

Assessment of sesame (*Sesamum indicum* L.) cake as a source of high-added value substances: from waste to health

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Abstract The risk of exhaustion of natural resources and raw materials have given rise to emerging trends such as recycling of food waste. From the economical and ecological points of view, conversion of biowaste to high added value compounds has been getting great attention among the science and commercial entities. Due to their high-added value phytochemicals, agricultural and food residues have been a great significant to the researchers around the world. This study focuses on the valorisation of cake derived from sesame oil processing. If the very valuable non-nutrient phytochemicals in sesame cake are not evaluated properly, they would be consumed as just animal feed or fertilizers. They might be employed as antiaging (in pharmaceutical products), or free radical scavenger (in dietary supplements), or preservative additive against lipid oxidation (in fat containing food products). This review article aims to present pharmacological and therapeutic effects of sesame cake extract by pointing out its application in pharmaceutical, cosmetic and food industries.

Keywords Sesame cake · Biowaste · Phytochemicals · High-added value chemicals · Natural additives · Natural preservatives

Abbreviations

BHA	Butylated hydroxyanisole
BHT	Butylated hydroxytoluene
CE	Conventional extraction
DPPH	2,2-Diphenyl-1-picryl hydrazyl
DW	Dry weight
FRAP	Ferric reducing/antioxidant power
GAE	Gallic acid equivalent
HVED	High voltage electrical discharges
QE	Quercetin equivalent
TBHQ	Tertiary butylhydroquinone
Pb	Lead
PEF	Pulsed electric fields
IR	Infrared spectroscopy
NMR	Nuclear magnetic resonance
MS	Mass spectrometry
SE	Sesamin equivalent
UAE	Ultrasound-assisted extraction
WHO	World Health Organization

Introduction

Natural plant extracts are complex mixtures obtained from fruits, leaves, flowers, roots, resins and seeds of a fresh or dried plant by various methods. They are high value-added products which are growing continuously in America, Europe and the Far East. According to a study conducted by the WHO in 91 countries, the total

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amount of medicinal plants used for medical treatment is around 20,000. It is recorded that about 500 of these have been made. Furthermore, few of the plants used for different purposes are registered in pharmacopoeias (codex). The number of plants registered in Turkish codex is around 140. However, the number of plants used for medical purposes among the population is very high (Mehlika Benli 2005). The developed countries of the world are especially oriented towards herbal resources. A significant proportion of medicines used in medical treatment constitute drugs of natural origin. The rate of natural product utilization is 60% in developed countries whereas 4% in developing countries (Tibbi ve Aromatik Bitkiler 2015). The methods for increasing the shelf-life of food products, which were found after many experiences since ancient times include also herbal mixtures as effective antioxidant additives. The therapeutic properties of plants used for nutrition were discovered later (Vinatoru 2001). Beneficial effects of natural plant extracts have been understood by chance and/or by testing out the curiosity. Over the years, it has been come out that different plants are remedies for several sufferings. Phytochemicals (such as phenolic compounds, alkaloids, steroids, flavonoids carotenoids, tocopherols, pigments and vitamins) present in plant materials play the prominent role for the health benefits of the natural resource (Bodoira et al. 2017). Therefore, determination of phytochemicals in plant extracts is of great importance owing to their antioxidant and antimicrobial activities due to increasing awareness of healthy nutrition and understanding of the toxic effects of synthetic additives in recent years (Şahin et al. 2017a). Another important detail that needs to be addressed here is that this concern for chemical antioxidants is not only about food, but also for cosmetic and pharmaceutical industries as a replacement for synthetic protective additives or active constituents in dermatological formulations. Hence, these three sectors have come together to focus on products known as “functional food”, “food supplements” and “nutraceuticals” (Peschel et al. 2006).

