

White Mustard (*Sinapis alba* L.): A Functional Food with Therapeutic Potential

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ABSTRACT: White mustard has been in use for centuries due to the biological and therapeutic value of its ingredients. It has been used in Ayurveda for centuries for a number of diseases and ailments, making use of its characteristic properties. In different parts of the globe, white mustard may have been used as a therapeutic agent for a number of pathological conditions, but now the main focus is turning towards the use of alternative sources of energy. White mustard, as a natural herb, contains a number of different ingredients and chemical constituents, each playing its unique role in the beneficial edible and non-edible uses of White mustard. As a therapeutic agent, white mustard has been used as an emetic, as an appetite enhancer, as a diuretic, as an anti-infectious agent and sometimes to clear the voice of the throat, reducing sore throat. White mustard extracts have demonstrated antiproliferative effects, anti-inflammatory, and antioxidant activity. Production of biodiesel from white mustard oil has been the key research area for researchers and scientists. The seeds of white mustard plants, as well as other parts, must be evaluated at large-scale research to produce other types of biofuels. The chemical conversion of the ingredients of white mustard must be explored to make the maximum use of its properties.

Keywords: White mustard, biodiesel, antioxidant, anti-inflammatory

INTRODUCTION

Mustard, a plant, a vegetable, or a condiment, belonging to the family Brassicaceae, has two types of origins: the Mediterranean region and a Himalayan region. The type of mustard belonging to Mediterranean origin is *Sinapis alba*, known as White or Yellow mustard, while that of Himalayan origin is *Brassica juncea*, also known as Indian or Brown Mustard (Mitrović et al., 2020). Brassicaceae was formerly known as Cruciferae (the mustard family of flowering plants), possessing the order “Brassicales” including 338 genera and 3700 species. Many plants of economic importance that are domesticated by humans are broccoli, turnip, cabbage, rutabaga, brussels sprouts, kale, and kohlrabi, which belong to the genus *Brassica* under the umbrella of family Brassicaceae. Other members are crops (horseradish, white mustard, radish), ornamentals (basket-of-gold, honesty and candytuft) and invasive species (Ropelewska et al., 2018). White mustard is a common herb that has multiple medicinal uses, proving its worth more than a spice and food additive. As a therapeutic agent, Hippocrates and ancient physicians have been using it as an emetic, as an appetite enhancer, as a diuretic to increase urine flow, as an anti-infectious agent and sometimes to clear the voice of the throat, reducing sore throat (Aboulthana et al., 2025). Along with oral use for certain types of ailments, white mustard may be used as a dermal product. It is also applied on the skin directly for rheumatism, osteoarthritis, lumbago and swollen

joints. It may help to reduce sinus infection by application on the chest for cough and cold and sometimes chest congestion. It is occasionally used in baths for the treatment of paralysis (Miękus et al., 2020).

Traditional use of white mustard that may run in continents for centuries is its inclusion in food as a spice, dating back to 3000 BCE. Tiny mustard seeds may be used as a symbol of faith under certain groups of faith. Of the three types of mustard, white mustard (*Brassica alba*) is the mildest one and may be used to make traditional American yellow mustard. The most pungent one is Black mustard, known as *Brassica nigra*, while brown mustard (*Brassica juncea*) possesses a pungent taste and is used to prepare Dijon mustard (Lietzow, 2021). Easy harvesting and fast production of brown mustard, as compared to black mustard seed has provided dominance to brown mustard use as a mustard condiment. Hungary, Britain, Canada and the Great Plains of the US are the most popular lands to cultivate and grow the mustard plants principally in the temperate regions of the world. It is the largest spice in the world by volume.

