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MINI REVIEW

Processing effects on antinutritional and mineral contents of sesame (*Sesamum indicum* L.)

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Abstract

Oilseeds are high in macro and micronutrients, but they also include antinutrients that interact with the available nutrients, rendering them less accessible to the body. Sesame is one of the most widely consumed oil seeds globally in various cuisines. Sesame seeds, oil, meal cake and other by-products are utilized for human and animal use. It has reasonable amounts of minerals such as calcium, iron, zinc, magnesium, and phosphorus, beneficial to our health. The seeds have nutraceutical and pharmaceutical properties. It also contains antinutrients such as oxalate, phytate and tannin, which can be eliminated or reduced using various processing procedures. After various processes such as roasting, germination, and fermentation, sesame seeds can be utilized as a functional food to address micronutrient deficiency due to the availability of micronutrients. This review comprehends the effects of different processing methods on antinutritional and mineral contents in sesame seeds to improve their nutritional value.

1. Introduction

Oilseed crops are rich in micro and macronutrients and can be used to address malnutrition as micronutrient supplementation like calcium, zinc, iron, magnesium and manganese (Obianjunwa *et al.*, 2005; Deme *et al.*, 2017). Among the oilseeds, sesame (*Sesamum indicum* L.) is one of the world's oldest and most widely grown oilseed crops (Jannat *et al.*, 2010) and is known as the "*queen of oilseeds*" due to its high oil, protein, calcium and phosphorus content (Prasad, 2002; El-Geddawy *et al.*, 2019). Sesame is also known as gingelly, beniseed, sim sim or *til*. India, China, Sudan, Nigeria and Myanmar have high sesame production (Wan *et al.,* 2015; Dossa *et al.,* 2016). India is the largest producer of sesame, and it also has the largest sesame-growing area in the world.

Sesame seeds provide a nutty taste in many food preparations (Anilakumar *et al.,* 2010). Sprouted sesame is used to prepare bread, confectionery (Namiki, 2007) and cookies (Elleuch *et al.*, 2011). Value-added sesame seed products like biscuits are easy to prepare at the household level with minimal cost (Jain and Joshi, 2015). Sesame oil is also used in cooking, dressing and other similar variations (Gandhi and Srivastava, 2007; Mondal *et al.*, 2010; Asghar *et al.,* 2014). It is also a natural additive to improve microbial quality and extended shelf life during cold storage of fresh meat products (Sallam *et al.*, 2021).

Sesame seed has oil content ranging from 46 to 52%. The seeds of white sesame have a higher quantity of oil content than black ones (Agidew *et al.*, 2021). The sesame oil contains linoleic, oleic, palmitic and stearic acids (Agidew *et al.*, 2021; Kazlauskienė *et al.*, 2021). The oil shows antioxidant activities due to sesamin, sesamol and tocopherols and is used for various medical benefits (Wan *et al.*, 2015; Amandeep *et al.*, 2019; Langyan *et al.*, 2022). Sesame lignans obtained from seeds (Dossou, Xu, You *et al.*, 2022), and sesame oil can be used to retard rancidity by adding in food oils due to their property as a natural antioxidant (Hadeel *et al.*, 2020). Melanin present in black sesame seeds has been found to be more beneficial than white sesame in food applications (Dossou, Luo, Wang *et al.*, 2022).

Sesame seeds have nutraceutical and pharmaceutical properties (Nagendra Prasad *et al.*, 2012; Abbas *et al.*, 2022), including antioxidative (Ha *et al.*, 2017; Sharma *et al.*, 2021; Dossou, Xu, You *et al.*, 2022), hepatoprotective and hypocholesterolemic benefits in preventing hypertension (Chen *et al.*, 2005; Anilakumar

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et al., 2010). It is also used as a topical agent in relieving pain in traumatic injuries (Gholami *et al.*, 2020).

Although sesame seeds are a good source of protein, fat, energy, fibre and minerals, including iron, calcium and zinc, they also contain a high amount of anti-nutritional factors such as oxalates, phytate (Obianjunwa *et al.*, 2005; Longvah *et al.*, 2017) (Table 1) and tannins (Abou-Gharbia *et al.*, 1997; Okudu *et al.*, 2016; Aglave, 2018). According to Longvah *et al.* (2017), the phytate content ranged from 845-927 mg/100 g for black, brown and white sesame seeds from different Indian varieties. Another study revealed 3.87% phytic acid in sesame seeds on dry weight basis (Ravindran *et al.*, 1994), and phytate in roasted seeds which contained 39.3–57.2 mg/g (Greiner and Konietzny, 2006). Toma *et al.* (1979) reported 2.23% and 2.02% phytate in raw red and white sweetened sesame seeds, respectively.

