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Wheat germ oil: a comprehensive review

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Abstract

Wheat germ is a valuable by-product of the wheat milling process, represents 10-15% lipid contents with other bioactive compounds. Various wheat germ oil (WGO) recovery methods have been adopted, including mechanical pressing, solvent extraction, and supercritical fluid extraction. Some modifications reported by different experimental studies to enhance the oil yield retain the nutritional attributes of fresh oil. However, in high enzymatic activities and unsaturated fatty acids, WGO loses its nutritional significance during storage and other processing treatments that ultimately decrease the oil's shelf life. The effectual pretreatments and storage conditions for WGO have been studied to valorize and retain healthful capability fully. WGO possesses phytogenic components with distinct potent health benefits. The association between dietary lipids and life-threatening disorders has instigated an expanding research curiosity in WGO. Diverse experimental studies have proved that the WGO embraces abundant beneficial effects besides many health disorders.

Keywords: attributes; extraction; pharmacological; processing; wheat germ oil.

Practical Application: Wheat is a crucial food crop that is grown and processed in enormous quantities worldwide. Wheat germ, for example, is one of its by-products that can be utilized to make value-added products. Wheat germ oil has been discovered to be a good source of various nutritionally beneficial elements and has essential health and functional aspects. The review will aid academics in conducting additional research to improve oil processing and quality while also emphasizing its benefits. It will also assist in developing value-added products and nutraceuticals using this wheat by-product after more investigation is completed.

1 Introduction

Since ancient times, edible fats and oils occupied a substantial part of human dietary habits, as these oils/fats provide the essential fatty acids, fat-soluble vitamins, and other bioactive components. They perform essential physiological and biochemical processes in the human body (Narayanankutty et al., 2018). Wheat (*Triticum aestivum* L.) is one of the oldest known and prevalent staple foods for humans since ancient times, with 652 million tons worldwide production (Food and Agriculture Organization, 2007). The United States, India, and China are some larger producers of wheat in the world.

A single whole fruit of wheat known as "caryopsis" holds a single grain that is divided into three parts; endosperm (80-84%), bran (14-15%), and germ (2-3%). Systematically, wheat is mainly known for its significant starchy portion of endosperm. However, the germ also referred to as the embryo of the wheat grain, is the primary energy source during germination. The Germ portion separates grains during the commercial milling process from whole wheat grain (Dunford, 2009). According to the literature, the nutritional importance of wheat germ has been reported back to the 1920s because of the significant importance of bioactive compounds concentrated in the germ (Currier, 1973; Zhou & Yu, 2004). This article provides a detailed review that explores wheat germ oil, advancements in its extraction methods, and possible health-related impacts on human wellbeing.

2 Physicochemical attributes of wheat germ oil (WGO)

Most of the commodity oils, e.g., sunflower oil, canola oil, is mainly used for cooking and frying purposes because of their heat transfer properties. WGO is a speciality oil with its high nutritional profile enriched with vitamin E. WGO possesses a significant amount of policosanols (Irmak et al., 2006), phytosterols (Nyström et al., 2007), tocopherols, carotenoids (Hidalgo & Brandolini, 2008), thiamin, riboflavin, flavonoids, sterols, octacosanols, glutathione, Steryl ferulates (Kumar & Krishna, 2015) and numerous enzymes (Zhu et al., 2011) (Table 1).

The oil contents of wheat germ vary from 10-15%, depending upon the variety, extraction method, and purity. Its crude oil is dark in color with an intense flavor and odor before any processing that varies with the oxidative circumstances. Nonetheless, unwanted foreign particles must be removed without losing other nutritional compounds (Wang & Johnson, 2001). The most abundant fatty acid in WGO is linoleic acid (n-6), followed by palmitic acid, oleic acid, and linolenic acid (n-3). The unsaturated fatty acids comprised 80% of the total triglycerides of WGO. The comparison of WGO with other plant-based oils has summarized in Table 2.

3 Effect of processing on WGO quality

Various studies have documented the potential effects of pretreatment (storage, thermal, or roasting) on wheat kernels' physicochemical and bioactive components before oil extraction.

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Table 1. Compositional analysis of wheat germ oil extracted by various methods.