NOMENCLATURE

White mustard is recognized in the nomenclature by several different names based on the taxonomy, classification, origin, medicinal, and general uses. Some of the different names used in different parts of the world to recognize white

mustard are, American Yellow Mustard, Bai Jie Zi, Brassica alba, Farine de Moutarde Blanche, Graine de Moutarde Blanche, Huile de Moutarde Blanche, Mostaza Blanca, Moutarde, Moutarde Anglaise, Moutarde Blanche, Moutarde Cultivée, Moutarde Rude, Mustard, Pâte de Moutarde Blanche, Plâtre de Moutarde Blanche, Poudre de Moutarde Blanche, Sinapis alba, Weibe Senfsamen, White Mustard Flour, White Mustard Greens, White Mustard Oil, White Mustard Paste, White Mustard Plaster, White Mustard Powder, White Mustard Seed, Yellow Mustard (Vaughan, 1977).

TAXONOMY AND ORIGIN

Annual, biennial, or perennial herbs are the characteristic properties of members of the mustard family. These herbs have white, yellow, or lavender flowers which bloom from May to June. Each flower has four petals and four sepals, arranged in a cruciform, so commonly referred as “cruciferous” or “crucifers”. The specific feature of flowers is a two-chambered ovary positioned above the other plant parts, accompanied by four long and two short stamens. Pedicels of flowers are 5-7mm long, 4 sepals are narrowly elliptical and 4-5 mm long, similarly 4 petals are obovate, bright yellow, 10 mm long and 4 mm wide, narrowly clawed at the lower base (Ekanayake et al., 2012).

The ovary is elongated and sessile, the pistil is slightly shorter than the longest stamens, giving it a delusion of stamen, while the style ends in a semi-globose stigma. The gynoeceum is fused in a single carpel. Almost 6 stamens are there, with inner whorls of 4 longer stamens and outer whorl of 2 shorter ones. The fruits are dry, pod-like with a partition at the center, existing in two different shapes: siliques (long, thin fruits) and silicles (short, rounded fruits). Hairy seed pods or siliques surround the fertile yellow flowers, possessing almost a half dozen seeds in each pod. Light yellow colored white mustard seeds are about 2.5 mm in size, approximately 0.1 inch, while brown mustard seeds, possessing the same size, are darker yellow in color. Seeds of both mustards are globular in shape and finely pitted, remain odorless when dry and as a whole. The seeds have a color range from beige or yellow to light brown, with a strong, hard nature and spherical with 1 to 1.5 millimeters in diameter. The taste appears to be pungent for both types of seeds, with a globular shape in appearance. The composition of seeds of both types of mustard is similar, containing a strong enzyme called myrosin, a small proportion of protein and almost thirty to forty percent of vegetable oil. These seeds are odorless in grounded form or dry form, but become pungent and produce an irritating odor and acrid taste if either the seed is chewed or if flour is mixed with water (Grygier, 2023).

A chemical reaction may occur between two of the constituents within mustard, either a glucoside or an enzyme, yielding an oil that is not present as such in the plant. The white mustard seeds on such a reaction, produce sinigrin mustard oil, which is a nonvolatile oil producing a heat sensation on the tongue and has negligible odor. The volatile oil produced by the same reaction of water with brown mustard seeds has an acrid taste and a severe, pungent, irritating odor. The leaves of the mustard plant have an uneven surface that is rugged,

lyrately pinnate, haphazardly dentate and their color is usually pale green. The petiole is the longest in the largest leaves, with the uppermost stem leaves clearly lobed. The leaves possess elliptical, ovate, outlined blades which are 15 cm long and divided to the midrib into 1-3 pairs of dentate-margined lobes (Ekanayake et al., 2016; Ekanayake et al., 2012).

CHEMISTRY AND CHEMICAL COMPOSITION OF WHITE MUSTARD

White mustard, as a natural herb, contains a number of different ingredients and chemical constituents, each playing its unique role in the beneficial edible and non-edible uses of White mustard. These ingredients are comprised of proteins 28%, fixed oil 35%, sinalbin 2.5 %, carbohydrate, dietary fiber, omega-3 fatty acids, iron, calcium, phosphorus and zinc and a small amount of a very well-known antimicrobial component, para-hydroxybenzyl isothiocyanate (p-HBITC) ($\text{HO-C}_6\text{H}_4\text{-CH}_2\text{-NCS}$) along with glucose (Aboulthana et al., 2025). p-HBITC and some other mustard flavor compounds were revealed by the chemical analysis of the essential oil of low volatility (White Mustard Essential Oil, WMEO), which was extracted from partially defatted white or yellow mustard seeds (Preedy, 2015).

