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Morchella esculenta L.: A Systematic Update on Chemical Components, Biological Activities and Commercial Significance

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***Abstract*:** *Morchella esculenta* L., is a cosmopolitan, edible mushroom, acknowledged as a nutritious species, naturally occurs in the humid and shaded forest habitats. Since ancient times it has been consumed as a dietary and medicinal supplement. In folk medicine, it has got repute for treatment of excessive phlegm, dyspepsia and shortness of breath. Traditionally, it also has promising therapeutic effects on cardiovascular disorders, diabetes, colon cancer and other malignancies. Additionally, in modern times this fungus has immense commercial applications worldwide, and being utilized for the production and formulation of several nutraceutical and other products. In this review, the prior research on *M. esculenta* related to its bioactive components, biological activities, commercial uses, is summarized in a systematic and critical manner. For this purpose, numerous research engine resources, including Pub Med, Google scholar and Science Direct were used. Among numbers of pharmacological activities, the anti-oxidant activity appears to be the most potent activity of *M. esculenta*, followed by anti-microbial, hepatoprotective, enzyme inhibitory and cytotoxic activities. Predominantly, the polysaccharides are responsible for these biological activities. The ethno medicinal and nutritional attributes, commercial significance as well as its emerging potential in nutraceutical and future drug development is also discussed in a comprehensive manner.

***Keywords*:** *Morchella*, Bioactive compounds, Pharmacological profile, Medicinal, Nutraceutical, Commercial applications

Mushrooms have high potential and are widely employed as a source of physiologically beneficial, nutritionally functional food as well as non-toxic medicines due to their distinctive chemical composition. Mushrooms are considered as the main component of gourmet food around the world, mainly for their distinctive flavor, as well as they have been appreciated by mankind as a delicacy, they are prominent for its unique edible and medicinal attributes (Li et al 2018, Shameem et al 2017). Botanically, mushrooms belonging to genus *Morchella* are widely known as 'Morels' or 'True morels'. They are cosmopolitan in distribution and are prevalent in the loamy soil rich in humus, thick coniferous forest, and found naturally in frigid habitats of high altitudes (Raman 2018). True morels (*Morchella* spp.) comprise the most iconic group of wild edible macro fungi with distinctive appearance of honeycomb-like structures (Acay 2021, Wang et al 2019). There are 87 taxonomically accepted species in this genus. Among them, *M. esculenta* L., known as the 'Common morel,' 'Gucchi,' 'Morel,' 'True morel,' 'Yellow morel,' 'Sponge morel,' and 'Morel mushroom,' is the utmost widely recognized *Morchella* species (Li et al 2018). It belongs to the Morchellaceae family of the Ascomycota division. The generic name "*Morchella*" is acquired from the German word "Morel" means "Mushroom," and the specific epithet "*esculenta*" is derived from the Latin word meaning "edible" (Kanwal 2016). This species is a native of North America, Asia, Europe, Australia, China and Japan. It is cherished for its medicinal and nutritional resources owing to the possession of numerous bioactive components including dietary fibers, polysaccharides, vitamins, proteins and other trace elements (Li et al 2019a, Cui et al 2011). Many taxonomists and field mycologists reported numerous chemical compounds from different parts of this mushroom such as fruiting bodies and the mycelia, which have been shown to play a pivotal role in combating varied major gastrointestinal, respiratory illness and so on. Mushroom is highly sought after and cultivated throughout the summer season (March to July) due to its remarkable distinct flavour and nutritional value (Raman 2018). *M. esculenta* is also appreciated economically and socially because of its quite nutritious properties which plays a vital and salutary role for the humankind.

Time to time, many gastronomists as well as science researchers have published valuable studies regarding the diverse aspects of *M. esculenta*. But most of the studies are focused on an individual aspect. Therefore, our main purpose for adopting this approach is to reveal its bio-active components, biological activities, medicinal and therapeutic potential along with its commercial and nutraceutical values in a systematic manner.

MATERIAL AND METHODS

Systematic search strategy: A systematic assessment was undertaken to identify all relevant and published articles which evaluated the aspects of bio-active components, biological activities and medicinal uses by various catalogues such as Google and Science, Direct and PubMed. We gathered the information on the basis of appropriate keywords "*Morchella*", "true morels", "edible mushroom", "bioactive compounds", "pharmacological activities", "medicinal", "nutraceutical" and "commercial applications". To sustain the novelty and authenticity of work, we included only those articles which were in line with our inclusion criteria. A total of 84 articles were retrieved after exclusion of the duplicate manuscripts manually. The systematic assessment was executed in accordance with the preferred reporting items for the systematic review with the help of PRISMA (Fig. 1).