Due to the antinutritional factors, macro and micronutrient availability, digestibility and absorption interfere (Kumar *et al.*, 2010). Therefore, it is essential to remove these antinutritional factors for maximum utilization of nutrients from sesame seeds (Aglave, 2018). This article reviewed the various processing methods to remove antinutrients and their impact on sesame's nutritional value.

2. Types of processing

It has been found that using various processing techniques, the antinutritional factors and phytochemicals can be altered (Greiner and Konietzny, 2006; Thakur *et al.*, 2019; Popova and Mihaylova, 2019), making the oilseeds have more nutritional value thereby utilizing it as functional food (Rizki *et al.*, 2015; Zebib *et al.*, 2015; Aglave, 2018). This includes various processing techniques *viz*. (i) Roasting (Jeong *et al.*, 2004; Embaby, 2010; Jannat *et al.*, 2010; Jimoh *et al.*, 2011; Adegunwa *et al.*, 2012; Hassan, 2013; Makinde and Akinoso, 2013; Makinde and Akinoso, 2014; Rizki *et al.*, 2015; Makinde *et al.*, 2016; Hama, 2017; Tenyang *et al.*, 2017; Aglave, 2018), (ii) Fermentation (Makinde *et al.*, 2013; Olagunju and Ifesan, 2013; Makinde and Akinoso, 2014), (iii) Germination or sprouting (Jain and Joshi, 2015; Mares *et al.*, 2017; Makinde and Victoria, 2018; Uzo-Peters and Karimat, 2018; Didier *et al.*, 2020) and (iv) Microwave heating (Hassan, 2013; Rizki *et al.*, 2015; Makinde *et al.*, 2016; El-Geddawy *et al.*, 2019). These techniques decrease antinutrients, increase nutrient availability, improve digestibility, increase shelf life (Ertop and Bektas, 2018), and help utilize it as a functional food (Zebib *et al.*, 2015; Aglave, 2018).

The loss and retention of the nutrients in the roasting technique differed significantly (Makinde *et al.,* 2016). The roasting of brown and white sesame seeds eliminated the major antinutritional factors (oxalates and phytic acid) and improved *in vitro* protein digestibility (Embaby, 2010). Sprouting (germination) causes metabolic changes that improve nutritional quality and reduce antinutritional factors like phytic acid and trypsin inhibitors (Agrahar-Murugkar *et al.*, 2013). In the sprouts, the free amino acids, c-amino-n-butyric acid, and total phenolic components rapidly increased as seedlings grew, whereas crude fat declined. Sprouts of sesame can be recommended as a functional meal due to their high level of free amino acids, GABA (gamma-aminobutyric acid) and phenolic compounds (Liu *et al.*, 2011). Research studies have shown that germination increased the protein content (Basso *et al.*, 2021) and bio-accessibility of lignans and tocopherols (Li *et al.*, 2020). The changes in nutritional quality due to germination also depend upon the quality of the seed, the conditions used for germination and even the process used for analysis (Basso *et al.*, 2021).

The effect of various processing techniques on antinutrients *viz.* oxalates, phytates and tannins and the availability of calcium, iron, zinc and magnesium as given by various authors are discussed below.

2.1 Effect of processing on oxalate

Roasting of sesame seeds reduced the oxalate content ranging from 31.64-76.20%, as reported by various authors (Table 2). The time duration and temperature varied depending on the type of sesame (black/white). The higher the temperature, the less time is required for roasting sesame (Table 2). Jimoh *et al.* (2011) reported that roasting reduced the oxalate content of dehulled, defatted sesame seed meal. The reduction in

Table 1. Macro, micro and antinutrients in sesame seeds per 100 g (Longvah *et al.*, 2017).

Sesame seed types	Energy (kcal)	Macronutrients (g/100 g)			Micronutrients (mg/100 g)			Antinutrients (mg/100 g)		
		Protein	Total fat	Total fiber	Iron	Calcium	Zinc	Total Oxalate	Phytate	Tannins
Black	507.65	19.17	43.1	17.16	13.9	1664	8.59	2156	845	134.6 (Deme *et al.*, 2017)
Brown	516.49	21.61	43.22	17.21	14.95	1174	7.84	2030	921	1.8 (Embaby, 2010)
White	519.60	21.7	43.05	16.99	15.04	1283	7.77	2004	927	2.7 (Embaby, 2010)

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Table 2. Effect of processing on oxalates in sesame.