	Hexane-extracted	Commercially refined	$SC\text{-}CO_2$-extracted	
Fatty Acid Composition (%, w/w)				Eisenmenger & Dunford (2008)
C16:0	16.7	15.8	16.8	
C18:0	0.77	0.72	0.5	
C18:1	16.9	15.8	13.6	
C18:2 (n-6)	57.6	58.4	59.7	
C18:3 (n-3)	6.4	6.7	7.3	
C20:1	1.7	1.6	1.45	
*Phospholipid Compositions (mg/g)				Eisenmenger & Dunford (2008)
PE	3.5	1.9	ND	
PI + PA	12.1	0.6	ND	
PS	3.3	ND	ND	
PC	0.9	ND	ND	
Tocopherol and Tocotrienol Contents (mg/kg)				Dunford & Martinez (2003)
α-Tocopherol	1377	6.9	1365	
β-Tocopherol	1209	0.7	998	
β-Tocotrienol + γ-tocopherol	48	0.1	24	
δ-Tocopherol	5	ND	5	
Sterols				Eisenmenger & Dunford (2008)
Campesterol	0.67	0.63	0.61	
Stigmasterol	0.25	0.21	0.2	
b-Sitosterol	2.77	2.59	2.94	
Total phytosterol	3.7	3.05	3.75	

*PE: phosphatidylethanolamine; PI + PA: phosphatidylinositol and phosphatic acid; PS: phosphatidylserine; PC: phosphatidylcholine; ND: Not detected.

Table 2. Comparison of WGO with other plant-based oils.

Fatty acids	Plant-based oils				
	Wheat germ oil (WGO)	Pomegranate seed oil (PSO)	Rice germ oil (RGO)	Corn germ oil (CGO)	Canola germ oil (CaGO)
C14:0	-	0.51	0.05	-	-
C16:0	16.7	4.60	22	13	3.6
C18:0	0.70	0.75	1.5	1.5	2
C18:1	16.9	10.61	34.8	29.3	66
C18:2 (n-6)	57.6	6.73	40	55	16
C18:3 (n-3)	6.4	76.66	1.5	1	8
C20:0	-	-	-	0.2	0.7
C20:1	1.7	-	-	-	1.3
SFA	17.4	6	23.55	15	6.7
UFA	82.6	94	76.3	85	92.3
SFA/UFA	0.20	0.06	0.30	0.18	0.07
	Eisenmenger & Dunford (2008)	Shabbir et al. (2017)		Winkler-Moser & Breyer (2011)	Jenab et al. (2006)

SFA: Saturated fatty acid. UFA: Unsaturated fatty acid.

Wheat kernels are thermally prepared before oil extraction to coagulate the proteins, rapture the oil cells, and inactivate the lipolytic enzymes, thus enhancing oil extraction. However, as compared to direct thermal treatment, the roasting process augments the antioxidant capacity and oxidative stability of WGO by increasing the total phenolics (TPC) and Millard reactions products (MRPs) with the better sweet taste, nutty flavor, and high oil yield (Zou et al., 2018). Wheat germ is susceptible to oxidation during storage due to the presence of lipase and lipoxygenase enzymes. With the use of temperature- controlled short wave infrared (SIR) radiation system (90 °C for 20 min), the activity of LA and LOX reduced to 18-19% (Li et al., 2016). WGO undergoes oxidation under storage and unfavorable conditions due to a high concentration of polyunsaturated fatty acids (PUFAs). Various studies evaluated the different methods and parameters to augment oil's shelf life and endurance during storage. Karadeniz et al. (2018) assessed the encapsulation of WGO by various coating materials, including maltodextrin (MD), whey protein concentrate (WPC), sodium caseinate (NaCa), gum arabic (GA), chitosan (CS). The encapsulation efficiency of MA: NaCa at the ratio of 1:3 was found superior to other coating materials.

Additionally, encapsulated oil's oxidative stability and tocopherol integrity were better than the fresh WGO during 24 days storage at 15 and 45 °C. Capitani et al. (2011) observed the significant effect of storage (35 days) and temperature (27 °C and 45 °C) on the quality attributes of WGO with a substantial decrease in total tocopherol contents. However, storage and temperature have no significant effect on fatty acid contents. In literature, various studies have reported the nutritional and health-related benefits of WGO. However, only fewer studies have observed manipulating pretreatments and storage conditions to enhance the shelf life and healthy reservoir of WGO. Therefore, in this view, there is a need to conduct some experimental studies to observe how different parameters are affecting the oil quality during storage.

4 Extraction methods of WGO

Conventionally, hydraulic press, expeller press, and solvent extraction are the three normal processes used to extract oil from edible sources. While solvent extraction is thought to be the most effective method of oil extraction, it has been prohibited by the US Environmental Protection Agency because to various health-related and unacceptable environmental concerns (Fang & Moreau, 2014). Due to the limitations of traditional extraction processes, researchers unfold some new ways to extract more oxidative stable oil with improved sensorial attributes.