BENEFITS AND USES OF WHITE MUSTARD

White mustard has been used for a long time for several different purposes, health-related and oil-related. The benefits and uses of white mustard seeds are listed below:

Non-Edible Uses of White Mustard

White mustard is being used for several different valuable processes, such as intercropping, biofumigation and phytoremediation, due to the presence of a number of compounds and different esters (methyl, ethyl, propyl, and butyl) derived from white mustard oil by homogeneous base-catalyzed transesterification, which was tested for diesel additives. It may be used as a protein and a source of amino acids. Industrial uses of white mustard on large scale may encompass the production of bio-polyols for the synthesis of rigid polyisocyanurate and polyurethane foams, formation of biopolymer films for interior boards of furniture and particles as well for food packaging (Özcan et al., 2024). Non-edible white mustard oil is used for lighting and as a lubricant. White mustard may be considered as a forage crop along with various other crop species with low gross and net calorific values, helping to create the use of some of its parts as forage, lignocellulosic raw material, or green manure. It may be used as an additional bioenergy source due to its highest heat of combustion, approximately 15.55 MJ/kg.

Edible Uses of White Mustard

Food preservation is the biggest industry that needs a lot of preservatives and additives to keep food edible for a long time, while maintaining its quality and edible value. White mustard seeds possess an essential oil that has the potential for food preservation. A major valid use of white mustard therapeutically is as a condiment with a variety of flavors of both white and brown mustard. Mustard appears in three solid

forms as a condiment, mostly used form is as seeds. The second preferred form is as a dry powder that may be mixed with water to give different flavors and aroma and sometimes treated with other species or herbs, such as vinegar or wine, to prepare a paste (Martinović et al., 2020). The third solid form is as a flour or starch to tone down the sharpness. Different aromas or flavors have different uses to further prepare different condiments, e.g., pungent brown mustard is used in French-type paste mustards, while white one is used to prepare milder American or German type pastes, and an amalgam of two or separately may be used to prepare English mustard products (Frazie et al., 2017). White mustard is used as a dominant part of spices and cooking material to make it a healthy choice of every cuisine; it may be mixed with various foods, such as sausages, salad dressings and cold meats, pickles, sauces and mayonnaise (Jankowski et al., 2020).

Medicinal Uses

Much more extensive use of white mustard seeds and other plant parts is witnessed in Ayurveda and homeopathy as well as naturopathy, for the treatment, palliation and cure of a number of health-related ailments. These may include its role as an anti-oxidant, to eradicate free radicals from the body, as an emetic to induce vomiting to throw out any unwanted material from the body, as a diuretic to increase the flow of water from the body in the form of urine, thus helping to ameliorate high blood pressure (Table 1). It is used frequently to treat inflammatory conditions related to gout, rheumatism and arthritis (Rahman et al., 2024). On a broader note, several cardiovascular issues may be dealt with the help of mustard oil seeds, such as high blood pressure, high cholesterol level, thrombosis, etc. Diabetes and cancer are the most prominent diseases that are considered to be treated by long-term therapeutic intake of white mustard oil and seeds (Sinha et al., 2007).

Enhanced Digestion and Immune Booster

Saliva production increases up to 8 times by the consumption of white mustard, which helps to increase the metabolism and digestion process of food. By increasing the immunity and strength of the body, the anti-fungal and anti-

septic effects of the ingredients of white mustard help to improve digestion. Certain types of minerals and natural components present in white mustard as iron, magnesium, selenium and manganese, help to maintain a balanced immune system that may work against any bacterial infection or viral attack (Zhang et al., 2024).