Eligibility criteria, extraction and management of data and quality assessment: On the basis of the following pre-defined eligibility criteria, only full-text, legitimate research-based manuscripts with more than five citations were considered for inclusion. Irrelevant content was eliminated at the very first step of the screening. Abstracts and review articles were also removed through exclusion criteria. Full texts were acquired for all the considered articles (n= 38) to meet the inclusion guidelines Figure 2 represents the quantitative assessment of a total number of articles which consists of pharmacological activities, medicinal uses, photochemistry and economic uses of *M. esculenta*.

Systematic Update

Phytochemistry of *M. esculenta* L.: The characterization of various major classes of secondary metabolites is the basis of pharmacological activities. The classification of major constituents is broadly based on the criteria of content and nature. The present study describes the pharmacological potential of different phytochemicals such as polysaccharides, phenolic compounds, sterols, organic acids, minerals, dietary fibers and trace elements extracted from *M. esculenta*. Moreover, the structural analysis of these phytochemicals with the help of Pub Chem is represented in Table 1 & Figure 3.

Biological activities of *M. esculenta* L.: The multitude of biological studies of *M. esculenta* have been reviewed in this paper and are summarized in Table 2 with the information regarding type of extracts/compounds/fractions, dosage, model and possible outcomes). Out of the total 38 authentic research articles, 26 were selected for pharmacological activities of *M. esculenta* with the help of predetermined inclusion criteria. Through quantitative analysis carried out on the findings published in the selected works, the anti-oxidant activity is found as the dominant activity of this plant, listed in 7 research articles, followed by anti-microbial activity (4 research studies). Moreover, three research articles showed multiple pharmacological properties including anti-oxidant, anti-diabetic and anti-microbial. Further 2 studies each for activities such as anti-inflammatory, anti-tumor, enzyme inhibitory, hepatoprotective, immunomodulatory, protective and 1 study each for other activities such as anti-aging, anti-diabetic, anti-melanogenesis, anti-proliferative, anti-viral, cytotoxic, anti-atherosclerotic, nephrotoxicity and proteolytic activities were examined and reviewed thoroughly.

Therapeutic and medicinal significance: From ancient times, *Morchella* species have been used in traditional Asian medicine for the treatment of various ailments, in China, India, Japan, and Malaysia (Li et al 2018, Kanwal 2016). *M. esculenta* not only has an extensive range of health benefits, but it also

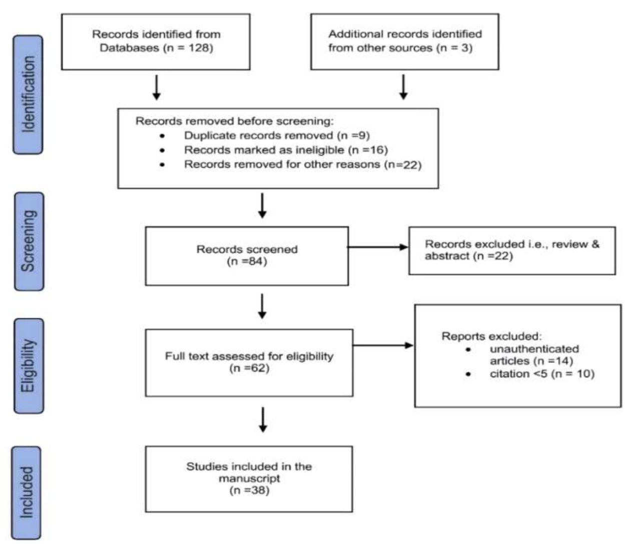

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Fig. 1. PRISMA flow diagram for search strategy

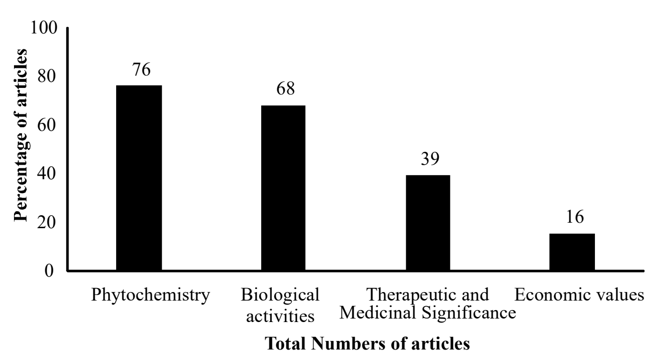

Fig. 2. Quantitative assessment of selected articles

has medical potential, with promising effects on colon cancer, diabetes and cardiovascular disorders. It also manifested several therapeutic applications such as antiseptic, aphrodisiac, emollient, laxative, narcotic and tonic (Li et al 2019a). Furthermore, this true morel helps to boost up the functioning of the immune system (Zhang et al 2018). Despite considerable recent studies to describe various medicinal as well as traditional uses of this mushroom species, the adequate

Table 1. Chemical constituents of *M. esculenta* L.