Accelerated/pressurized solvent extraction (ASE/PSE) methods utilize different organic/aqueous solvents at elevated temperatures and pressure to enhance extraction and reduce the extraction time. This method significantly decreases the time and solvent consumption as compared to the traditional solvent extraction method. ASP exerts no adverse effect on oil quality with no changes in the fatty acid profile (Dunford & Zhang, 2003). Temperature and the solvent type have a meaningful impact on the extraction yield, composition, and policosanols contents of WGO (Dunford et al., 2010).

The aqueous enzymatic extraction (AEE) method is considered a reliable and environment-friendly extraction process, excluding the solvent use that ultimately reduces the energy and cost needs with invigorating health concerns. AEE method also improves the nutritional quality of extracted oil, although the extracted oil is in stable cream form and requires free oil recovery (40 mL dist. water required for 8.5 g wheat germ). Nevertheless, numerous studies documented oil extraction efficiency utilizing the AEE process, although fewer studies listed the free oil recovery procedures. Fang & Moreau (2014) optimized the conditions for WGO extraction by the AEE method. Firstly, wheat kernels were pretreated at 180 °C in a hot air oven following protease and cellulase enzymes and obtained 72% emulsified oil. Later on, different enzymatic methods (Alcalase, Protex 6L, Fermgen, Protex 7L, G-zyme 999, Lysomax) and physical demulsification methods (pH adjustments, heating, and freeze-thawing) were compared for free oil recovery. The highest free oil yield (64%) was obtained by Protex 6L (*Bacillus licheniformis*) at pH 8.

The supercritical carbon dioxide (SC-CO_2) extraction method is an efficient extraction method to substitute traditional extraction methods. It is a non-toxic, economical, and non-hazardous method that extracts oil at low temperatures and eliminates solvent from the oil. Extraction was performed above the critical values of pressure and temperature of the used supercritical fluids. These circumstances develop a phenomenal solvent for the extraction of oil (Shao et al., 2008). Various investigations have reported the efficiency of the SC-CO_2 extraction process. Shao et al. (2008) observed the difference between the extraction efficiency of the SC-CO_2 and the solvent extraction method. The SC-CO_2 extraction method reduced the solvent consumption and extraction time compared to the traditional extraction method with no changes in fatty acid composition and sensory attributes. However, the overall quality of the end product was the same. Likewise, Piras et al. (2009) observed similar results while comparing the SC-CO_2 and solvent extraction method. Eisenmenger (2005) investigated the withdrawal of free fatty acids (FFA) from crude WGO through supercritical fluid fractionation (SFF) and observed it as an efficient technique for FFA's removal from both conventional and SC-CO_2 extracted oil. Analysis of the raffinate fraction (collected from the bottom of the column) showed that triglycerides retained the tocopherol contents compared to the fraction collected from the top of the column.

5 Pharmacological attributes

WGO has numerous beneficial health and nutritional outcomes because of the wide range of phytochemicals. The antioxidant potential of WGO was examined by various studies, which promoted nutritionists to explore its nutraceutical aspects further (Table 3).

Lipid oxidation is the precursor to chronic disorders such as Alzheimer's problems, cancer, rheumatoid arthritis, Parkinson's disease, AIDS, and diabetes in humans. These conditions are exacerbated and accelerated by the pleonastic deposit of free radicals (Zhong et al., 2019). Various experimental studies indicated the antioxidant capacity of WGO and found it productive against scavenging free radicals. The antioxidant ability of WGO is enlightened by building complexes with free radicals and reduced metals. Various animal studies showed that the administration of WGO enhances the level of tocopherol and other bioactive components in different organs, i.e., brain, liver, spleen, heart, kidneys, and provide shelter against the oxidation process (Field et al., 2008). WGO has been associated with physical continuance, deferred aging, and counterbalance of the various biochemical factors in rat trials (Megahed, 2011).

According to the findings of Khalifa et al. (2011), the mixture of wheat germ and grapeseed oil (200 mg/kg diet) improved liver enzymes functions, serum MDA, erythrocytes SOD, and other biochemical parameters. In an experimental study, WGO combined with alpha-tocopherol and alpha-lipoic acid was fed to a day-old male broiler at different ratios to enhance the broiler meat oxidative stability. The study revealed the supplementation of WGO with alpha-tocopherol and alpha-lipoic acid augments oxidative stability and retains the nutritional quality of broiler meat (Arshad et al., 2013). WGO also significantly reduces the TBARS and glutathione contents, inhibits oxidative damage in

Table 3. Summary of WGO effect on animal and human health.