Valorisation of agro-industrial wastes are of great interest due to their phytoconstituents with free radical scavenging activities for both ecological and economical reasons. Recently, recycling of seeds have been very popular as well as leaves, peels and pomaces (Peschel et al. 2007). Apart from seed wastes derived from fruit processing, those obtained from oil crops

possess a great variety of bioactive substance with so many medical properties (Matth Us 2002). Oilseed cakes, also known as pressing residuals are rich in major bioactive ingredients, remained from oil processing, including mainly polar antioxidants as well as lipophilic phytochemicals.

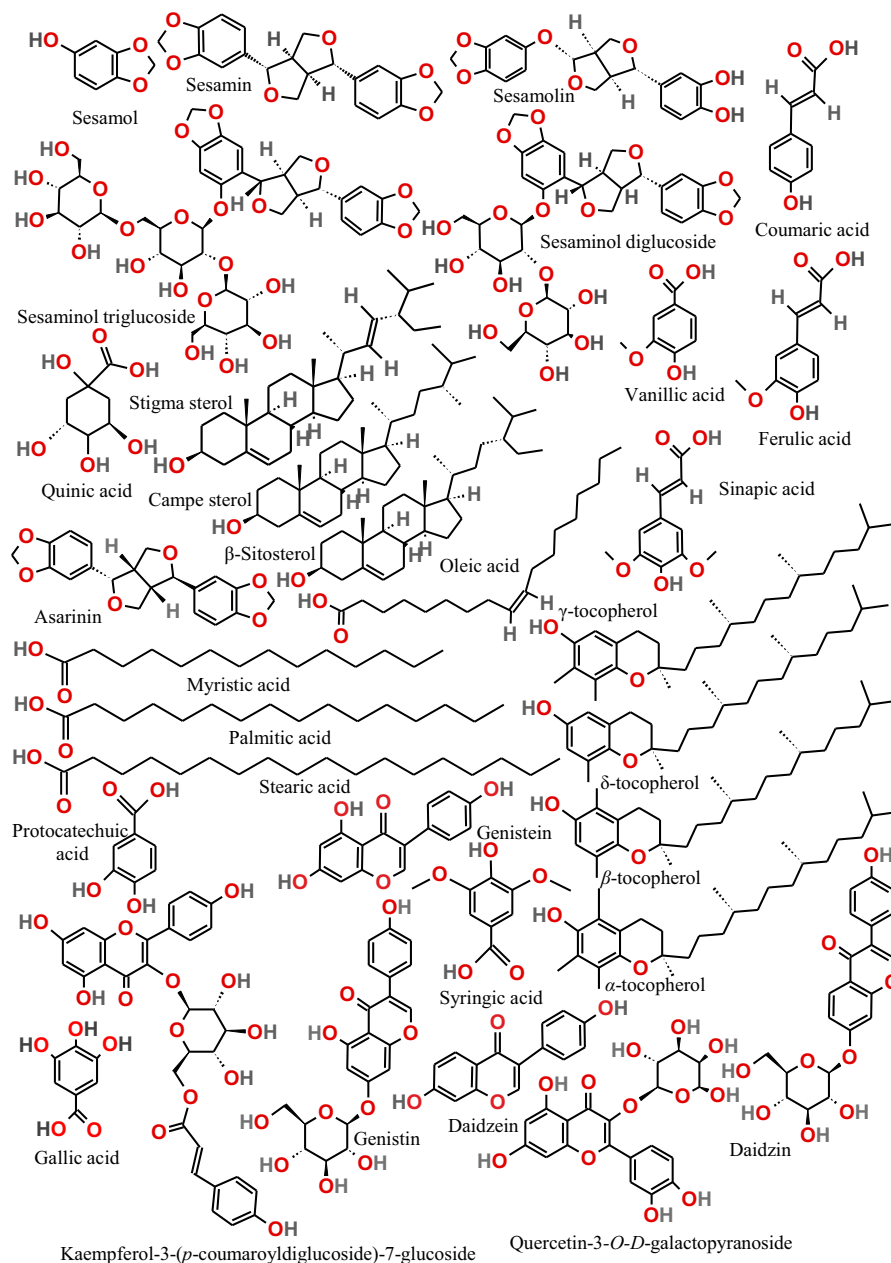
As far as we know, there is no comprehensive literature review on the waste of sesame crop, even though we encountered with few review articles on sesame seed and oil (Nagendra Prasad et al. 2012; Pathak et al. 2014). As a significant oilseed crop, sesame (*Sesamum indicum* L.) cake has been investigated thoroughly with respect to its high-added value compounds. Although this biomass has diverse bioactive substances, it is generally utilized as animal feed, fertilizer or discarded in its production areas (Mohdaly et al. 2013).