Major classes	Chemical constituents	References
Amino acid	Alanine, Arginine, Aspartic acid, Cystine, Glutamic acid, Glycine, Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Proline, cis-3-amino-L-Proline, Serine, L-Threonine, Tyrosine, Valine.	Cai et al 2018a, Buscot and Bernillon 1991, (Zhang et al 2019), (Fu et al 2013), (Rossbach et al 2017), (Li et al. 2016), (Lee et al 2018), (Meng et al 2019)
Carbohydrates	Exopolysaccharides, Free sugars, Galactomannan, Heteropolysaccharides, Mannitol, Monosaccharides, Polysaccharide FMP-1, Polysaccharides.	(Raman 2018), (Cai et al 2018b), (Li et al 2018), (Li et al 2019a), (Liu et al 2016), (Ali and Verma 2014), (Cai et al 2018a), (Li et al 2013), (Fu et al 2013), (Cui et al 2011), (Rossbach et al 2017), (Li et al 2016), (Li et al 2017), (Meng et al 2010), (Nitha et al 2013), (Li et al 2019b),(Meng et al 2019), (Lee et al 2018), (Heleno et al 2013), (Wang et al 2021)
Dietary fibers		(Liu et al 2016), (Fu et al 2013), (Cui et al 2011), (Strapáč et al 2019), (Nitha et al 2013), (Meng et al 2010), (Cai et al 2018b), (Meng et al 2019)
Fatty acid	Arachidic acid, Arachidonic acid, Ergosterol (Ergosta153 5,7,22-trien-3-ol), 5-Hydroxymethylfurfural, Docosahexaenoic acid, Docosanoic acid, Eicosadienoic acid, Eicosatrienoic acid, Elaidic acid, Heneicosanoic acid, Heptadecanoic acid, Hexadecanoic acid, α- & γ- Linolenic acid, Myristic acid, Nervonic acid, 1-Octadecanoic acid, (Z,Z)-9,12-Octadecadienoic acid, Oleic acid, Palmitoleic acid, Pentadecanoic acid, Stearic acid, Tetracosanoic acid.	(Bisakowski et al 2000), (Lee et al 2018), (Shameem et al 2017), (Ali and Verma 2014)
Flavonoid	Flavones, Flavonoids, Quercetin.	(Doğan et al 2018), (Zhao et al 2018), (Ali and Verma 2014), (Meng et al 2019)
Minerals	Arsenic, Cadmium, Calcium, Chromium, Copper, Iron, Lead, Manganese, Mercury, Potassium, Selenium, Sodium, Sulphate, Zinc and other trace elements.	(Nitha et al 2013), (Meng et al 2019), (Liu et al 2016), (Fu et al 2013), (Cui et al 2011), (Strapáč et al 2019)
Organic compounds	Citric acid, Citric acid, p-Coumaric acid, Fumaric acid, Lycopene, Malic acid, Organic acid, Oxalic acid, Polyphenol, Quinic acid.	(Ali and Verma 2014), (Li et al 2016), (Raman 2018), (Heleno et al 2013)
Phenolic Compounds	Benzoic acid, Cinnamic acid, Gallic acid, p-Hydroxybenzoic acid, Phydroxybenzoic acids, Protocatechuic acid, Vanillic acid.	(Ali and Verma 2014), (Raman 2018), (Doğan et al 2018), (Zhao et al 2018), (Heleno et al 2013)
Protein	Glycoproteins.	(Li et al 2019a), (Liu et al 2016), (Fu et al 2013), (Cui et al 2011), (Rossbach et al 2017), (Strapáč et al 2019), (Wei et al 2001), (Nitha et al 2013), (Cai et al 2018b), (Meng et al 2019)
Polyol	Quinic acid.	(Ali and Verma 2014)
Sugar acids	Uronic acid, Total sugar.	(Li et al 2019a), (Liu et al 2016)
Steroids	Sterol, Ergosterol derivatives	(Lee et al 2018), (Zhao et al 2018), (Heleno et al 2013)
Terpenoids		(Nitha et al 2013), (Meng et al 2019)
Vitamins	Tocopherols α, γ- & δ	(Liu et al 2016), (Ali and Verma 2014), (Cui et al 2011), (Strapáč et al 2019), (Cai et al 2018b), (Raman 2018), (Heleno et al 2013)
Others	(3β,5α,22E)-Ergosta7,22,24(28)-trien-3-ol, (3β,5α,8α,22E)-5,8-epidioxyergosta-6,22- dien-3-yl β-D-glucopyranoside, (3β,5α,8α,22E,24S)-5,8-epidioxyergosta-6,22-dien-3-ol, (3β,5α,8α,22E,24S)-5,8-epidioxyergosta-6,9(11),22-trien-3-ol, 1-O-octadecanoyl-sn-glycerol, Mycosporin glutamic acid, Mycosporin glutamine,	(Meng et al 2019), (Lee et al 2018)