Source	Study model system	Mechanism of activity	Outcomes	Authors
Lutein and WGO	Male albino mice	↓ polar lipids and intestinal lipase activity	Higher plasma lutein levels, decrease in plasma malondialdehyde (MDA) levels	Gorusupudi & Baskaran (2013)
WGO	Female albino rats	Stimulates estrogen secretion and inhibits oxidative damage	Significant increase in antioxidant enzymes	Anwar & Mohamed (2015)
WGO	Male Balb/C mice	-	Reduce the oxidative stress	Karabacak et al. (2011)
WGO	Human monocytic THP-1 cells	Inhibition of cyclooxygenase activity	Anti-inflammatory effect	Janthachotikun (2015)
WGO	Male albino mice	-	Improve metabolic functions by decreasing lipid peroxidation and increasing antioxidant status	Shedid (2008)
WGO and ginseng	Male adult Wistar albino rats	Altered enzyme activity, decreased DNA repair, and impaired utilization of oxygen, lipid peroxidation and protein oxidation.	Significantly less severe damage and remarkable improvement in antioxidant enzymes	Abdel Fattah et al. (2011)

hepatic and renal tissues, and provokes the estrogen secretion associated with bioactive components (policosanol, specially octacosanol) (Anwar & Mohamed, 2015).

WGO can be used as a good food additive against pesticide intoxication, as supported by some studies. In an experimental study, the antioxidant effect of WGO (1.5 mL/kg.bw/day) was investigated against coumaphos (pesticide) intoxication and the harmful effects of oxidative stress. Oxidative stress markers showed the ameliorated outcomes of WGO to reduce the detrimental effects induced by coumaphos administration. Because of the inclusion of bioactive components, such as highly unsaturated fatty acids, tocopherols, and phytosterols, WGO causes intoxication (Karabacak et al., 2011). The addition of nitrate to WGO compensated for the anomalies in liver enzymes (AST, ALT, ALP) and butyrylcholinesterase (BChE) levels in hepatic tissues caused by sodium nitrate intake (Mohamed & Anwar, 2010).

Mohamed et al. (2005) investigated the efficiency of WGO against acute and chronic inflammation, and a dose-dependent pattern reduction in inflammation was observed. Policosanol, known as the chief bioactive component of WGO and its consumption at 5-20 mg/day, is effective in lowering low-density lipoprotein (LDL) by 21-29%, total cholesterol by 17-21%, and improving high-density lipoprotein (HDL) by 8-15% (Gouni-Berthold & Berthold, 2002). WGO administration was efficacious against oxidative stress and platelet formation when investigated in hypercholesterolemic patients in a double-blinded study (Alessandri et al., 2006). WGO treated rats significantly reversed the scopolamine-induced deficit of spatial and non-spatial working memory impairment in the T maze alternation task and object recognition test. WGO-treated rats showed a significant increase in GSH to a level similar to that observed in the donepezil group. It showed a substantial decrease in cholinesterase activity as compared to scopolamine group and significantly elevated brain TNF-a content when compared to donepezil group) (El-Marasy et al., 2012). Supplementation of WGO (3 mL/kg/dose) has a significant radio-protective effect in Wistar albino rats when rats are exposed to radiation at 0.564 Gry/min in an experiment. Results showed that WGO protected the cellular systems from the harmful effect of radiation. WGO possesses natural radio-protectors that can scavenge the free radicals from the system and induce radio-protective effects without toxicity (Barakat et al., 2011).

WGO has been linked to an increase in the bioavailability and bioactivity of lutein in mice compared to groundnut oil (GNO). Lutein is a xanthophyll carotenoid that significantly delays the risks associated with degenerative and nutritional disorders. The findings suggested that the WGO group had significantly higher plasma and liver lutein levels and lower plasma malondialdehyde (MDA) levels than the GNO group. The results support the higher bioactivity and bioavailability of lutein in the presence of WGO. The improved activity may attribute to the more elevated polar lipids and intestinal lipase activity in the WGO group (Gorusupudi & Baskaran, 2013). WGO is one of the best substitutes to replace and overcome fish oil in aquaculture to feed marine fish because of its enriched physiological components. Baoshan et al. (2019) replaced the fish oil with WGO at different ratios and observed effects on juvenile hybrid grouper's growth, fat deposition, and fat metabolic enzymes. There is no significant difference observed in growth parameters (weight gain and specific growth rate, feed conversion ratio), body composition, and lipid enzymes (hepatopancreas lipoprotein and hepatic lipase, fatty acid synthase) in all diet groups. There is an elevated level of the viserosomatic index and mesenteric fat ratios observed in the WGO group. According to the study, dietary fish oil (71%) can substitute with 12% WGO in the marine fish diet.