Effect of roasting

Sesame Type	Temperature and Duration	Oxalates (mg/100 g) Raw	Roasted	% Reduction	References
Dehulled, defatted, seed meal	180°C for 5 mins	15.66±0.45	9.40±0.02	39.97	Jimoh *et al.* (2011)
	180°C for 10 mins		8.60±0.78	45.08	
	180°C for 15 mins		5.11±0.23	67.36	
Seed flour	110°C for 30 mins	88.57±8.43	51.84±3.06	41.47	Adegunwa *et al.* (2012)
White	120°C for 1 hr	183.42±1.68	125.37	31.64	Makinde and Akinoso (2013)
Black	120°C for 1 hr	154	104.62	32.06	
Nigeria white seed flour	Dehulled, dried in an oven at 105° C for 12 hrs, milled and kept at 160°C for 25 mins	85.67±0.23	36.00±1.00	57.97	Makinde and Akinoso (2014)
Nigeria white seed flour	Dried dehulled Open pan Roasted at 75-85°C for 20 mins	63.70±0.11 Dehulled sundried (4 hrs) flour	15.16±0.03	76.20	Makinde *et al.* (2016)
	Microwave Roasted at 665 W for 10 mins		17.50±0.05	72.52	

Effect of fermentation

Sesame type	Duration	Oxalates (mg/100 g) Raw	Fermented	% Reduction	References
Red sweetened		2.23%	No change		Toma *et al.* (1979)
Red sweetened		2.02%			
Nigeria white seeds	Fermentation in Banana Leaf	85.67±0.58	30.33±0.09 (Day 7)	64.59	Makinde *et al.* (2013)
	Fermentation in Plastic bowl		24.95±0.58 (Day 7)	70.87	
Nigeria white seeds	Fermentation 96 hrs	1.05±0.10	0.48±0.052	54.28	Olagunju and Ifesan (2013)
Nigeria white seeds	Nigeria white sesame seeds	85.67±0.23	24.95±0.18	70.87	Makinde and Akinoso (2014)

Effect of germination

Seed Type	Duration	Oxalates (mg/100 g) Raw	Germination	% Reduction	References
Whole white	Germination: 5 days	183.42±1.68	97.6	46.78	Makinde and Akinoso (2013)
Whole black		154	74.73	51.47	
Whole seed	Soaking: 12 hrs Germination: 48 hrs		1.33±0.01		Jain and Joshi (2015)
Dehulled white	Soaking: 4 hrs, dehulled and germinated 96 hrs	3.05±0.01	2.04±0.03	33.11	Makinde and Victoria (2018)
Raw seed flour	Soaking: 24 hrs	140	104.12	25.62	Didier *et al.* (2020)
	Germination: 48 hrs		136	2.85	

oxalate in seed meal was higher (67.36%) when treated at 180ºC for 15 mins, followed by 45.08% at 180ºC for 10 min and 39.97% at 180ºC for 5 mins. It has been found that the highest reduction in oxalate content occurred in an open pan roasting of dried and dehulled white sesame seed flour at 75-85ºC for 20 mins (Makinde *et al.*, 2016), which is an easy homestead method to reduce oxalates. Fermentation directly causes a reduction of oxalates in sesame seeds up to a maximum of 70.87% in white sesame seeds (Makinde *et al.*, 2013) (Table 2). Fermented sesame is commonly consumed by people living in African states. In India, fermented sesame usually is not consumed, but this form of sesame can be added to Indian fermented food preparations.

The lipids, carbohydrates and storage proteins are broken down on seed germination to give energy and amino acids for plant development (Ali and Elozeiri, 2017). The percent oxalate reduction in sesame ranged from 33.11-51.47%, as reported by various authors (Table 2). The soaking time and germination time significantly impact the reduction of oxalates (Table 2). Maximum reduction in oxalates was observed in pre-soaked sesame seeds for 24 hrs before keeping them for germination (Didier *et al.*, 2020). This might be due to the presence of maximum oxalates (50-70%) in water-soluble form and removed by soaking and throwing the soaked water (Noonan and Savage, 1999).

Before roasting, dehulling of sesame seeds proved a more effective way of reducing oxalates (Toros and Guzmán-Alvarez, 2022) because the water-soluble

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oxalates get removed during the soaking of seeds (Noonan and Savage, 1999).

2.2 Effect of processing on phytate

Roasting of sesame seeds caused a reduction in phytate, ranging from 13.33 to 80.23%. It is reported that the reduction in phytate contents increased with temperature and the duration of roasting, but it may impact the sensory quality of the food product (Table 3). Jimoh *et al.* (2011) reported that roasting reduced the phytate content of dehulled, defatted sesame seed meal ranging from 54.73-62.59% at 180ºC with a time difference of 5 -15 mins.

