation associated with obesity [37].

Conclusion

Fermentation of turmeric has indeed demonstrated its ability to significantly impact the bioactive compounds within this crucial spice, particularly the enhancement of curcumin, its primary medicinal component. A wealth of research indicates that fermentation leads to the amplification of turmeric's antioxidant, anti-inflammatory, and antimicrobial properties, rendering it a compelling candidate as a functional food with substantial health benefits. Looking ahead, future research and applications of turmeric fermentation hold exciting prospects. Firstly, optimizing the conditions for fermentation, including the selection of specific microorganisms, fine-tuning fermentation time, temperature, and refining processing methods, will be crucial. These parameters can be tailored to achieve precise outcomes, whether for food production, pharmaceuticals, or other applications, ensuring consistency and efficacy. In the food and pharmaceutical industries, the fermentation of turmeric opens doors to novel product development, each with its own unique health-promoting properties. This innovation could potentially yield a broader range of functional foods, dietary supplements, and pharmaceutical formulations, meeting the increasing demand for natural, plant-based remedies and supplements. As scientific understanding of turmeric fermentation deepens, it holds the promise of enriching our choices for health-enhancing products, impacting a diverse array of applications, and ultimately improving human well-being. Future research is expected to play a pivotal role in harnessing the full potential of fermented turmeric, driving innovation and the development of health-promoting products.

Acknowledgements

None.

Conflict of Interest

None.

References

1. Giannenas I, Sidiropoulou E, Bonos E, Christaki E, Florou-Paneri P. 2020. The History of Herbs, Medicinal and Aromatic Plants, and Their Extracts: Past, Current Situation and Future Perspectives. In Florou-Paneri P, Christaki E, Giannenas I (eds) Feed additives, Academic Press, pp 1-18.
2. El-Hack AME, El-Saadony MT, Swelum AA, Arif M, Ghanima AMM, et al. 2021. Curcumin, the active substance of turmeric: its effects on health and ways to improve its bioavailability. *J Sci Food Agric* 101: 5747-5762. https://doi.org/10.1002/jsfa.11372
3. Polshettiwar SA, Sawant DH, Abhale NB, Chavan NB, Baheti AM, et al. 2022. Review on regulation of herbal products used as a medicine across the globe: a case study on turmeric-golden medicine. *Biomed Pharmacol J* 15: 1227-1237. https://dx.doi.org/10.13005/bpj/2458
4. Lim J, Nguyen TT, Pal K, Kang CG, Park C, et al. 2022. Phytochemical properties and functional characteristics of wild turmeric (*Curcuma aromatica*) fermented with *Rhizopus oligosporus*. *Food Chem X* 13: 100198. https://doi.org/10.1016/j.fochx.2021.100198
5. Purpura M, Lowery RP, Wilson JM, Mannan H, Münch G, et al. 2018. Analysis of different innovative formulations of curcumin for improved relative oral bioavailability in human subjects. *Eur J Nutr* 57: 929-938. https://doi.org/10.1007/s00394-016-1376-9
6. Aljutaily T. 2022. Evaluating the nutritional and immune potentiating characteristics of unfermented and fermented turmeric camel milk in cyclophosphamide-induced immunosuppression in rats. Antioxidants 11(4): 792. https://doi.org/10.3390/antiox11040792
7. Hassan B, Chatha SA, Hussain AI, Zia KM, Akhtar N. 2018. Recent advances on polysaccharides, lipids and protein based edible films and coatings: a review. Int J Biol Macromol 109: 1095-1107. https://doi.org/10.1016/j.ijbiomac.2017.11.097

