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A comprehensive review on *Tricholoma matsutake*

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Abstract
Tricholoma matsutake, commonly known as the pine mushroom, is a highly valued ectomycorrhizal fungus recognized for its nutritional, medicinal, and pharmaceutical significance. The mushroom is rich in proteins, essential amino acids, minerals, polysaccharides, peptides, and volatile compounds that contribute to its nutritional value and therapeutic potential. Extensive research demonstrates that *T. matsutake* exhibits a broad spectrum of pharmacological activities, including antioxidant, anti-aging, anti-fatigue, antitumor, antihypertensive, anti-inflammatory, antimicrobial, immunomodulatory, hypoglycaemic, radioprotective, skin-whitening, and wound-healing effects, mainly attributed to its bioactive polysaccharides and peptides. However, its strict ecological requirements, limited cultivability, overharvesting, habitat loss, metal accumulation, and allergenic potential pose challenges for its safe and sustainable utilization. This review highlights the importance of *T. matsutake* as a promising natural source for functional foods, nutraceuticals, and pharmaceutical agents, while emphasizing the need for further studies on standardization, safety evaluation, clinical validation, and conservation strategies to ensure its sustainable and effective application.

Keywords: *Tricholoma matsutake*, medicinal mushroom, bioactive polysaccharides, highly prized mushroom, anti-aging activity, skin-lighting mushroom

Introduction

Tricholoma matsutake, commonly known as the pine mushroom, is an ectomycorrhizal fungus that forms a symbiotic association with the roots of *Pinus densiflora* trees. One significant class of fungi in the soil environment are mycorrhizal fungi. They exchange vital chemicals and nutrients in a mutualistic interaction with living plants [1].

The pine mushroom's fruiting body is a prized delicacy in the Far East due to its therapeutic properties as well as its appealing flavour. Numerous bioactive compounds, including α-galactosidase, lactase, polysaccharide, and nuclease, have been extracted from *Tr. matsutake*. These compounds, which have a variety of biological activity, are helpful in protecting the environment and are good for human health [2].

It is a rare edible fungus that is mostly found in Taiwan, Yunnan, Northeast China, Japan, the Korean Peninsula, and other places. Rich in protein, polysaccharides, amino acids, and dietary fibre, matsutake is a prized wild edible and medicinal fungus with thick flesh and excellent flavour. It is regarded as one of nature's most popular foods and most valuable herbal medicinal ingredients, and is known as the "king of fungi". According to recent research, *Tricholoma Matsutake* polysaccharides (TMP) are thought to have numerous bioactivities, including enhancing immune function, anti-cancer, anti-aging, and anti-radiation properties, making them perfect components for nutritious foods and medications [3].

This review is aimed at recapitulating the research established on the photochemistry, pharmaceutical and other applications of *Tricholoma matsutake* Further, this review highlights the importance of *Tricholoma matsutake* and provides a baseline for future research studies.

Common names: In Japan, *matsutake* which literally means "pine mushroom" (*Matsu* meaning pine, and *take* meaning mushroom) is the name that most people use for *Tricholoma matsutake*, a mushroom that grows exclusively in pine forests. In China, this mushroom is known by various names, including “song-koumo” (pine-*Tricholoma*), “song-rong” (pine mushroom), “song-jun” (pine fungus), and “qing-gang-jun” (oak mushroom) [4].

Geographical distribution: *Tricholoma matsutake* is regarded as the authentic or “true” matsutake (“Hong” in Japanese) in Japan. It is widely distributed across several regions of Asia, including Japan, China, North Korea, South Korea, Russia, and Bhutan, as well as parts of Europe such as Turkey, Sweden, Finland, Norway, Germany, the former Czechoslovakia, Austria, Switzerland, and Italy. In addition, it is found in North Africa, particularly in Algeria and Morocco. Several closely related species also occur in China [4].

Morphological Characteristics of *Tricholoma matsutake*

Tricholoma matsutake is a large, ectomycorrhizal basidiomycete with distinctive macroscopic and microscopic features that support its taxonomic identification and ecological role.