Sesame (*Sesamum indicum* L.) crop

Sesame (*Sesamum indicum* L.) is an ancient oilseed crop, coming from Pedaliaceae family (Wang et al. 2012; Zeb et al. 2017). Table 1 presents the taxonomic classification of sesame plant (Classification/USDA PLANTS 2018). The relevant plant crop has a small, oval and flat seed with diverse colors (black, white, grey, yellow, brown and red) depending on the cultivar (Nagendra Prasad et al. 2012). This oilseed crop is cultivated on 7.54 million hectares with 3.34 million tones of production on earth (Singh et al. 2014;

Table 1 Taxonomic classification of sesame crop up to the Kingdom

Kingdom	Plants
Subkingdom	Vascular plants
Superdivision	Seed plants
Division	Flowering plants
Class	Dicotyledons
Subclass	Asteridae
Order	Scrophulariales
Family	Sesame family
Genus	<i>Sesamum</i> L.
Species	<i>Sesamum alatum</i> Thonn. <i>Sesamum orientale</i> L. <i>Sesamum radiatum</i> Schumach.

Fig. 1 Phytochemical profile of sesame seed

Raikwar and Srivastva 2013). When looking at the distribution of the crop, it seems to be located in generally tropical and subtropical regions (Zerihun 2013). Almost 70% of the world crop belongs to India, China, Ethiopia, Pakistan, Myanmar, Nigeria, Sudan, Paraguay, Uganda and Tanzania (Reshma et al. 2010; Wang et al. 2012; Zerihun 2013; Dar et al. 2015). India is the first producer, accounting for almost 27% of total production and 40% cultivation area of the world (Zerihun 2013; Singh et al. 2014). Due to its very

valuable phytochemical content, it is one of the most resistant vegetable oil to oxidative rancidity. Therefore, it is also known as *queen of the oilseed crops* (Zeb et al. 2017). This highly nutritional and therapeutic preciousness is mostly attributable to the related phytochemicals with antioxidant, antimicrobial, anti-inflammatory, hypo-cholesterolemic, anticarcinogenic and antiproliferative activities (Aued-Pimentel et al. 2006; Moazzami et al. 2006; Schwertner and Rios 2012; Wu et al. 2016; Zeb et al. 2017). Figure 1

Table 2 Proximate composition of the sesame cake depending on the relevant references

Proximate compositions (%)	Sunil et al. (2015)	Reshma et al. (2013)	Esmailzadeh Kenari et al. (2014)	Nascimento et al. (2012)	Nagendra Prasad et al. (2012)
Moisture	9.2 ± 0.33	0.25 ± 0.04	7.92	8.1 ± 0.1	5
Fat	9.3 ± 0.14	0.40 ± 0.06	27.83	11.2 ± 0.2	48
Ash	8.9 ± 0.16	11.87 ± 1.39	5.27	8.6 ± 0.0	4
Protein	34.0 ± 0.22	31.02 ± 2.57	30.56	35.0 ± 0.3	16.96
Fiber	8.2 ± 0.08	–	6.22	22.7 ± 0.0	N/A
Carbohydrates	30.4	56.47 ± 5.61	28.14	14.4	26.04