Various research has shown that fermentation of the sesame can reduce the phytate content ranging from 33.93 to 65.57% (Table 3). Fermentation of various types of sesame seeds have been reported. Various storage mediums like a banana leaf and plastic bowl have been used as fermentation technique aids

Table 3. Effect of processing on phytate in sesame.

Effect of roasting					
Seed Type	Temperature and duration	Phytate mg/100 g			References
		Raw	Roasted	% Reduction	
Red sweetened		2.23%	No change		Toma *et al.* (1979)
White sweetened		2.02%			
Dehulled, defatted, seed meal	180°C, 5 mins	25.05±4.6	11.34±0.01	54.73	Jimoh *et al.* (2011)
	180°C, 10 mins		10.92±0.02	56.40	
	180°C, 15 mins		9.37±0.01	62.59	
Brown	10 min until lightly browned	6.5±0.05	5.0±0.17	23.08	Embaby (2010)
White		4.2±0.14	3.0±0.10	28.57	
Seed flour- (seed treatments were given)	110°C, 30 mins	1.02	0.74	13.33	Adegunwa *et al.* (2012)
Whole white	120°C, 1 hr	62.67±2.52	47.89	23.58	Makinde and Akinoso (2013)
Whole black		52.60±1.53	42.96	18.33	
Nigerian white seed flour	160°C for 25 mins	30.00±1.00	18.33 ±0.18	38.9	Makinde and Akinoso (2014)
Nigeria white seed flour	75-85°C for 20 mins	25.64±0.42	5.07±0.03	80.22	Makinde *et al.* (2016)
	Medium power (665W) for 10 mins		8.02±0.04	80.23	
Effect of fermentation					
Sesame type	Duration	Phytate mg/100 g			References
		Raw	Fermented	% Reduction	
Red sweetened		2.23%			Toma *et al.* (1979)
White sweetened		2.02%			
White dehulled	Fermentation in Banana Leaf (Day 7)	30.00±3.00	11.02±0.02	55.94	Makinde *et al.* (2013)
	Fermentation in Plastic bowl (Day 7)		10.33±0.50	65.57	
Whole white		62.67±2.52	34.22	45.40	Makinde and Akinoso (2013)
Whole black		52.60±1.53	21.43	59.26	
Whole raw seed	Fermentation 96 hrs	31.59±0.95	18.13±0.00	42.60	Olagunju and Ifesan (2013)
	Fermentation 48 hrs		20.87±0.47	33.93	
White dehulled		30.00±1.00	10.33±0.50	65.57	Makinde and Akinoso (2014)
Effect of germination					
Sesame type	Duration	Phytates mg/100 g			Reference
		Raw	Germination	% Reduction	
Whole white seed	Germination: 5 days	62.67±2.52	34.22	45.39	Makinde and Akinoso (2013)
Whole black seed	Germination: 48 hrs	52.6	21.43	59.25	
Whole seed	Soaking: 12 hrs Germination: 48 hrs		1.003±0.28		Jain and Joshi (2015)
Dehulled white seed	Germination: 96 hrs	9.02±0.06	5.78±0.01	35.92	Makinde and Victoria (2018)
Raw seed flour	Soaking: 24 hrss Germination: 48 hrs	134.66	43	68.06	Didier *et al.* (2020)

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(Makinde *et al.*, 2013). Fermentation of sesame seeds in a plastic bowl for seven days caused a higher reduction (65.57%) in phytate than banana leaf (55.94%) for seven days (Makinde *et al.*, 2013). Makinde and Akinoso (2014) reported a reduction of phytate by 65.57% in fermented white dehulled sesame seeds. At the same reduction value, Makinde *et al.* (2013) reported seven days of white dehulled sesame fermentation. The reduction in phytate content increased with an increase in the duration of fermentation. The reduction in phytate content ranged from 35.92 to 68.06%, as reported by various authors (Table 3).

The phytate content was reduced (35.92-68.06%) after seed germination. Didier *et al.* (2020) reported a 68.06% reduction in phytate content involving soaking for 24 hrs and a germination period of 48 hrs. Makinde and Akinoso (2013) germinated whole white seed for five days and whole black seed for 48 hrs and reported 45.39 and 59.25% reductions in phytate, respectively.

2.3 Effect of processing on tannin

Tannins are a group of polyphenolic compounds which hinder the absorption of minerals. The reduction of tannin in sesame ranged from 16.66% to 76.14% in sesame as reported by various authors (Table 4).

Roasting reduced the tannins when microwave heated at 1 min, 2 mins and 3 mins by 20.4% and 22.4%, respectively.