8. Dutta H. 2023. Potential of Polysaccharide Nanoparticles in Foods. In Goyal MR, Malik JA, Kumar S, Watharkar RB (eds) Nanotechnology Horizons in Food Process Engineering: Food Preservation, Food Packaging, and Sustainable Agriculture. Apple Academic Press, New York, pp 85-155.
9. Filho JGO, de Almeida MJ, Sousa TL, dos Santos DC, Egea MB. 2021. Bioactive Compounds of Turmeric (*Curcuma longa* L.). In Murthy HN, Paek KY (eds) Bioactive Compounds in Underutilized Vegetables and Legumes. Springer, Cham, pp 297-318.
10. Jayaprakasha GK, Rao LJ, Sakariah KK. 2005. Chemistry and biological activities of *C. longa*. *Trends Food Sci Technol* 16(12): 533-548. https://doi.org/10.1016/j.tifs.2005.08.006
11. Wissgott U, Bortlik K. 1996. Prospects for new natural food colorants. *Trends Food Sci Technol* 7(9): 298-302. https://doi.org/10.1016/0924-2244(96)20007-x
12. Yodkeeree S, Chaiwangyen W, Garbisa S, Limtrakul P. 2009. Curcumin, demethoxycurcumin and bisdemethoxycurcumin differentially inhibit cancer cell invasion through the down-regulation of MMPs and Upa. *J Nutr Biochem* 20(2): 87-95. https://doi.org/10.1016/j.jnutbio.2007.12.003
13. Aggarwal BB, Yuan W, Li S, Gupta SC. 2013. Curcumin-free turmeric exhibits anti-inflammatory and anticancer activities: Identification of novel components of turmeric. *Mol Nutr Food Res* 57(9): 1529–1542. https://doi.org/10.1002/mnfr.201200838
14. Jurenka JS. 2009. Anti-inflammatory properties of curcumin, a major constituent of *Curcuma longa*: a review of preclinical and clinical research. *Altern Med Rev* 14(2): 141-153.
15. Martgrita MM, Kembaren RF, Manurung A, Hutapea HN, Lumbangaol TM. 2022. Activity enhancement of antioxidant contained in sugar palm fruit (*Arenga pinnata* Merr) through solid state fermentation by *Aspergillus oryzae.* In 4th International Conference on Life Sciences and Biotechnology, Jember, Indonesia.
16. Singgih M, Julianti E. 2015. Food Colorant from Microorganisms. In Liong MT (ed) Beneficial Microorganisms in Food and Nutraceuticals. Microbiology Monographs. Springer, Cham, pp 265-284.
17. Azhar SH, Abdulla R, Jambo SA, Marbawi H, Gansau JA, et al. 2017. Yeasts in sustainable bioethanol production: a review. Biochem Biophys Rep 10: 52–61. https://doi.org/10.1016/j.bbrep.2017.03.003
18. Brown DG, May-Dracka TL, Gagnon MM, Tommasi R. 2014. Trends and exceptions of physical properties on antibacterial activity for Gram-positive and Gram-negative pathogens. *J Med Chem* 57(23): 10144-10161.
19. Pianpumepong P, Noomhorm A. 2010. Isolation of probiotic bacteria from turmeric (*Curcuma longa* Linn.) and its application in enriched beverages. *Int J Food Sci Technol* 45(12): 2456–2462. https://doi.org/10.1111/j.1365-2621.2010.02337.x
20. Gholipour F, Amini M, Baradaran B, Mokhtarzadeh A, Eskandani M. 2023. Anticancer properties of curcumin-treated Lactobacillus plantarum against the HT-29 colorectal adenocarcinoma cells. Sci Rep 13(1): 2860. https://doi.org/10.1038/s41598-023-29462-7
21. Sharif A. 2022. Evaluation of Encapsulation Efficiency of Spray Drying and Freeze Drying for Probiotic *Lb. rhamnosus* & *Lb. fermentum*. Department of Bioinformatics and Biosciences, Faculty of Health and Life Sciences, Capital University of Science and Technology, Islamabad. (Graduate Thesis)
22. Chen W, Xie C, He Q, Sun J, Bai W. 2023. Improvement in color expression and antioxidant activity of strawberry juice fermented with lactic acid bacteria: a phenolic-based research. *Food Chem X* 17: 100535. https://doi.org/10.1016/j.fochx.2022.100535