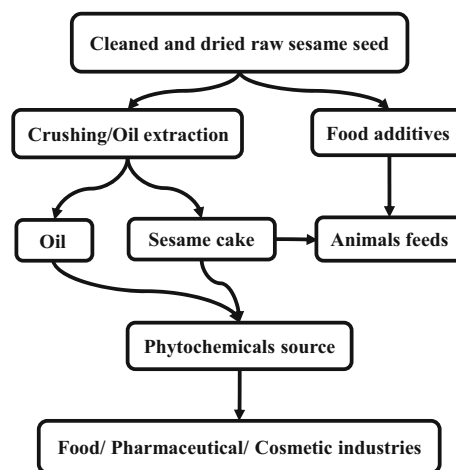
Table 3 Mineral composition of the sesame cake depending on the relevant references

Mineral compositions (mg/100 g)	Sunil et al. (2015)	Nagendra Prasad et al. (2012)
Iron (Fe)	55.6 ± 0.01	14.55
Zinc (Zn)	13.0 ± 0.05	10.23
Sodium (Na)	23.3 ± 0.22	39
Potassium (P)	117.0 ± 0.04	406
Calcium (Ca)	560.9 ± 0.06	153

demonstrates the phytochemical ingredients of sesame crop regarding its seed and oil (Aued-Pimentel et al. 2006; El Khier et al. 2008; Reshma et al. 2010; Schwertner and Rios 2012; Wang et al. 2012; Gornas et al. 2014; Area et al. 2015; Dar et al. 2015; Wu et al. 2016; Zeb et al. 2017).

Sesame cake

The annual world production of sesame seed contains is approximately 50% of oil. The press cake remaining after extraction of the oil includes almost 30% of protein (Table 2). Generally, this waste of sesame oil industry is utilized as animal feed or fertilizer in its production areas (Suja et al. 2005a). The waste by-product is also rich in minerals as seen in Table 3. On the other hand, its health benefits are ascribable to its phytochemicals, which possess free radical scavenging activities. The related medical properties of sesame cake have been verified by several researchers through in vitro tests such as β -carotene bleaching, linoleic acid emulsion system/thiocyanate, superoxide scavenging, DPPH radical scavenging, ABTS radical scavenging and FRAP methods (Suja et al. 2005a, b; Mohdaly et al. 2010; Esmailzadeh Kenari et al. 2014). Therefore, valorisation of this cheap and easily

**Fig. 2** Summary of the valorisation of sesame cake from waste to health

available residue is social, economic and ecological value. Figure 2 summarizes the evaluation process of the biowaste from harvesting of the crop to its potential applications.

High-added value phytochemicals in sesame cake

Sesame oil is known to be one of the most qualitative and stable vegetable oil with respect to both nutrition

and shelf-life (Nagendra Prasad et al. 2012). Its resistance to oxidation is mostly attributable to its natural antioxidants such as sesamol, sesamol and sesamin. Furthermore, its easily available waste still contains phenolic, flavonoid and flavonol compounds after extraction of oil from the sesame seed (Mohdaly et al. 2013). Suja et al. (2005a) identified the polar sesamol and several lignans in sesame cake extract obtained by methanol. According to the HPLC chromatogram, methanol extract included sesamol, sesamin, sesamol, sesaminol diglucoside and sesaminol triglucoside, showing highly antioxidant activity comparing to that of BHT. Moreover, the purified extract had higher quantity of total lignans than oil. In order to identify the same phytochemicals, the same research group used also novel characterization techniques such as IR, NMR and MS (Suja et al. 2005b). Bigoniya et al. (2012) also qualified and quantified sesamol and sesamin, by showing their health benefits against obesity. Sarkis et al. (2014) found sesaminol triglucoside as the major compound of the cake including sesamol, sesamin and other lignan glucosides.

Sesamin, sesamol, sesamol and other minor lignans mentioned above are known as sesame lignans. Those phytochemicals have vital pharmacological effects such as lowering the level of blood cholesterol, decreasing the oxidative stress, having anticancer, antiinflammatory and antihypertensive activities (Dar and Arumugam 2013). Recent studies on therapeutic effects of the relevant main phytochemicals are listed under each subheading.