6 Utilization of wheat germ oil (WGO)

The WGO is a unique commodity used for nutritional purposes compared with other standard plant oils, such as canola oil, sunflower oil, etc. The other conventional oil used in cooking, which has excellent heat transfer properties and a good mouthfeel. There is a broad range of WGO applications from toiletries, cosmetics, pharmaceuticals to food products.

Natural plant oils have been used in various bakery products to enhance the stability and quality parameters of the final product. The efficiency of WGO has been investigated by multiple studies to review its suitable utilization in numerous products. Debonne et al. (2018) observed the impact of WGO as compared to other plant oils (thyme oil, cumin seed oil, and blackcurrant oil) on the technological quality and antimicrobial activity in bread. According to the results, WGO enhanced the bread shelf life up to 33% and improved the overall technical quality, including kneading properties, water absorption, and dough consistency.

The infusion of natural ingredients/essential oils in WGO is an ingenious strategy that is gaining importance day by day, even though WGO maintains a broader spectrum of biological activities such as anti-oxidative effect, cell proliferation, and so on. Gumus et al. (2015) infused the *Calendula* flower in WGO and observed the phytochemicals contents and biological impact of infused oil on live cells through various *in-vitro* analyses. Infused WGO showed significantly better results through biological activity (radio-protective activity, cytotoxicity, cell-based antioxidant activity, wound healing) than plain oil. The prepared formulation can be a promising ingredient as a food supplement and in cosmetic products with chemotherapeutic attributes.

The prevalence of liver ailments is growing drastically globally, and its appropriate treatment is imperative to reduce the risks associated with chronic liver diseases. In developing drugs related to liver diseases, WGO is a promising ingredient that possesses potent antioxidant properties to embellish the endogenous antioxidant defense system. Elmotasem et al. (2018) developed water in oil (W/O) emulsion hepatoprotective drug (Caffeine) with WGO and stabilized with synthesized magnesium oxide nanoparticles (MgO NPs). The developed drug had a powerful hepatoprotective effect, as evidenced by inflammatory markers, oxidative stress parameters, and a histopathological review. It could be an economical approach to reduce the multiple therapies and deliver a safe level of major drug release in the body without burst release and lower the subsequent threatening blood spikes. WGO is also known as a food supplement for sport-persons to improve fitness and stamina. Policosanol, the critical ingredient of WGO, is also used in anti-fatigue drug formulations. WGO is also the ingredient in the cosmetic formulation in 0.5-50% concentration depending upon its application (Dunford, 2009).

7 Future prospective

This review presented the latest information on wheat germ oil composition, extraction, and health-promoting benefits. Considering the excellent nutritional demeanor of wheat germ oil, today, researchers working beyond its conventional uses just as economic amalgamation to animal feeds. The advancement of oil extraction techniques allows for the full recovery of bioactive molecules from fresh oil. The improvement in processing methods and oil stabilization techniques is the key factor to extend the shelf life of WGO to expand its share with other edible oils in the market. Comprehensive research is required to evaluate the impacts of WGO and its functional components of policosanols on ailment aversion and treatment at a substantial scale through animal studies and clinical examinations, including different ethnic gatherings and subjects with various wellbeing histories.

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References

Abdel Fattah, S. M., Fahim, T. M., & El-Fatih, N. M. (2011). Prophylactic role of combined treatment with wheat germ oil and ginseng against radiation injury in male rats. *The Egyptian Journal Of Hospital Medicine*, 45(1), 403-415. http://dx.doi.org/10.21608/ejhm.2011.16367.

Alessandri, C., Pignatelli, P., Loffredo, L., Lenti, L., Del Ben, M., Carnevale, R., Perrone, A., Ferro, D., Angelico, F., & Violi, F. (2006). Alpha-linolenic acid-rich wheat germ oil decreases oxidative stress and CD40 ligand in patients with mild hypercholesterolemia. *Arteriosclerosis, Thrombosis, and Vascular Biology*, 26(11), 2577-2578. http://dx.doi.org/10.1161/01.ATV.0000242795.08322.fb. PMid:17053175.