Macroscopic Morphology

The basidiome of *T. matsutake* is robust and well developed. The pileus (cap) is typically large, fleshy, and initially convex, becoming plano-convex to flattened with maturity. Its surface is characteristically covered with brownish fibrillose scales or squamulose over a whitish background, and the margin is often enrolled in young specimens. Aoki *et al*. (2023) [5] describe this scaled and cracked appearance of the cap as a stable taxonomic character across geographically distinct populations.

The stipe (stem) is thick, solid, and fibrous, usually cylindrical to slightly clavate, and often deeply embedded in the soil. It is whitish above and brownish below, reflecting the extension of the cap's fibrillose surface pattern. A persistent partial veil is present in young fruiting bodies, leaving a cottony or membranous annulus (ring zone) on the stipe after rupture [5].

The lamellae (gills) are white to cream in color, moderately crowded, and attached in a sinuate to adnexed manner to the stipe. They remain pale throughout maturation and do not darken with age, which is a distinguishing feature compared with some related species [5, 6].

The flesh is dense, firm, and white, with a strong, characteristic spicy or cinnamon-like aroma that is considered a key diagnostic feature and is frequently used for field identification [6, 7].

Microscopic Morphology

Microscopically, *Tricholoma matsutake* produces hyaline basidiospores that are broadly ellipsoid to sub globose in shape. The spores are smooth-walled and lack distinctive ornamentation. Basidia are typically four-spored, which is consistent with diagnostic characteristics of the genus *Tricholoma*. These microscopic features support the taxonomic placement of *T. matsutake* within the family Tricholomataceae and are considered stable across geographically distinct populations [5].

Taxonomic classification [8]

Domain	Eukaryota
Kingdom	Fungi
Division	Basidiomycota
Class	Agaricomycetes
Order	Agaricales
Family	Tricholomataceae
Genus	*Tricholoma*
Species	*T. matsutake*

Ecology and Conservation of *Tricholoma matsutake*

In Japan, matsutake, the fruit of *Tricholoma matsutake*, is said to as "a taste of autumn from the old days." Coniferous trees and the ectomycorrhizal (EM) fungus *Tricholoma matsutake* develop a symbiotic relationship. In well-drained, nutrient-poor forest soil, this species forms mycelial aggregations known as "Shiros" with an ectomycorrhizal roots and soil particles. In an autumn, *Tricholoma matsutake* fruiting bodies emerge on the shiros edge. The fruiting bodies of *Tricholoma matsutake* develop within a narrowly defined zone located approximately 25 cm inward from the actively expanding margin of the shiro, commonly referred to as the "active mycorrhizal zone." The shiro represents a mycelial aggregation associated with host tree roots and expands radially at an estimated rate of 10–15 cm per year. Fruiting of *T. matsutake* is strictly seasonal and occurs during the autumn months, coinciding with a decline in ambient temperatures. Consequently, the annual productivity of this species is largely governed by climatic conditions, particularly rainfall and temperature patterns prevailing in the autumn season.

Ecologically, *T. matsutake* is adapted to nutrient-poor, well-drained forest soils derived from substrates such as granite, chert, limestone, and sandstone. These soils are typically acidic, with pH values ranging from 4.5 to 5.0, conditions that are favourable for the establishment and persistence of the species. In addition to soil chemistry, soil temperature plays a significant role in regulating the initiation and development of fruiting bodies [9].

In natural ecosystems, the growth of *Tricholoma matsutake* is extremely slow and restricted to specific environmental conditions. The species is mainly found in undisturbed, high crown-density forests with low levels of pollution, which limits its natural population size. Although ecological factors such as temperature, moisture, soil characteristics, and topography are believed to influence the development of fruiting bodies, their precise roles are not yet fully understood.

In addition to climate change, human activities strongly influence the distribution of *T. matsutake*. Because of its medicinal value and distinctive flavour, the species is highly sought after in Asian and global markets, resulting in excessive harvesting of wild populations. Although *T. matsutake* could theoretically occur in all suitable habitats, anthropogenic pressures such as deforestation and overgrazing have caused its disappearance from many traditional sites, leading to irreversible habitat fragmentation. Numerous attempts to establish artificial cultivation systems for high-quality *T. matsutake* have been unsuccessful; therefore, conservation efforts must focus on protecting and enhancing natural populations in suitable habitats. Encouragingly, increased awareness of environmental protection and the implementation of conservation regulations, particularly in protected areas, have improved the preservation of *T. matsutake* shiros. Furthermore, controlled introductions into appropriate natural environments have contributed to the expansion of its native range [10].