Sesamin

Sesamin is one of the major lignan compounds of sesame seed and its cake. It is a type of lignan, known as furofuran (Dar and Arumugam 2013). Molecular weight and formula are 354.35 g/mol and $C_{20}H_{18}O_6$ as shown in Fig. 3. Sesamin possesses various therapeutic features. Papadopoulos et al. (2016) proved its free

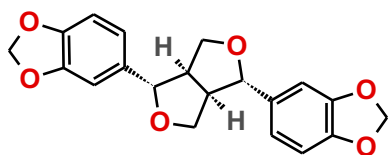


Fig. 3 Molecular structure of sesamin

radical scavenging activity in vivo besides several in vitro testing of bioactivity. Akl et al. (2013) reported sesamin together with γ -tocotrienol had anticancer activity against breast cancer depending on the findings of cytostaticity on mouse and human breast cancer cells. Its chemopreventive and anticancer effects were also revealed by both in vitro and in vivo studies by demonstrating cytotoxicity against cancer cells (Saeed et al. 2014). Liang et al. (2015) indicated its lowering the cholesterol level by displaying its effect on the cholesterol absorption pathway. It has been also a cure for hair loss and canities as an alternative medicine, and has been suggested as an active ingredient in hair cosmetic formulations (Manosroi et al. 2015). The findings of Takada et al. (2015) demonstrated that sesamin inhibited the decrease in exercise capacity of high fat diet-induced diabetic mice. Furthermore, mice treated with sesamin had a resistance to chronic stress and anxiety-like disorders (Zhao et al. 2017). This fine chemical also has ability to prevent health problems in humans such as obesity and atherosclerosis by lowering the storage of serum lipids and the level of blood cholesterol (Dar and Arumugam 2013; Yashaswini et al. 2017).

Sesamol

Figure 4 shows the structure of sesamol with 370.357 g/mol of molecular weight and $C_{20}H_{18}O_7$ of molecular formula. This lignan is present in the cake as glucosides with its properties such as cholesterol and blood pressure lowering, neuroprotective and anti-inflammatory activities in addition to its free radical scavenging activity (Ide et al. 2009; Jeon et al. 2016). On the other hand, its antioxidant capacity was also verified in vivo by exploring the prevention of lipid peroxide in liver and kidney of rats (Kang et al. 1998). This sesame lignan was also found to be an antime-lanogenic, prohibiting the melanin production (Sri-sayam et al. 2017). Kim and Lee (2015) showed an

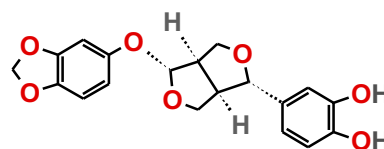


Fig. 4 Molecular structure of sesamol

evidence of the antitumor activity of sesamol in by proposing an alternative value for treating the cancer.

Sesamol

Sesamol is another valuable ingredient of sesame cake with its excellent antioxidant activity, which is more powerful than those of sesamin and sesamol (Dar and Arumugam 2013). Its molecular weight and formula are 138.12 g/mol and $C_7H_6O_3$, respectively. Figure 5 shows its molecular structure with a phenolic and benzodioxole groups, which are responsible for its biological activities. Joshi et al. (2005) evaluated its antioxidant activity against DNA degradation, lipid peroxidation and deoxyribose degradation by means of cyclic voltammetry (Joshi et al. 2005). Although it is produced from the degradation of sesamol, it has metabolic activities against inflammation as well as platelet aggregation, mutagen and tumor activation (Chang et al. 2010; Liu et al. 2017; Yashaswini et al. 2017). In addition to being a thermal stable antioxidant, its solubility in both hydrophilic and lipophilic phases make sesamol recommendable additive in vegetable oils for cooking at high temperatures (Joshi et al. 2005). Besides, Hwang et al. (2013) declared that sesamol could be used instead of synthetic preservatives in soybean oil for frying conditions. Moreover, this thermally stable natural phenolic derivative also showed antidepressant activity against depression and chronic stress in murine model (Kumar et al. 2011).