Anti-Spasmodic Effect and Natural Decongestant

Possessing a rich amount of calcium and potassium, white mustard may help to ameliorate the muscle spasms, pains and cramps. Potassium and calcium are essential nutrients to provide strength to muscles, joints and bones (Rahman et al., 2018). White mustard oil possesses a wide range of therapeutic capacities. Massaging the affected area with the oil 2 to 3 times a day for 8 to 10 days may help to seek relief from body aches and pains (Akhtar and Khan, 2024). White mustard may help to remove congestion from the chest to provide relaxed breathing and inhalation. Gargling the mouth with mustard tea or inhaling the steam of heated mustard seeds may help to clear the mucus in the air passage, thus expelling g mucus out of the lungs and throat.

Cardiovascular Effects

Increasing the level of high-density lipoproteins (Good cholesterol) and decreasing the level of low-density lipoproteins (LDLs) helps to balance the level of cholesterol in the body. White mustard oil, being rich in polyunsaturated fats and monounsaturated fats, helps to achieve the desired cholesterol level, thereby combating heart-related ailments and diseases. Low cholesterol levels and decreased obesity help to reduce the risk of cardiovascular diseases (Das et al., 2022; Gammone et al., 2019).

Anti-Cancer Effects

White mustard extracts have demonstrated antiproliferative effects, anti-inflammatory and antioxidant activity (scavenging free radicals) on cancer cell lines. By altering signaling pathways such as MAPK (Mitogen-Activated Protein Kinases), the glucosinolates and isothiocyanates can cause cell cycle arrest and trigger apoptosis, or programmed cell death (Boscaro et al., 2018). It

Table 1. Medicinal and traditional uses of white mustard (*Sinapis alba*)

Medicinal Use	Part Used	Preparation / Form	Traditional Benefits	Cautions
External pain relief (counter-irritant)	Seeds (ground)	Mustard plaster/poultice	Stimulates blood circulation, helps relieve muscular pain, rheumatism, and lumbago	Can irritate or burn skin if left on too long (limit to 10–15 min)
Respiratory support	Seeds (ground)	Poultice on chest or back	Used to relieve congestion, coughs, and bronchitis by increasing warmth and blood flow	Avoid on broken skin; not for sensitive skin
Digestive stimulant	Seeds (whole or powdered)	Small oral doses/condiment	Improves appetite, stimulates gastric juices, aids sluggish digestion	High doses can irritate the stomach; avoid in ulcers
Laxative (mild)	Seeds (whole)	Taken with water	Acts as a mild bulk laxative by triggering intestinal movement	Not for long-term use; may cause cramping
Emetic (induces vomiting)	Seeds (powder)	Warm-water mixture (rare, historical use)	Used traditionally to induce vomiting in poisoning emergencies	Not recommended today; potentially dangerous
Topical warming agent	Seeds (ground)	Mixed with warm water	Increases local circulation, used in cold extremities	Test patch recommended to avoid burns
Anti-microbial / antiseptic	Seeds (essential oil compounds)	Infusion or paste	Mild antimicrobial effects used traditionally for minor skin issues	Not a replacement for modern antiseptics
Anti-inflammatory (mild)	Seeds	Poultice or topical application	Reduces localized swelling via increased circulation	Monitor skin for irritation

has also been scientifically demonstrated that glucosinolates can prevent cancers of the bladder, colon, and cervical regions. Due to its high glucosinolate phytochemical content, white mustard has the capacity to combat malignant cells (Das et al., 2022).

Anti-inflammatory and Antioxidant Effects

Joint conditions like rheumatoid arthritis, gout, inflammation, and other issues linked to the body's excessive citric acid levels can be lethal if treatment is not received (Aboulthana et al., 2025). White mustard is a staple of a healthy diet since it contains natural phytoconstituents like magnesium and selenium. Mustard white phenolic compounds and flavonoids, such as sinapic acid and other polyphenols, scavenge reactive oxygen species (ROS) and lessen oxidative stress in cells (Sadowska et al., 2023).