Fig 1: *Tricholoma matsutake*

Chemical constituents

According to literatures, the contents like Ca, Cu, Fe, K, Mg, Na and Zn are present in fruiting bodies of *T. matsutake* mushroom. It consists of phytoconstituents like phenol, flavonoids, alkaloids, steroids, saponins, terpenoids and cardiac glycosides. It is an important edible mushroom that has been artificially cultivated and used as a food and medicinal ingredients in traditional Chinese medicines [11].

The fruiting bodies of *Tricholoma matsutake* are characterized by a high content of dietary fiber and protein. Potassium was identified as the predominant mineral element present. A total of seventeen amino acids were detected in the fruiting bodies, including seven essential amino acids required for human nutrition, indicating that *Tr. matsutake* represents a valuable dietary source of amino acids. Among these, glutamate was found to be the most abundant amino acid. In addition, a total of sixty-six volatile compounds has been identified in *T. matsutake*, including key aroma constituents such as 1-octen-3-ol, methyl cinnamate, 3-octanone, and benzaldehyde, along with several C8 compounds such as 1-octene, (2Z)-2-octen-1-ol, 3-methyl-1-heptene, (E)-2-octenal, 1,3,5,7-cyclooctatetraene, octanal, and phenylacetaldehyde. Other volatile components detected include 3,6-dodecadienoic acid methyl ester, D-limonene, 1,2-benzofulvene, nonanal, and hexanal [12].

Table 1: polysaccharides isolated from *Tricholoma Matsutake* [13]

No	Name	Monosaccharide composition	M.W. (Da)
1	TMP5II	D-Glu, D-Gal, D-Man, and D-Fuc.	1.58 × 104
2	TMP-B	α-D-Glu and α-D-Gal in a ratio of 7:2.	1.64 × 104
3	TMP-A	D-Glu, D- Gal, and D- Xyl in a ratio of 79.37:9.81:10.82.	8.89 × 104
4	TMP30	L-Fuc, D-Gal, D-Glc, D-Xyl, and D-Man in a ratio of 9.3:26.8:40.1:2.6:16.4.	Unknown
5	TMP60	L-Fuc, D-Gal, D-Glc, D-Xyl, and D-Man in a ratio of 6.6:17.6:42.3:12.1:21.1. L-Fuc, D-Gal, D-Glc, D-Xyl, and D-Man in a ratio of 8.1:21.2:43.0: 4.2:23.6.	Unknown
6	TMP80		Unknown
7	TM-P1	Glu, Gal, and mannose in a ratio of 5.9:1.1:1.0.	3.61 × 105
8	TM-P2	Glu, Gal, Man, Fuc in a ratio of 7.7:4.0:1.9:1.0.	3.72 × 105
9	TM-P3	Glu, Gal, Man, Fuc in a ratio of 5.1:4.9:2.2:1.0. Glu and Glucuronic acid.	3.65 × 105
10	TM-APS-1	Glu and Glucuronic acid.	2.8 × 105
11	TM-APS-2		5.4 × 104

Toxicity of *Tricholoma matsutake*

Tricholoma matsutake is generally considered a non-toxic, choice edible mushroom and has been consumed safely for centuries. However, specific risks exist regarding environmental contamination, severe allergic reactions, and dangerous look-alikes.

Metal-Related Toxicity

Wild-grown edible mushrooms play an important role in human diets worldwide and efficiently accumulate metallic elements from their environment. Yunnan Province in southwest China represents a major production region of *Tricholoma matsutake* and contains naturally high geochemical metal backgrounds. Several studies have evaluated how environmental factors influence metal bioaccumulation, tissue distribution, and associated human health risks using paired soil and *T. matsutake* samples.

Tricholoma matsutake grows predominantly in acidic soils with pH values ranging from 3.95 to 6.56. Soil metal concentrations vary widely, with iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu). Within the fruiting body, *T. matsutake* stores Fe mainly in the stipe, whereas Mn, Zn, and Cu accumulate primarily in the cap. Health risk assessments show that Fe in the stipe poses the greatest potential risk (HRI = 1.28–26.9), followed by Cu in the cap (HRI = 1.01–2.33), while Mn and Zn remain within safe limits in most samples. Although Fe serves as an essential micronutrient, excessive intake through consumption of *T. matsutake* from geochemically enriched areas may cause toxic effects [14, 15].