Anwar, M., & Mohamed, N. (2015). Amelioration of liver and kidney functions disorders induced by sodium nitrate in rats using wheat germ oil. *Journal of Radiation Research and Applied Sciences*, 8(1), 77-83. http://dx.doi.org/10.1016/j.jrras.2014.11.004.

Arshad, M. S., Anjum, F. M., Khan, M. I., Shahid, M., Akhtar, S., & Sohaib, M. (2013). Wheat germ oil enrichment in broiler feed with α-lipoic acid to enhance the antioxidant potential and lipid stability of meat. *Lipids in Health and Disease*, 12(1), 164. http://dx.doi.org/10.1186/1476-511X-12-164. PMid:24499336.

Baoshan, L., Jiying, W., Yu, H., Tiantian, H., Shixin, W., BingShan, H., & Yongzhi, S. (2019). Effects of replacing fish oil with wheat germ oil on growth, fat deposition, serum biochemical indices and lipid metabolic enzyme of juvenile hybrid grouper (*Epinephelus fuscoguttatus*♀× *Epinephelus lanceolatus*♂). *Aquaculture*, 505, 54-62. http://dx.doi.org/10.1016/j.aquaculture.2019.02.037.

Barakat, I. A., Abbas, O. A., Ayad, S., & Hassan, A. M. (2011). Evaluation of radio protective effects of wheat germ oil in male rats. *The Journal of American Science*, 7, 664-673.

Capitani, M., Mateo, C., & Nolasco, S. (2011). Effect of temperature and storage time of wheat germ on the oil tocopherol concentration. *Brazilian Journal of Chemical Engineering*, 28(2), 243-250. http://dx.doi.org/10.1590/S0104-66322011000200008.

Currier, T. K. (1973). Physiological effects of wheat germ oil on humans in exercise. *Physical Therapy*, 53(2), 222. http://dx.doi.org/10.1093/ptj/53.2.222a.

Debonne, E., De Leyn, I., Verwaeren, J., Moens, S., Devlieghere, F., Eeckhout, M., & Van Bockstaele, F. (2018). The influence of natural oils of blackcurrant, black cumin seed, thyme and wheat germ on dough and bread technological and microbiological quality. *LWT*, 93, 212-219. http://dx.doi.org/10.1016/j.lwt.2018.03.041.

Dunford, N. T. (2009). Wheat germ oil. In R. A. Moreau & A. Kamal-Eldin (Eds.), *Gourmet and health-promoting specialty oils* (pp. 359-376). Champaign: Elsevier. http://dx.doi.org/10.1016/B978-1-893997-97-4.50019-X.

Dunford, N. T., & Martinez, J. (2003). Nutritional components of supercritical carbon dioxide extracted wheat germ oil. In *Proceedings of the 6th International Symposium on Supercritical Fluids* (pp. 273-278). Nancy: Institut National Polytechnique de Lorraine,.

Dunford, N. T., & Zhang, M. (2003). Pressurized solvent extraction of wheat germ oil. *Food Research International*, 36(9-10), 905-909. http://dx.doi.org/10.1016/S0963-9969(03)00099-1.

Dunford, N. T., Irmak, S., & Jonnala, R. (2010). Pressurized solvent extraction of policosanol from wheat straw, germ and bran. *Food Chemistry*, 119(3), 1246-1249. http://dx.doi.org/10.1016/j.foodchem.2009.07.039.

Eisenmenger, M. J. (2005). *Supercritical fluid extraction, fractionation, and characterization of wheat germ oil*. Stillwater: Oklahoma State University.

Eisenmenger, M., & Dunford, N. T. (2008). Bioactive components of commercial and supercritical carbon dioxide processed wheat germ oil. *Journal of the American Oil Chemists' Society*, 85(1), 55-61. http://dx.doi.org/10.1007/s11746-007-1163-0.

El-Marasy, S. A., El-Shenawy, S. M., El-Khatib, A. S., El-Shabrawy, O. A., & Kenawy, S. A. (2012). Effect of Nigella sativa and wheat germ oils on scopolamine-induced memory impairment in rats. *Bulletin of Faculty of Pharmacy, Cairo University*, 50(2), 81-88. http://dx.doi.org/10.1016/j.bfopcu.2012.05.001.

Elmotasem, H., Farag, H. K., & Salama, A. A. (2018). In vitro and in vivo evaluation of an oral sustained release hepatoprotective caffeine loaded w/o Pickering emulsion formula–Containing wheat germ oil and stabilized by magnesium oxide nanoparticles. *International Journal of Pharmaceutics*, 547(1-2), 83-96. http://dx.doi.org/10.1016/j.ijpharm.2018.05.038. PMid:29777765.