Antimicrobial / Food Preservation and Aroma Enhancer

White mustard extracts or essential oils have been researched for their potential as preservatives and for their ability to eradicate or suppress pathogenic organisms like *Salmonella*. Bacterial membranes can be disrupted by the lipophilic volatile isothiocyanates, particularly allyl isothiocyanate. Additionally, they may induce oxidative stress in microorganisms, causing ROS production to harm proteins, lipids, and DNA (Peng et al., 2014). According to one study, many *Salmonella* serovars were reduced by roughly 6 to 7 logarithmic units when white mustard essential oil (WMEO) was added at a concentration of 0.84% v/v (Porter and Monu, 2019). A tablespoon of white mustard oil swished for about a minute and later rinsed thoroughly with water may help to remove any bad aroma from the mouth. Being a natural aromatic plant, its aroma reduces breath odor, especially after seafood intake or morning fetid smell (Gammone et al., 2019).

Oral Health

According to a double-blind clinical investigation including 113 gingivitis patients, mustard extract toothpaste decreased plaque index more than a placebo, decreased bleeding on probing, and decreased *Streptococcus mutans* and *Lactobacillus* salivary load. Randomized clinical trials have examined the effects of toothpastes or oral hygiene formulations containing white mustard extract on gingivitis, plaque buildup, and the decrease in *Lactobacillus* spp. and *S. mutans* counts. Myrosinase enzyme present in mustard extract causes the breakdown of glucosinolates into isothiocyanates. These compounds cause bacterial cell membranes to rupture (increasing permeability), cytoplasmic contents to leak, disrupt cell wall synthesis, and inhibit important bacterial enzymes (by reacting with thiol groups) (Michałowski et al., 2025).

Antirheumatic Effect

According to Ayurvedic medicines, a tablespoon of Mustard powder mixed with four tablespoons of flour may be applied on the affected area as a paste for 15-20 minutes of duration. It may help to relieve the stiffness of rheumatism. A paste of coriander leaves, coriander leaf extract and White

mustard seed extract may be prepared and applied on the back of the body to relieve pain in the lower back or sometimes sciatica pain (Miękus et al., 2020).

Allergies and Asthma

Sneezing reflexes or allergies presenting in the form of sneezing may be relieved according to Ayurvedics by applying a few drops of White Mustard oil by dipping a little finger and applying in the nostril. It may be inhaled deeply. Repeat the same procedure with another nostril. This exercise may be repeated before the onset of winter on a yearly basis. Alternatively, oil may be applied on chest before sleeping to keep the chest warm (Ruan et al., 2019). Formerly, it was used as mustard plasters to treat chest colds and other such ailments due to its counter-irritant properties. Although the clinical trial-based evidences are minimal to support all the claims, a large population witnesses the use of white mustard seeds and oil for several pathological disorders.

Precautions

There is no clinical trial report yet available to support the data on the use of white mustard preparations by different means, either dermally, orally, or during any specific period. Still, there are a few distinguished features to be considered for its therapeutic uses and applications. White mustard has been used as an important culinary material for centuries. Although it has been witnessed to provide several therapeutic and non-therapeutic effects throughout the world during all eras, some precautionary measures must be adopted to avoid any severe side effects.

The adulteration of edible mustard with argemone oil results in the development of a pathological condition called dropsy. In humans, oil adulterated with argemone oil causes oxidative stress and death of red blood cells. The mechanism involves the formation of methemoglobin, a dysfunctional form of hemoglobin that is incapable of transporting oxygen, thus reducing blood oxygenation and inducing tissue hypoxemia. Antioxidant therapy was considered to be a therapeutic intervention for argemone oil toxicity (Babu et al., 2007). Erucic acid, a very long-chain monounsaturated fatty acid (22:1) present in mustard oil, also causes cardiovascular toxicity. Animals fed high levels of erucic acid develop accumulation of fat in the heart muscle (lipidosis), leading to potential dysfunction. This is reversible in some animal models when exposure is removed (Michałowski et al., 2025). Mustard seeds or oil effectiveness is accompanied by potential toxicity due to elevated contents of allyl isothiocyanate and erucic acid. Despite this, these oils are widely used across Asian countries, primarily due to their nutritional advantages outweighing the associated toxicity.

WHITE MUSTARD USE FOR BIODIESEL PRODUCTION

White mustard seeds and their powder are widely used in many parts of the world according to their taste and geographical area, either as a spice on the dining table or as a supplement in certain eateries or as an important ingredient of certain therapeutic applications in Ayurveda or naturopathy

(Ahmad et al., 2013). However, due to its irritant, hot and strong taste and odor, its use is restricted at few places, but its use outside these industries is in the production of biodiesel.