Allergenicity and Immunological Toxicity

Anaphylaxis represents one of the most severe forms of allergic disease and can be life-threatening. Certain edible mushrooms act as food allergens, and matsutake mushroom (*Tricholoma matsutake*) has been identified as one such allergen.

A clinical case report describes an 8-year-old Japanese girl who developed anaphylaxis after consuming matsutake mushrooms. During the allergic episode, investigators detected significantly elevated levels of histamine, tryptase, and eosinophil cationic protein (ECP), along with increased production of several cytokines. Eosinophils and mast cells played central roles in mediating the allergic response. In addition, $CD4^+CD25^+$ regulatory T cells releasing interleukin-10 (IL-10) became activated, suggesting an immunoregulatory response during anaphylaxis.

These findings demonstrate that *T. matsutake* can function as a potent food allergen and trigger severe hypersensitivity reactions, particularly in sensitized individuals and children [16].

Overall Toxicological Implications

The toxicity profile of *Tricholoma matsutake* therefore includes both chemical toxicity through the accumulation of potentially harmful metals and biological toxicity through allergenic and immunological mechanisms. Although consumers widely value *T. matsutake* as a nutritious and medicinal mushroom, its consumption may pose health risks when harvested from geochemically enriched environments or when eaten by individuals with allergic predisposition [14-16].

Consequently, researchers recommend monitoring metal concentrations in wild-harvested *T. matsutake* and increasing awareness of its allergenic potential to ensure consumer safety.

Pharmacological properties

Anti – aging activity

Recent studies have demonstrated that *Tricholoma matsutake* possesses significant anti-aging properties, particularly in the protection of skin from ultraviolet (UV) radiation–induced damage [17, 19]. Extracts of *T. matsutake* have been shown to reduce oxidative stress, inflammation, and collagen degradation in skin cells exposed to UVA and UVB radiation. The mushroom extract inhibits the production of reactive oxygen species and suppresses matrix metalloproteinases, thereby preventing the breakdown of collagen and maintaining skin elasticity [17, 18]. Furthermore, when combined with active compounds such as bakuchiol and ergothioneine, *T. matsutake* extract exhibits enhanced protective and regenerative effects against photoaging [17]. Advanced delivery systems, including deep eutectic solvent microemulsions, have also been developed to improve the extraction efficiency, skin penetration, and biological activity of the extract [19]. These findings suggest that *T. matsutake* is a promising natural source of anti-aging agents for cosmetic and pharmaceutical applications [17, 19].

Antioxidant activity

Tricholoma matsutake has been widely reported to exhibit strong antioxidant activity, mainly due to its bioactive polysaccharides. Previous studies have shown that polysaccharides extracted and purified from *T. matsutake* possess significant free radical scavenging ability and can reduce oxidative stress *in vitro*. Structural characterization of these polysaccharides has further confirmed their role in antioxidant mechanisms **[20-22]**. Additionally, fermentation using *T. matsutake* mycelia has been found to enhance the antioxidant properties of food materials **[23]**. These results suggest that *T. matsutake* is a promising natural source of antioxidants for pharmaceutical and nutraceutical applications.

Anti-fatigue activity

Several studies have demonstrated that *Tricholoma matsutake* possesses significant antifatigue activity. Li *et al*. (2015) reported that liquid-cultured *T. matsutake* mycelium reduced physical fatigue in mice, which was partially attributed to the regulation of antioxidant pathways and a reduction in oxidative stress markers [24]. Similarly, Ma *et al*. (2020) showed that functional cookies fortified with *T. matsutake* powder significantly improved exercise endurance and decreased fatigue-related biochemical indicators in animal models [25]. These findings suggest that *T. matsutake* exerts antifatigue effects by enhancing antioxidant defense mechanisms, improving energy metabolism, and reducing exercise-induced oxidative damage, indicating its potential as a natural functional food or therapeutic agent for fatigue management [24, 25].