Fang, X., & Moreau, R. A. (2014). Extraction and demulsification of oil from wheat germ, barley germ, and rice bran using an aqueous enzymatic method. *Journal of the American Oil Chemists' Society*, 91(7), 1261-1268. http://dx.doi.org/10.1007/s11746-014-2467-5.

Field, R., Verghese, M., Walker, L., Panala, V., Shackelfo, L., & Boateng, J. (2008). Feeding wheat germ meal and wheat germ oil reduced azoxymethane-induced aberrant crypt foci in fisher 344 male rats. *International Journal of Cancer Research*, 4(4), 127-136. http://dx.doi.org/10.3923/ijcr.2008.127.136.

Food and Agriculture Organization – FAO, Codex Alimentarius Commission. (2007). *Procedural manual.* Rome: FAO.

Gorusupudi, A., & Baskaran, V. (2013). Wheat germ oil: a potential facilitator to improve lutein bioavailability in mice. *Nutrition*, 29(5), 790-795. http://dx.doi.org/10.1016/j.nut.2012.11.003. PMid:23352176.

Gouni-Berthold, I., & Berthold, H. K. (2002). Policosanol: clinical pharmacology and therapeutic significance of a new lipid-lowering agent. *American Heart Journal*, 143(2), 356-365. http://dx.doi.org/10.1067/mhj.2002.119997. PMid:11835043.

Gumus, Z. P., Guler, E., Demir, B., Barlas, F. B., Yavuz, M., Colpankan, D., Senisik, A. M., Teksoz, S., Unak, P., Coskunol, H., & Timur, S. (2015). Herbal infusions of black seed and wheat germ oil: their chemical profiles, in vitro bio-investigations and effective formulations as phyto-nanoemulsions. *Colloids and Surfaces. B, Biointerfaces*, 133, 73-80. http://dx.doi.org/10.1016/j.colsurfb.2015.05.044. PMid:26087391.

Hidalgo, A., & Brandolini, A. (2008). Kinetics of carotenoids degradation during the storage of einkorn (*Triticum monococcum* L. ssp. *monococcum*) and bread wheat (*Triticum aestivum* L. ssp. aestivum) flours. *Journal of Agricultural and Food Chemistry*, 56(23), 11300-11305. http://dx.doi.org/10.1021/jf802448t. PMid:18998697.

Irmak, S., Dunford, N. T., & Milligan, J. (2006). Policosanol contents of beeswax, sugar cane and wheat extracts. *Food Chemistry*, 95(2), 312-318. http://dx.doi.org/10.1016/j.foodchem.2005.01.009.

Janthachotikun, S. (2015). *Anti-inflammatory effects of wheat germ oil on lipopolysaccharide-activated human monocytic THP-1 cells* (Doctoral dissertation). Stillwater: Oklahoma State University.

Jenab, E., Rezaei, K., & Emam-Djomeh, Z. (2006). Canola oil extracted by supercritical carbon dioxide and a commercial organic solvent. *European Journal of Lipid Science and Technology*, 108(6), 488-492.

Karabacak, M., Kanbur, M., Eraslan, G., & Sarıca, Z. S. (2011). The antioxidant effect of wheat germ oil on subchronic coumaphos exposure in mice. *Ecotoxicology and Environmental Safety*, 74(7), 2119-2125. http://dx.doi.org/10.1016/j.ecoenv.2011.07.002. PMid:21851982.

Karadeniz, M., Sahin, S., & Sumnu, G. (2018). Enhancement of storage stability of wheat germ oil by encapsulation. *Industrial Crops and Products*, 114, 14-18. http://dx.doi.org/10.1016/j.indcrop.2018.01.068.

Khalifa, F. K., Khalil, F. A., Barakat, H. A., & Hassan, M. M. (2011). Protective role of wheat germ and grape seed oils in chlorpyrifos-induced oxidative stress, biochemical and histological alterations in liver of rats. *Australian Journal of Basic and Applied Sciences*, 5, 54-66.

Kumar, G. S., & Krishna, A. G. (2015). Studies on the nutraceuticals composition of wheat derived oils wheat bran oil and wheat germ oil. *Journal of Food Science and Technology*, 52(2), 1145-1151. http://dx.doi.org/10.1007/s13197-013-1119-3. PMid:25694731.