Sesaminol glucosides

Sesaminol monoglucoside, sesaminol diglucoside and sesaminol triglucoside are known as lignan glucosides (Pathak et al. 2014). Their molecular weights and formulas are 532.50, 694.64 and 856.78 g/mol, and $C_{26}H_{28}O_{12}$, $C_{32}H_{38}O_{17}$ and $C_{38}H_{48}O_{22}$, respectively. The molecular structures of the relevant compounds are indicated in Fig. 6a–c. Those mainly retain in the cake rather than oil, since the concerned glycosylated lignans are hydrophilic compounds. Sesaminol

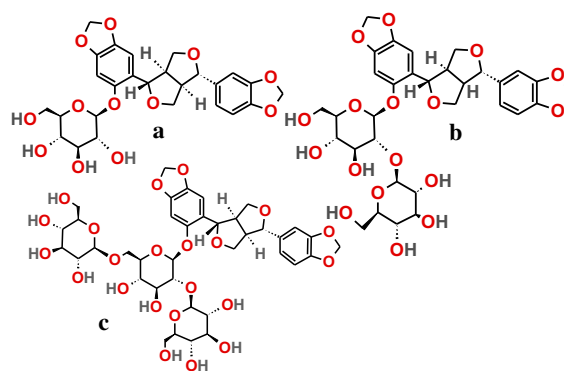


Fig. 6 Molecular structure of sesamol glucosides **a** sesamol monoglucoside, **b** sesamol diglucoside and **c** sesamol triglucoside

triglucoside is the most plentiful of them in the sesame cake (Zhu et al. 2013; Sarkis et al. 2014). Lignan glucosides identified in sesame cake have ability to scavenge peroxy radical due to its glucoside group (Kang et al. 1999). Sesaminol glucosides showed also reaction to oxidative stress, and impeded allergen sorption (Dar and Arumugam 2013). Furthermore, the most dominant phytochemicals of the cake extract have also bioactivities such as neuroprotective and anticancer effects (Hung et al. 2013).

Recovery processes of phytochemicals

In order to obtain extract rich in phytochemicals from natural sources such as plants and crops, care must be taken while developing the extraction methods. Because solvent type, composition and its ratio to solid raw material, pH of the media, extraction time, pressure and temperature influence process yield to a great extent. Table 4 presents the summary of the extraction methods applied to sesame cake at different conditions with the target contents and their concentrations. Mohdaly et al. (2010) applied classical extraction to sesame cake samples through several organic solvent types. Total phenolic and flavonoid concentrations of the extract decreased in the order of methanol, ethanol, acetone, diethyl ether, hexane and petroleum ether while total flavonols declined in the order of methanol, ethanol, acetone, hexane, diethyl ether and petroleum ether. Esmaeilzadeh Kenari et al. (2014) compared conventional (CE) and ultrasound-

Fig. 5 Molecular structure of sesamol

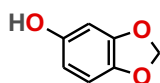


Table 4 Recovery processes of sesame cake extract at several conditions

Process	Process conditions	Target ingredients	Composition	References
CE	In a shaker at ambient temperature with methanol, ethanol, acetone, hexane, petroleum ether and diethyl ether for 24 h	Total phenolics	0.12–0.81 (mg GAE g ⁻¹ DW)	Mohdaly et al. (2010)
		Total flavonoids	0.01–0.40 (mg QE g ⁻¹ DW)	
		Total flavonols	0.09–0.16 (mg QE g ⁻¹ DW)	
CE	In a shaker at ambient temperature with methanol, ethanol, their water mixtures (50%, v/v) and water in the 10/1 of liquid to solid ratio for 24 h	Total phenolics	22.03–61.22 (mg GAE g ⁻¹ extract)	Esmailzadeh Kenari et al. (2014)
UAE	In an ultrasonic bath with methanol, ethanol, their water mixtures (50%, v/v) and water in the 10/1 of liquid to solid ratio for 45 min	Total phenolics	30.28–82.90 (mg GAE g ⁻¹ extract)	
CE	In a glass vessel on a magnetic stirrer under 25–90 °C of temperature with 0.03–0.11 g mL ⁻¹ solid to solvent ratio and 0–95% ethanol concentration for 2 h	Total phenolics	1.30–3.55 (mg GAE g ⁻¹ extract)	Sarkis et al. (2014)
		Sesamin	0.03–0.26 (mg g ⁻¹ extract)	
		Sesaminol triglucoside	2.08–5.36 (mg g ⁻¹ extract)	
CE treated with PEF/HVED	In an incubator shaker 20–60 °C of temperature with 20 (w/w) solvent to solid ratio and 10–50% ethanol concentration for 1 h at 150 rpm	Total phenolics	0.54–4.40 (mg GAE g ⁻¹ DW)	Sarkis et al. (2015)
		Lignan glucoside	0.64–2.43 (mg SE g ⁻¹ DW)	