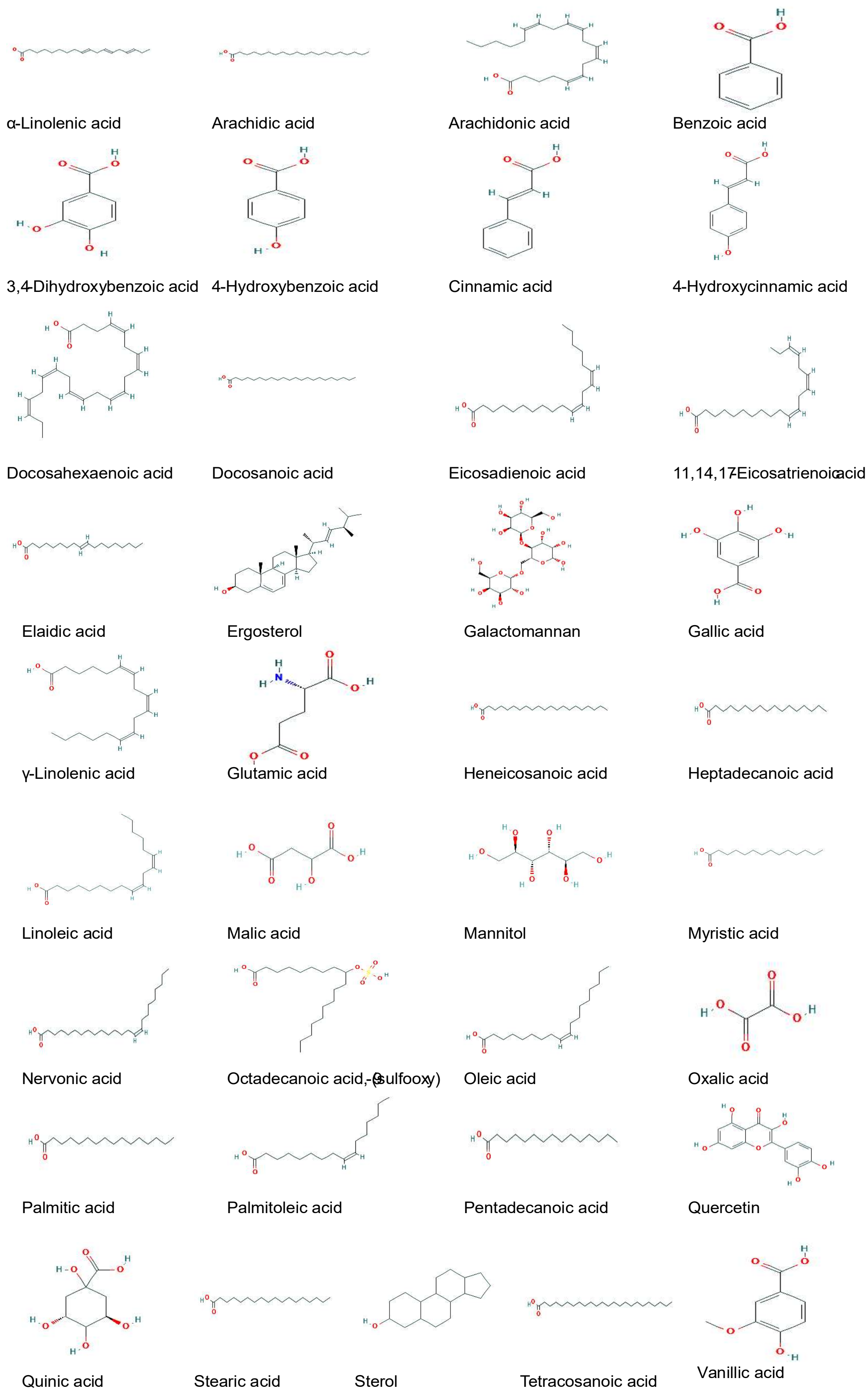

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Fig. 3. Major bioactive components of *M. esculenta* L.