Certain characteristic properties of white mustard make it superior for use as a biodiesel, high amount of erucic acid presence in the white mustard, its ability to grow spontaneously on abandoned land or on the land under cultivation in rotation with cereal crops, its resistance to many diseases and insect pests, its ability to endure harshness of extreme weathers (Mitrović et al., 2020). Its ability to grow on multiple types of soils all adds to the use of white mustard as an alternative feedstock for the production of biodiesel (Falasca and Ulberich, 2011).

The presence of erucic acid in the white mustard seeds that limits its use for being a bit strong for human use in either food or therapeutically, is the real gemstone for its use in biodiesel production. The transesterification of erucic acid provides alkyl esters, possessing enhanced lubricant properties that serve for better engine operation (Tabtabaei et al., 2014). The biodiesel production from soybean oil and white mustard is comparable according to many researchers, estimated by the parameters as oil content and its conversion into methyl esters, but is considered minimal compared to that produced from rapeseed, palm oil, or sunflower.

CONCLUSION

White mustard can be made useful more than a condiment or a spice by exploring its contents at grass root level and taking advantage of its wonderful characteristics that may help humankind to develop alternative energy sources. The seeds of white mustard plants, as well as other parts, must be explored at large-scale research to produce biofuels by gasification, liquefaction, and pyrolysis. Overall biodiesel production process should be made possible by developing novel biodiesel production processes, including continuous reactors with improved mass transfer characteristics, integration of reaction and separation phases in a single stage and unconventional heating methods (ultrasonication and microwave irradiation).

REFERENCES

Aboulthana WM, AM El-Feky, NES Ibrahim et al., 2025. Phytochemical analysis and biological study on *Sinapis alba* L. seeds extract incorporated with metal nanoparticles, in vitro approach. *Scientific Reports* 15:13782.

Ahmad M, M Zafar, S Rashid et al., 2013. Production of methyl ester (biodiesel) from four plant species of Brassicaceae: Optimization of the transesterification process. *International journal of green energy* 10:362-69.

Akhtar MJ and SA Khan, 2024. Chemistry and biological activity of mustard oil: Therapeutic benefits and risk to healthcare. *Revista Brasileira de Farmacognosia* 34:65-79.

Babu CK, S K Khanna and M Das, 2007. Adulteration of mustard cooking oil with argemone oil: do Indian food regulatory policies and antioxidant therapy both need revisitation? *Antioxidants and Redox Signaling* 9:515-25.

Boscaro V, L Boffa, A Binello, et al., 2018. Antiproliferative, proapoptotic, antioxidant and antimicrobial effects of *Sinapis nigra* L. and *Sinapis alba* L. extracts. *Molecules* 23:3004.

Das G, OAG Tantengco, R Tundis, et al., 2022. Glucosinolates and Omega-3 fatty acids from mustard seeds: Phytochemistry and pharmacology. *Plants* 11:2290.

Ekanayake A, RJ Strife, GN Zehentbauer et al., 2016. Yellow or white mustard (*Sinapis alba* L.) oils. In *Essential oils in food preservation, flavor and safety* (pp. 857-63): Elsevier.

Ekanayake A, PH Zoutendam, RJ Strife et al., 2012. Development of white mustard (*Sinapis alba* L.) essential oil, a food preservative. *Food chemistry* 133:767-74.

Falasca S and A Ulberich, 2011. Aptitude of the lands of the semiarid zone of Argentina to cultivate non traditional species to produce biodiesel. *Biodiesel: blends, properties and applications*, in press. Nova Publishers, NY, 123:150.

Fraze MD, MJ Kim and KM Ku., 2017. Health-promoting phytochemicals from 11 mustard cultivars at baby leaf and mature stages. *Molecules* 22:1749.

Gammone MA, G Riccioni, G Parrinello et al., 2019. Omega-3 polyunsaturated fatty acids: benefits and endpoints in sport. *Nutrients* 11:46.