23. Kusumoto KI, Yamagata Y, Tazawa R, Kitagawa M, Kato T, et al. 2021. Japanese traditional miso and koji making. *J Fungi* 7(7): 579. https://doi.org/10.3390/jof7070579
24. Le Rouzic M, Bruniaux P, Raveschot C, Krier F, Phalip V, et al. 2022. *Lactobacillus* Use for Plant Fermentation: New Ways for Plant-Based Product Valorization. In Laranjo M (ed) Lactobacillus - A Multifunctional Genus IntechOpen.
25. Noomhorm A, Ahmad I, Anal AK. 2014. Functional Food and Dietary Supplements: Processing Effects and Health Benefits. John Wiley & Sons.
26. Yuandani, Jantan I, Rohani AS, Sumantri IB. 2021. Immunomodulatory effects and mechanisms of *Curcuma* species and their bioactive compounds: a review. *Front Pharmacol* 12: 643119. https://doi.org/10.3389/fphar.2021.643119
27. Paramera EI, Konteles SJ, Karathanos VT. 2011. Stability and release properties of curcumin encapsulated in *Saccharomyces cerevisiae*, β-cyclodextrin and modified starch. *Food Chem* 125(3): 913-922. https://doi.org/10.1016/j.foodchem.2010.09.071
28. Pianpumepong P, Anal AK, Doungchawee G, Noomhorm A. 2012. Study on enhanced absorption of phenolic compounds of *lactobacillus*-fermented turmeric (*Curcuma longa* Linn.) beverages in rats. *Int J Food Sci Technol* 47(11): 2380-2387. https://doi.org/10.1111/j.1365-2621.2012.03113.x
29. Kumar M, Kaur P, Garg R, Patil RK, Patil HC. 2020. A study on antibacterial property of *curcuma longa*-herbal and traditional medicine. *Adesh Uni J Med Sci Res* 2(2): 103–108.
30. Budiari S, Mulyani H, Filailla E, Maryati Y, Devi AF, et al. 2022. The physicochemical, antioxidant, and antibacterial properties of turmeric extract fermented with kombucha culture. AIP Conf Proc 2493: 040001. https://doi.org/10.1063/5.0109979
31. Sharifi-Rad J, Rayess YE, Rizk AA, Sadaka C, Zgheib R, et al. 2020. Turmeric and its major compound curcumin on health: bioactive effects and safety profiles for food, pharmaceutical, biotechnological and medicinal applications. Front Pharmacol 11: 01021. https://doi.org/10.3389/fphar.2020.01021
32. Memarzia A, Khazdair MR, Behrouz S, Gholamnezhad Z, Jafarnezhad M, et al. 2021. Experimental and clinical reports on anti-inflammatory, antioxidant, and immunomodulatory effects of *Curcuma longa* and curcumin, an updated and comprehensive review. *BioFactors* 47(3): 311–350. https://doi.org/10.1002/biof.1716
33. Razavi BM, Rahbardar MG, Hosseinzadeh H. 2021. A review of therapeutic potentials of turmeric (Curcuma longa) and its active constituent, curcumin, on inflammatory disorders, pain, and their related patents. Phytother Res 35(12): 6489–6513. https://doi.org/10.1002/ptr.7224
34. Lee HS, Lee SJ, Ho JN, Cho HY. 2020. Preventive effect of fermented chestnut inner shell extract on obesity-induced hepatic steatosis. *Prev Nutr Food Sci* 25(1): 32–40. https://doi.org/10.3746/pnf.2020.25.1.32
35. Bozkurt O, Kocaadam-Bozkurt B, Yildiran H. 2022. Effects of curcumin, a bioactive component of turmeric, on type 2 diabetes mellitus and its complications: an updated review. *Food Funct* 13: 11999–12010. https://doi.org/10.1039/d2fo02625b
36. Vafaeipour Z, Razavi BM, Hosseinzadeh H. 2022. Effects of turmeric (*Curcuma longa*) and its constituent (curcumin) on the metabolic syndrome: an updated review. *J Integr Med* 20(3): 193–203. https://doi.org/10.1016/j.joim.2022.02.008
37. Baziar N, Parohan M. 2020. The effects of curcumin supplementation on body mass index, body weight, and waist circumference in patients with nonalcoholic fatty liver disease: a systematic review and dose-response meta-analysis of randomized controlled trials. Phytother Res 34(3): 464–474. https://doi.org/10.1002/ptr.6542