Table 2. Biological activities of *M. esculenta* L.

Biological activities	Extracts/ Fractions/ Compounds	Models/ Cell lines	Assays/Methods	Outcomes	References
Anti-aging activity	Extracellular polysaccharides	Male ICR strain mice	*In vitro* (OH radical, DPPH and reducing power assays); *In vivo* (D-galactose induced mice model)	*In vitro* (EC_{50} = 0.86, 1.09 & 0.481 mg/ml); *In vivo* significantly increased anti-oxidant enzymes activity and function of immune system to reduce oxidative stress.	(Fu et al 2013)
Anti-atherosclerotic activity	Novel polysaccharide (MCP)	LDLR-deficient (LDLR−/−) mice		Decreaseden face and sinus, serum, low-density lipoprotein cholesterol and triglyceride levels and hepatic lipid accumulation.	(Wang et al 2021)
Anti-diabetic activity	*Morchella* protein hydrolysate (MPH), microwave-irradiated (M-MPH) and selenized (Se-MPH) (0.4-2.0 mg/ml)	α-glucosidase and α-amylase enzyme		MPH increased inhibition of enzymes dose dependently.	(Zhang et al 2019)
Anti-inflammatory activity	Total flavones by broth fermentation of co-culture (*M. esculenta* and *Coprinus comatus*)	LPS-stimulated RAW264.7 macrophages		Inhibited nitric oxide (NO) production through the suppression of iNOS expression, TNF-α & IL-1β (pro-inflammatory cytokines) and restrained COX-2 expression.	(Zhao et al 2018)
	Sulfated polysaccharide (SFMP-1) and its derivatives	PM2.5 in rat alveolar macrophage NR8383 cells		Decreased cell death (PM2.5-induced); production (TNF-α & IL-1β); cell apoptosis; iNOS & COX-2 expressions; NF-κB nuclear translation and IκBα phosphorylation.	(Li et al 2019b)
Anti-melanogenesis activity	Polysaccharide FMP-1	B16F10 melanoma cells, Zebrafish larvae.		Decreased melanin contents, tyrosinase activities, expression of MC1R, MITF, TRP-1 and TRP-2, melanogenesis-related proteins.	(Cai et al 2018a)
Anti-microbial activity	Methanol, ethanol and chloroform extracts (30 & 15 mg/ml)	*Escherichia coli, Klebsiella pneumonia* and *Enterobacter aerogenes* etc. and fungal strains	Agar dilution	Maximum ZI 21-28 mm against *K. pneumonia* in methanol and chloroform extracts. And ZI 22.5 & 20 mm for *E. aerogenesand E. coli* in ethanol extract.	(Badshah et al 2012)
	ME-AuNPs	*Escherichia coli, Staphylococcus aureus, Bacillus subtilis* and *Candida albicans*	Micro-dilution	Level of inhibition 0.2210, 0.4421 & 0.1105 mg/ml for *E. coli, S. aureus* and *C. albicans.*	(Acay 2021)
	Ethyl acetate and butanol fractions and morel compounds 1, 2 & 3 (15 & 30 mg/ml)	*Escherichia coli*, *Staphylococcus aureus* &*Pseudomonas aeruginosa*		Butanol fractions showed highest MIC value of 250 µg/ml against *E. coli* & *S. aureus*; MIC values ranged from 250-750 µg/ml for compounds 1 to 3.	(Shameem et al 2017)
	M. esculenta extract	Gram-negative & positive bacterial and fungal strains.	Micro-dilution	MIC ranged between 0.02 to >10 µg/ml. Minimum demelanizing concentration 0.02-0.60 mg/ml against all fungal strains.	(Heleno et al 2013)
Anti- oxidant activity	*M. esculenta* SO-01 exopolysaccharide (25-400 mg /kg b.w.)	Kunming mice (Male)	SOD, GSH-Px and MDA assays for blood, spleen, liver, heart, and kidney	Increased levels of SOD (125, 46.11, 23.33, 12.19 & 41.29%) and GSH-Px (63.24, 63.12, 166.54, 98.01 & 57.68%); ↓ level of MDA (21.80, 67.84, 28.48, 56.15 & 41.62%).	(Meng et al 2010)
	Purified polysaccharides before fermentation (PMPS) and after fermentation (PUPS) (0, 2, 4, 6, 8 & 10 mg/ml)		DPPH, OH radical, Fe metal ions and ABTS radical cation	PMPS exhibited high activity than PUPS among all the assays.	(Li et al 2013)

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Table 2. Biological activities of *M. esculenta* L.