Li, B., Zhao, L., Chen, H., Sun, D., Deng, B., Li, J., Liu, Y., & Wang, F. (2016). Inactivation of lipase and lipoxygenase of wheat germ with temperature-controlled short wave infrared radiation and its effect on storage stability and quality of wheat germ oil. *PLoS One*, 11(12), e0167330. http://dx.doi.org/10.1371/journal.pone.0167330. PMid:27936025.

Megahed, M. G. (2011). Study on stability of wheat germ oil and lipase activity of wheat germ during periodical storage. *Agriculture and Biology Journal of North America*, 2(1), 163-168. http://dx.doi.org/10.5251/abjna.2011.2.1.163.168.

Mohamed, D. A., Ismael, A. I., & Ibrahim, A. R. (2005). Studying the anti-inflammatory and biochemical effects of wheat germ oil. *Deutsche Lebensmittel-Rundschau*, 101(2), 66-72.

Mohamed, N., & Anwar, M. (2010). Efficacy of wheat germ oil in counteracting of some biochemical hazards induced by sodium nitrate in rats. *Isotope and Radiation Research*, 42, 211-227.

Narayanankutty, A., Palliyil, D. M., Kuruvilla, K., & Raghavamenon, A. C. (2018). Virgin coconut oil reverses hepatic steatosis by restoring redox homeostasis and lipid metabolism in male Wistar rats. *Journal of the Science of Food and Agriculture*, 98(5), 1757-1764. http://dx.doi.org/10.1002/jsfa.8650. PMid:28862329.

Nyström, L., Paasonen, A., Lampi, A.-M., & Piironen, V. (2007). Total plant sterols, steryl ferulates and steryl glycosides in milling fractions of wheat and rye. *Journal of Cereal Science*, 45(1), 106-115. http://dx.doi.org/10.1016/j.jcs.2006.08.003.

Piras, A., Rosa, A., Falconieri, D., Porcedda, S., Dessì, M., & Marongiu, B. (2009). Extraction of oil from wheat germ by supercritical CO_2. *Molecules*, 14(7), 2573-2581. http://dx.doi.org/10.3390/molecules14072573. PMid:19633624.

Shabbir, M. A., Khan, M. R., Saeed, M., Pasha, I., Khalil, A. A., & Siraj, N. (2017). Punicic acid: a striking health substance to combat metabolic syndromes in humans. *Lipids in Health and Disease*, 16(1), 99. http://dx.doi.org/10.1186/s12944-017-0489-3. PMid:28558700.

Shao, P., Sun, P., & Ying, Y. (2008). Response surface optimization of wheat germ oil yield by supercritical carbon dioxide extraction. *Food and Bioproducts Processing*, 86(3), 227-231. http://dx.doi.org/10.1016/j.fbp.2007.04.001.

Shedid, S. M. E. (2008). *Role of wheat germ oil in radiation-induced oxidative stress and alteration in energy metabolism in rats* (Thesis). Helwan: Helwan University.

Wang, T., & Johnson, L. A. (2001). Refining high-free fatty acid wheat germ oil. *Journal of the American Oil Chemists' Society*, 78(1), 71-76. http://dx.doi.org/10.1007/s11746-001-0222-2.

Winkler-Moser, J. K., & Breyer, L. (2011). Composition and oxidative stability of crude oil extracts of corn germ and distillers grains. *Industrial Crops and Products*, 33(3), 572-578. http://dx.doi.org/10.1016/j.indcrop.2010.12.013.

Zhong, S., Li, L., Shen, X., Li, Q., Xu, W., Wang, X., Tao, Y., & Yin, H. (2019). An update on lipid oxidation and inflammation in cardiovascular diseases. *Free Radical Biology & Medicine*, 144, 266-278. http://dx.doi.org/10.1016/j.freeradbiomed.2019.03.036. PMid:30946962.

Zhou, K., & Yu, L. (2004). Effects of extraction solvent on wheat bran antioxidant activity estimation. *LWT-Food. Sciences et Techniques (Paris)*, 37, 717-721.

Zhu, K.-X., Lian, C.-X., Guo, X.-N., Peng, W., & Zhou, H.-M. (2011). Antioxidant activities and total phenolic contents of various extracts from defatted wheat germ. *Food Chemistry*, 126(3), 1122-1126. http://dx.doi.org/10.1016/j.foodchem.2010.11.144.

Zou, Y., Gao, Y., He, H., & Yang, T. (2018). Effect of roasting on physicochemical properties, antioxidant capacity, and oxidative stability of wheat germ oil. *LWT*, 90, 246-253. http://dx.doi.org/10.1016/j.lwt.2017.12.038.