Grygier A, 2023. Mustard seeds as a bioactive component of food. *Food Reviews International* 39:4088-4101.

Jankowski KJ, D Załuski, and M Sokólski 2020. Canola-quality white mustard: Agronomic management and seed yield. *Industrial Crops and Products* 145:112138.

Lietzow J, 2021. Biologically active compounds in mustard seeds: A toxicological perspective. *Foods* 10:2089.

Martinović, N., Polak, T., Ulrih, N. P., and Abramović, H. (2020). Mustard seed: phenolic composition and effects on lipid oxidation in oil, oil-in-water emulsion and oleogel. *Industrial Crops and Products* 156:112851.

Michałowski K, B Górski and A Brodzikowska, 2025. The Clinical and Antibacterial Effects of a Herbal Toothpaste Containing White Mustard *Sinapis alba* Extract: A Randomized Clinical Trial. *Dentistry Journal* 13:165.

Miękus N, K Marszałek, M Podlacha et al., 2020. Health benefits of plant-derived sulfur compounds, glucosinolates, and organosulfur compounds. *Molecules* 25:3804.

Mitrović PM, OS Stamenković, I Banković-Ilić et al., 2020. White mustard (*Sinapis alba* L.) oil in biodiesel production: A review. *Frontiers in Plant Science* 11:299.

Özcan MM, N Uslu, N Yalım, et al., 2024. White mustard (*Sinapis alba* L.) seeds: the role of oven and microwave roasting on their bioactive components, antioxidant potential, fatty acids and mineral contents. *European Food Research and Technology* 250:1563-72.

Peng C, SQ Zhao, J Zhang et al., 2014. Chemical composition, antimicrobial property and microencapsulation of Mustard (*Sinapis alba*) seed essential oil by complex coacervation. *Food chemistry* 165:560-68.

Porter JA and EA Monu, 2019. Evaluating the antimicrobial efficacy of white mustard essential oil alone and in combination with thymol and carvacrol against *Salmonella*. *Journal of Food Protection* 82:2038-43.

Preedy VR, 2015. *Essential oils in food preservation, flavor and safety*: Academic press.

Rahman M, A Khatun, L Liu et al., 2018. Brassicaceae mustards: Traditional and agronomic uses in Australia and New Zealand. *Molecules* 23:231.

Rahman M, A Khatun, L Liu et al., 2024. Brassicaceae mustards: phytochemical constituents, pharmacological effects, and mechanisms of action against human disease. *International journal of molecular sciences* 25:9039.

Ropelewska E, KJ Jankowski, P Zapotoczny et al., 2018. Thermophysical and chemical properties of seeds of traditional and double low cultivars of white mustard. *Zemdirbyste-Agriculture* 105:257-64.

Ruan S, Z Wang, S Xiang et al., 2019. Mechanisms of white mustard seed (*Sinapis alba* L.) volatile oils as transdermal penetration enhancers. *Fitoterapia* 138:104195.

Sadowska U, K Jewiarz, M Kopak et al., 2023. Proximate analysis and antioxidant properties of young plants of *Sinapis alba* L. depend on the time of harvest and variety. *Applied Sciences* 13:7980.

Sinha S, JK Jha, MK Maiti, 2007. Metabolic engineering of fatty acid biosynthesis in Indian mustard (*Brassica juncea*) improves nutritional quality of seed oil. *Plant Biotechnology Reports* 1:185-97.

Tabtabaei S, DG Boocock and LL Diosady, 2014. Biodiesel feedstock from emulsions produced by aqueous processing of yellow mustard. *Journal of the American Oil Chemists' Society* 91:1269-82.

Vaughan J, 1977. A multidisciplinary study of the taxonomy and origin of Brassica crops. *BioScience* 27:35-40.

Zhang Y, J Lu, Y Liu et al., 2024. Polyphenols of brown (*Brassica juncea*) and white (*Sinapis alba*) mustard seeds: Extraction optimization, compositional analysis, antioxidant, and immunomodulatory activities. *Food Bioscience* 58:103753.