Biological activities	Extracts/ Fractions/ Compounds	Models/ Cell lines	Assays/Methods	Outcomes	References
	Methanol extract from mycelia (0.5-25 mg/ml)		Anti-oxidant activity, reducing power, DPPH radicals and Fe ions chelating effect	EC_{50} values of all the assays were 2.78±0.14, 1.25±0.06, 3.71±0.03 & 3.55±0.01 μg/ml, respectively.	(Mau et al 2004)
	Methanol extract of fruiting body from two location i.e. Serbia and Portugal		Folin–ciocalteu, Prussian blue, DPPH scavenging, β-carotene and Thiobarbituric acid reactive substances (TBARS) assays	Extract (Portugal) increased reducing power in Folin–ciocalteu, Prussian blue (EC_{50} 34.64±1.24, 6.34±0.07 mg GAE/g extract), and DPPH (EC_{50} 6.06±0.05 mg/ml from Portugal had higher); while from Serbia showed higher lipid peroxidation inhibition with EC_{50} 2.39±0.09 & 2.23±0.46 mg/ml in β-carotene and TBARS assays.	(Heleno et al 2013)
	Glycosylated *Morchella* protein hydrolysate (MPH)		ABTS, DPPH, H_2O_2, reducing power, nitrite and superoxide radicals.	MPH increased anti-oxidant activity as comparison to native, heat-treated or xylose mixture of MPH.	(Zhang et al 2018)
	Synthesized *M. esculenta*-based gold nanoparticles (ME-AuNPs) (1, 2, 5 & 10 mg/ml)		DPPH, AA & β-carotene linoleate model system and chelating iron ions.	ME-AuNPs (10 mg/ml) exhibited anti-oxidant capacity of 82, 85 & 77%, respectively for the tested assays.	(Acay 2021)
	Morchella protein hydrolysate (MPH)		ABTS, DPPH, and H_2O_2& reducing power	IC_{50} 71.30, 6030.91, 5276.61 μg/ml & 4.76 μg Vc/mg sample, respectively for the tested assays.	(Zhang et al 2019)
Anti-proliferative activity	MeOH extract, hexane, CH2Cl2, EtOAc & n-BuOH-soluble fractions, and the isolated compounds from fruiting body (100- 600 μM)	A549, H1264, H1299 & Calu-6	WST-1 assay	Cell viability decreased by extract (IC_{50} 0.49-1.35 mg/ml); Hexane-soluble fraction (IC_{50} 205.5-267.9 μg/ml); Compounds 1-O-octadecanoyl-sn-glycerol, (3β,5α,22E)-Ergosta-7,22,24(28)-trien-3-ol and (3β,5α,8α,22E,24S)-5,8-epidioxyergosta-6,9(11),22-trien-3-ol (IC_{50} 171.6-278.0, 169.1-223.8 & 133.1-221.3 μM) in all tested human lung cancer cell lines.	(Lee et al 2018)
Anti-tumor activity	Polysaccharide and its hydrolysate fractions (M1-M4) (200-1000 μg/ml)	HT-29 cells	MTT assay	Fraction M2 significantly increased activity (54.29%) even at 200 μg/ml in 24 h; non-significantlyincreased the inhibitory activity after 48 h up to 800 μg/ml.	(Liu et al 2016)
	Crude Polysaccharides (by *M. esculenta* fermented soybean residue) and its fractions (MP-1, -3 & -4) (50 μg/ml)	HepG2 and HeLa	MTT assay	MP-1 increased growth inhibition effect (68.01%) on HepG-2 cells	(Li et al 2017)
Anti-viral activity	Hexane and ethanol extracts from fruiting body.	efavirenz/FIV reverse transcriptase		Moderate FIV-RT activity with IC_{50} 77.59±8.31 & 211.90±64.25 μg/ml, respectively for both extracts.	(Seetaha et al 2020)
Cytotoxic activity	ME-AuNPs	A549 and HepG2	MTT assay	ME-AuNPs showed activity with IC_{50} 0.548 & 11.672 μg/ml, respectively against both the cell lines.	(Acay 2021)
Enzyme inhibitory activity	Crude extract (FI) and other fractions (a, b, c) isolated from *M. esculenta*	Lipoxygenase activity		12.8% and 2.5-fold increase in purification; Linolenic acid has 29% activity i.e. approx mono-, di- and trilinolein was 11% (enzymic activity has strong specificity); LOX activity has relatively strong affinity 83% (Substrate: Arachidonic acid)	(Bisakowski et al 2000)
	MPH, M-MPH, and Se-MPH (0.6, 1.2, 1.8, 2.4 & 3 mg/ml)			Se-MPH (3 mg/ml) inhibited 41.77% the tyrosinase, that was 1.79- and 1.73-fold high then MPH and M-MPH, respectively.	(Zhang et al 2019)

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Table 2. Biological activities of *M. esculenta* L.