assisted extraction (UAE) methods along with various solvents. First of all, the novel ultrasound technology surpassed the classical maceration method with each solvent. Regarding CE, the phenolic yield performance for each solvent was found to be in the order of methanol > ethanol > 50% methanol–water solution > 50% ethanol–water solution > water. The performance of the solvents was in the order of ethanol > methanol > 50% ethanol–water solution > 50% methanol–water solution > water considering UAE. The findings were explained by vapor pressure, viscosity, and surface tension of the fluids. Sarkis et al. (2014) carried out an optimization study through a classical method on a magnetic stirrer. They found out that the ratio between solid and solvent and the solvent concentration were the most effective parameter on the extraction yield. Finally, an advanced technology was also exploited to extract sesame cake through two different electrotechnologies

such as pulsed electric fields (PEF) and high voltage electrical discharges (HVED) (Sarkis et al. 2015). The relevant technologies favoured the extraction by reducing the solvent amount and temperature value, which is very valuable from the industrial point of view.

Potential applications of sesame cake extract

Fat containing food products such as vegetable oils are susceptible to be oxidized by atmospheric air, light and temperature leading to unpleasantness and formation of toxic components (Frega et al. 1999; Kochhar and Henry 2009; Şahin et al. 2017b). This qualitative problem in food industry known as lipid oxidation might be eliminated by food additives such as antioxidants (Şahin et al. 2017c). BHA, BHT and TBHQ are the most consumed synthetic antioxidants

although their health effects have not been proved yet. Therefore, there is a growing interest in application of additives derived from natural resources such as plant extracts (Bodoira et al. 2017). Suja et al. (2005a) reported that sesame cake extract compensated for the synthetic food additive in model vegetable oils such as safflower, soybean and sunflower by showing better performance in improving the stability of the oils than BHT at lower amount. Mohdaly et al. (2011) utilized the cake extract in order to favour the quality of sunflower and soybean oils with respect to peroxide value, *p*-anisidine value, conjugated trienes and conjugated dienes. The natural source of antioxidant was found as effective as BHT and BHA at 200 ppm level, which is suggested by the authorities. A different fat containing product, olein butter was also investigated concerning rancidity resulted from autoxidation of unsaturated fatty acids (Nadeem et al. 2014). 150 ppm concentration of sesame cake extract expanded the oxidative induction time of the butter much better than that of BHT, even without disturbing the sensory properties of the product.

Another application of sesame cake extract was hold in an environmental study (Govarthanan et al. 2015). Govarthanan et al. studied on elimination of hazardous material such as heavy metal (Pb) from the soil by means of immobilization through cake extract.

Concluding remarks

Findings of the present study suggest that sesame seed cake is a potential source of natural preservatives and additives. On the other hand, exhaustive studies are required including microbial and cytotoxicity tests, and sensory and nutritional quality analyses of the final industrial products from the safety point of view. As far as we are concerned, the literature on investigation of sesame cake such as metabolic profile, biological activities, chemical stability, obtaining methods, valorisation and application studies is scarce. Therefore, this review article aims to shed light on further studies to fill the gaps on this field by summarizing what has been done so far.

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