Antitumor activity

Several studies have demonstrated that *Tricholoma matsutake* exhibits significant anti-tumor activity. Hou *et al*. (2013) reported that a novel polysaccharide isolated from *T. matsutake* showed anti-microbial, immunomodulatory, and anti-tumor effects, indicating its potential role in enhancing host immune responses against cancer [26]. In a subsequent study, Hou *et al*. (2017) elucidated the structure of a new polysaccharide from Maerkang *T. matsutake* and confirmed its strong anti-tumor activity in experimental models [27]. Similarly, Kim *et al*. (2009) [28] demonstrated that extracts of *T. matsutake* exhibited both ABTS radical scavenging activity and inhibitory effects on tumor cell growth [28]. Collectively, these findings suggest that the polysaccharides and bioactive compounds present in *T. matsutake* contribute to its anti-tumor potential and support its possible application as a functional food and therapeutic agent in cancer management [26-28].

Antihypertensive activity

Several studies have reported that *Tricholoma matsutake* exhibits anti-hypertensive activity through inhibition of angiotensin-converting enzyme (ACE). Geng *et al*. (2016) [2] identified a bioactive peptide from *T. matsutake* that showed strong ACE inhibitory and antioxidant activities and significantly reduced blood pressure in spontaneously hypertensive rats [2]. Similarly, Kim *et al*. (2008) [29] demonstrated that pine mushroom (*T. matsutake*) juice possessed antioxidant, fibrinolytic, and ACE inhibitory activities, suggesting its potential role in cardiovascular protection [29]. Together, these findings indicate that the bioactive peptides and compounds present in *T. matsutake* may contribute to its anti-hypertensive effects and support its possible use as a functional food or therapeutic adjunct for hypertension management [2, 29].

Antiradiation activity

Several studies indicate that *Tricholoma matsutake* possesses protective effects against radiation-induced damage. Wang (2008) demonstrated that polysaccharides isolated from *T. matsutake* significantly improved immune function in radiation-injured mice, suggesting a radioprotective and immunomodulatory role. These polysaccharides were shown to enhance immune cell activity and support recovery from radiation-related suppression **[30]**. Furthermore, Li *et al*. (2022) [13] reviewed the structural characteristics, biological activities, and applications of *T. matsutake* polysaccharides and reported that they exhibit multiple bioactivities, including antioxidant, immunoregulatory, and protective effects against cellular stress, which contribute to their anti-radiation potential **[13]**. Collectively, these findings support the conclusion that *T. matsutake* polysaccharides act as natural radioprotective agents by reducing radiation-induced immune damage and enhancing the body's defence mechanisms.

Anti-inflammatory activity

Several studies have demonstrated that *Tricholoma matsutake* exhibits significant anti-inflammatory activity through its bioactive peptides and polysaccharides. Li *et al*. (2021) reported that peptides derived from *T. matsutake* reduced inflammation and improved mitochondrial function in RAW 264.7 macrophages by inhibiting the NF-κB/COX-2 inflammatory signalling pathway. This indicates that *T. matsutake* peptides can suppress the production of pro-inflammatory mediators at the cellular level [31]. In addition, Liu *et al*. (2020) [32] showed that polysaccharides from *T. matsutake* alleviated spinal cord injury in experimental models by promoting axonal regeneration and reducing neuroinflammation [32]. Together, these findings suggest that *T. matsutake* contains bioactive compounds with strong anti-inflammatory and neuroprotective properties, supporting its potential therapeutic application in inflammatory and neuroinflammatory disorders.

Antimicrobial activity

Several studies have shown that *Tricholoma matsutake* possesses significant anti-microbial activity due to the presence of bioactive polysaccharides, peptides, and metal–organic complexes. Hou *et al*. (2013) isolated a novel polysaccharide from *T. matsutake* and demonstrated that it exhibited strong antimicrobial, antitumor, and immunostimulatory activities, indicating its potential as a natural therapeutic agent [27]. Li *et al*. (2022) [13] reported that antibacterial peptide-based microsphere coatings effectively inhibited microbial growth on *T. matsutake* during cold storage, highlighting the antimicrobial effectiveness of *T. matsutake*-derived peptides [33]. In addition, Nishino *et al*. (2017) [34] identified an oxalato-aluminate complex produced in the "shiro" zone of *T. matsutake* that protects the fungus from soil microorganisms, suggesting an intrinsic microbial defence mechanism [34]. Collectively, these findings confirm that *T. matsutake* produces multiple antimicrobial substances that contribute to its resistance against microbial contamination and support its potential application as a natural antimicrobial agent.