Biological activities	Extracts/ Fractions/ Compounds	Models/ Cell lines	Assays/Methods	Outcomes	References
Hepatoprotective activity	Aqueous-ethanolic extract from mycelia (250 & 500 mg/kg b.w.)	Ethanol and CCl_4 induced elevated GOT, GPT and ALP (liver function enzymes) in male Wistar rats serum		Decreased GOT, GPT & ALP dose dependently; Restored the depleted levels of antioxidants subsequent to ethanol and CCl_4 challenge as compared to 100 mg/kg p.o. Liv 52 with CCl_4 (control).	(Nitha et al 2013)
	ME from fruiting body	Inflammatory factors C57BL/6 mouse		Decreased levels of kappa-B kinase α/β (phosphorylated nuclear factor);Decreased kappa-B α & kappa-B p65 (nuclear factor); alcohol-induced imbalance in prooxidative and anti-oxidative signaling as indicated by upregulation of superoxide dismutase-1 & -2, catalase, hemeoxygenase-1 & -2 and downregulation of kelch-like ECH-associated protein.	(Meng et al 2019)
Immunomodulatory activity	Crude Polysaccharides (by *M. esculenta* fermented soybean residue) and its fractions (MP-1, -3 & -4) (0-100 µg/ml)	LPS		MP-3 & -4 increased proliferation ratio of 313.57 & 190 %, respectively at 25 µg/ml concentration; All polysaccharides increased NO production in macrophages; MP-3 displayed the potent phagocytosis effect on macrophages with absorbance of 0.44 µM at 50 µg/ml.	(Li et al 2017)
	Water-soluble polysaccharide, MEP and its fractions (MEP-I & -II) from mycelium (0-60 mg/kg)	Mice		MEP increased immune-stimulatory activity, with selectively activated T cells, purified lymphocytes; stimulated splenocyte proliferation and improved the level of NO.	(Cui et al 2011)
Nephrotoxicity	Aqueous-ethanolic extract from mycelia (250-500 mg/kg b.w.)	Swiss Albino mice		Decreased serum urea and creatinine;increased SOD levels and restored the MDA and GPx	(Nitha and Janardhanan 2008)
Protective activity	Polysaccharide (FMP-1) from fruiting body *In-vitro* (50 to 400 µg/ml);*In vivo* (50, 100 & 200 µg/ml)	*In-vitro* (Hydroxyl, DPPH and superoxide radicals, reducing power);*In-vivo* (Zebrafish embryos)		*In-vitro*increased scavenging activity with IC_{50} 74.26, 119.32 & 161.49 µg/ml, respectively and reducing power 0.84 at 400 µg/ml; *In-vivo* significantly protect AAPH-induced oxidative damage in zebrafish embryos with rates of 77.33, 83.67 & 90.67%, respectively.	(Cai et al 2018b)
	Polysaccharide (FMP-1) from fruiting body (50, 100, 150, 200, 250 & 300 µg/ml)	A549 cells		Decreased Caspase-3 release and H_2O_2-induced cytochrome C to inhibit cell apoptosis by MDA and ROS level reduction and cellular oxidative stress through PI3K/AKT pathway; increased enzymatic activities of SOD and T-AOC.	(Li et al 2018)
Proteolytic activity	Water, phosphate-buffered saline (PBS) extract and a suspension (200 mg d.w. of spruce in PBS solution)			Increased non-specific proteolytic activity in the PBS fungal suspension of 22.9 mg trypsin/kg d.w., followed by PBS and water extract (13.6 & 10.94 mg trypsin/kg d.w.)	(Strapáč et al 2019)

knowledge of many other remedial uses is still unknown and further investigation on the morels will be required in terms of medicative aspects. The ethno medicinal uses of this species, as published by various authors are summarized in Table 3.

Economic values of *M. esculenta* L.: Since ancient times, the morels have been regarded as having great economic value. Because of their delicious flavor, the consumption of this morel is considerably high throughout the globe. It also forms a well-known mushroom in terms of edibility, medicinal and therapeutic attributes to humankind. Multi-dimensional applications of *M. esculenta* have been demonstrated in Figure 4.

Table 3. Ethno-medicinal uses of *M. esculenta* L.

Major disorders	Indications	References
Respiratory disorders	Shortness of breath, excessive phlegm, excessive sputum, cough and cold.	(Cui et al 2011), (Fu et al 2013), (Lee et al 2018), (Wang et al 2021)
Gastrointestinal disorders	Stomach and gastrointestinal problems, indigestion.	(Raman 2018), (Cui et al 2011), (Fu et al 2013), (Lee et al 2018), (Sulaiman et al 2020)
Immunity and general health	General debility, weak immune system.	(Ali and Verma 2014), (Raman 2018), (Wei et al 2001), (Pfab et al 2008)
Vulnerary	Wounds	(Acay 2021)

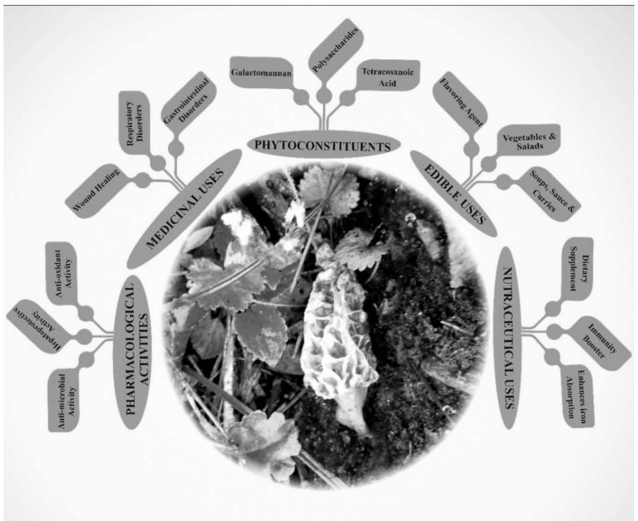

Fig. 4. Applications of *Morchella esculenta* L. (Image is an unpublished image of author)

Edible and nutritional significance: The specific epithet of the name *Morchella esculenta* itself described its edible attributes. Ethno-botanically, at many places in India and Nepal, this mushroom is placed near the traditional cooking stove for slight fermentation. Alternatively, it can be kept in sunlight. Thereafter, fruiting bodies are fully dried in the sun and they can be stored for future consumption in this form. This mushroom is a saprotroph that is used as vegetable due to its flavor and quality and considered equivalent to meat. It is known as *Gucchi* in the Punjab state of India (Kanwal 2016). It is edible as directly in diet, as a soup and also as flavoring agent (Ali and Verma 2014, Nitha and Janardhanan 2008). This morel is regarded for its health-promoting effects, pertinacious edible taste and quality. Additionally, this mushroom includes carbohydrates (4.25 g), some lipids, and proteins (1.62 g), as well as essential amino acids, which make it a good source of proteins (Ali and Verma 2014).

Commercial significance: The mushroom is one of the most nutritious, palatable and tasty foods known throughout the globe. It has lots of commercial uses which are aptly explained by many researchers and gastronomists in their studies. Additionally, fresh as well as dried fruit bodies of this species are consumable. They can be easily stored and packed, to be used for the future consumption. Due to its specific growing requirements, its cultivation is difficult, the labor expenses involved in its cultivation, harvesting and processing are very high; therefore, this morel is one of very expensive mushrooms. It is estimated that about 225 million tons of dried morel is traded internationally every year. Like all forms of morels, *M. esculenta* is one of the extremely culinary important and most valued of all edible mushrooms.

CONCLUSION

Many scientific researchers have described several biological activities of this mushroom. However, none of them described its harmful or toxicological effects. Consequently, a lot of in-depth future investigations on the toxicological aspects of this edible mushroom can be carried out by researchers. Besides, very few studies have been carried out related to its medicinal uses, as became evident during perusal of literature for this review work, and as described in this manuscript. It is thus recommended that further studies should be conducted on its medicinal properties. On the basis of this scientific data available, this species can be considered as edible rather than toxic as no toxic phytochemicals have been reported till date from this mushroom. In light of these findings, further studies to evaluate the toxicological aspects of this mushroom will be a concern. The above data, which was gathered over the last five years, probably sufficiently reveals significant aspects of *M. esculenta* in a comprehensive and methodical manner, yet further studies on many aspects are worth undertaking.

AUTHOR CONTRIBUTIONS

All authors have made a substantial and direct contribution to the work.

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