Immunomodulatory activity

Several studies have demonstrated that *Tricholoma matsutake* exhibits significant immunomodulatory activity. Li *et al*. (2017) [35] reported that *T. matsutake* mycelium enhanced immune function in cyclophosphamide-induced immunosuppressed mice by improving immune organ indices and regulating immune-related cytokines, indicating its ability to restore immune balance under immunocompromised conditions [35]. Similarly, Lv *et al*. (2025) [36] showed that dietary supplementation with *T. matsutake* modulates immune responses through the direct regulation of immune cells and signalling pathways [36]. Collectively, these findings suggest that *T. matsutake* acts as a natural immunomodulator capable of enhancing and regulating immune function, supporting its potential therapeutic application in immune-related disorders.

Hypoglycaemic activity

Several studies have shown that *Tricholoma matsutake* exhibits significant hypoglycaemic activity, primarily due to its bioactive polysaccharides. Yang *et al*. (2021) [20] reported that a purified polysaccharide from *T. matsutake* demonstrated strong *in vitro* hypoglycaemic effects along with antioxidant activity, indicating its ability to regulate glucose metabolism and reduce oxidative stress **[37]**. Similarly, Liu *et al*. (2025) [38] showed that selenium-enriched mycelial polysaccharides from *T. matsutake*, produced through submerged fermentation, exhibited enhanced antioxidant and hypoglycaemic activities **[38]**. These findings suggest that *T. matsutake* polysaccharides can contribute to blood glucose regulation and may have potential therapeutic value in the management of diabetes and related metabolic disorders.

Skin whitening activity

Recent studies suggest that *Tricholoma matsutake* is a promising natural ingredient for cosmetic and cosmeceutical formulations due to its skin-whitening and anti-melanogenic properties. Polysaccharides derived from *T. matsutake* have been highlighted as safe and functional bioactive compounds with potential use in topical products aimed at improving skin tone and reducing hyperpigmentation [13, 39]. Experimental and clinical studies have shown that *T. matsutake* polysaccharides effectively suppress excessive melanin synthesis by regulating melanogenesis-related signalling pathways, particularly through inhibition of the JNK-mediated pathway [40]. These properties support the use of *T. matsutake* as a natural skin-whitening agent in cosmetic formulations designed to promote even skin tone and manage pigmentary disorder.

Wound healing activity

Zhu *et al*. (2021) [41] reported that extracts of *Tricholoma matsutake* exhibit significant wound-healing activity. In their study, the extracts promoted the proliferation of HaCaT human keratinocyte cells *in vitro* and accelerated the wound closure process in mice *in vivo*. These findings indicate that *T. matsutake* enhances skin cell growth and tissue regeneration, suggesting its potential usefulness as a natural agent for wound healing and skin repair applications [41].

Conclusion

Tricholoma matsutake is a nutritionally rich and pharmacologically important ectomycorrhizal mushroom with significant potential for pharmaceutical, nutraceutical, and cosmeceutical applications. This review has summarized its taxonomy, morphology, ecology, chemical composition, safety aspects, and a wide range of biological activities. The pharmacological properties of *T. matsutake*, including antioxidant, anti-inflammatory, antitumor, antihypertensive, immunomodulatory, hypoglycaemic, antimicrobial, radioprotective, anti-aging, and wound-healing effects, are mainly attributed to its bioactive polysaccharides and peptides.

Despite these promising benefits, the practical utilization of *T. matsutake* is limited by ecological constraints, poor cultivability, habitat degradation, overharvesting, and safety concerns related to metal accumulation and allergenicity. Therefore, sustainable harvesting, conservation strategies, and environmental monitoring are essential to protect natural populations and ensure consumer safety.

Future research should focus on the isolation and characterization of active compounds, elucidation of molecular mechanisms, standardization of extracts, evaluation of clinical efficacy, and development of sustainable cultivation or biotechnological production methods. Such efforts will be critical for the safe, effective, and sustainable pharmaceutical exploitation of *Tricholoma matsutake*.

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