Antinutrients in the seed can be reduced by fermentation (Thakur *et al*., 2019). The reduction in tannins caused due to fermentation for 24 hrs, 48 hrs and 72 hrs was reported as 24.4%, 25.5% and 49.0%, respectively (El-Geddawy *et al.*, 2019).

The germination technique can help reduce the tannin content in sesame seeds (Table 4). Makinde and Victoria (2018) reported a reduction in tannin content by 76.14%, while El-Geddawy *et al.* (2019) reported a 34.69% reduction. On the contrary, Didier *et al.* (2020) reported an increase of 23.98% in phytate content. Germination reduced the highest amount of tannin (76.14%), followed by roasting (65.58%) and fermentation (49.0%).

2.4 Effect of processing on calcium

Sesame seeds are rich in calcium. Roasting increased the calcium content of sesame as reported by most researchers, while few studies reported a decrease in the calcium content of sesame (Table 5). The reductions in calcium content ranged from 16.89-29.49%, while the

Table 4. Effect of processing on tannin in sesame.

Effect of roasting

Sesame type	Temperature and duration	Tannin (mg/100 g)			References
		Raw	Roasting	% Reduction	
White seed	For 10 mins until lightly browned	2.7±0.08	1.7±0.07	37.03	Embaby (2010)
Brown seed		1.8±0.04	1.50±0.08	16.66	
Dehulled, defatted, seed meal	180°C for 5 mins	5.62±0.32	2.19±0.01	58.36	Jimoh *et al.* (2011)
	180°C for 10 mins		1.83±0.01	65.20	
	180°C for 15 mins		1.81±0.01	65.58	
Seeds	Microwave heating	490.0			El-Geddawy *et al.* (2019)
	1 min		390.0	20.4	
	2 mins		380.0	22.4	
	3 mins		370.0	24.4	

Effect of fermentation

Sesame type	Duration	Tannin (mg/100 g)			References
		Raw	Fermentation	% Reduction	
Seeds		490.0			El-Geddawy *et al.* (2019)
	24 hrs		370.0	24.4	
	48 hrs		360.0	26.5	
	72 hrs		250.0	49.0	

Effect of germination

Sesame type	Duration	Tannin (mg/100 g)			References
		Raw	Germination	% Reduction	
Whole seeds	Soaking time: 12 hrs Germinated for 72 hrs	490.0	320.0	34.69	El-Geddawy *et al.* (2019)
White	Germination: 96 hrs	16.64±0.07	3.97±0.01	76.14	Makinde and Victoria (2018)
Raw seed flour	Soaking time: 24 hrs Germinated for 48 hrs	229.52±4.37	284.56±5.40	23.98 (+)	Didier *et al.* (2020)

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roasting increased the calcium content ranging from 0.68% to 26.40% (Table 5). Tenyang *et al.* (2017) reported an increase in calcium by 26.40% in brown sesame seeds. In contrast, Jimoh *et al.* (2011) reported a reduction in calcium contents of sesame ranging from 25.68-29.49%.

Fermentation increased the calcium content of sesame ranging from 14.89% to 94.06%. It is an effective technique to enhance calcium content (Table 5). However, Olagunju and Ifesan (2013) reported a reduction in calcium content by 26.34%.

Germination increases the availability of minerals in the sesame. Due to germination, an increase in the calcium content of sesame by 36.12% was observed. Soaking of seeds before germination increased calcium contents by up to 137.41% (Didier *et al.*, 2020) (Table 5). During germination, the phytates are converted into soluble phosphorus, which enhances the absorption and availability of calcium.

2.5 Effect of processing on iron

Iron is an essential mineral that every age group requires a sufficient quantity. Depending upon the type of sesame, the iron content may increase or decrease, but it can be stated that generally, the roasting enhances the iron content in sesame (Table 6). Deviation in iron content was observed and found to increase and decrease both, as reported by various authors (Table 6).

Adegunwa *et al.* (2012) reported an enhancement in iron content by 32.10% when roasted seed flour at 110ºC for 30 min. Jimoh *et al.* (2012) reported a reduction in iron in dehulled, defatted sesame seed meal ranged from 40.05-47.78%. The presence of iron in the hull of the seeds, which is removed during the dehulling process, may cause it to decrease. Tenyang *et al*. (2017) reported an increment in iron values of brown and white seeds

Table 5. Effect of processing on calcium in sesame.

Effect of roasting					
Sesame type	Temperature and duration	Calcium (mg/100 g)			References
		Raw	Roasted	% Deviation	
		Ca and soluble oxalates were observed in dehulled roasted seeds			Toma *et al.* (1979)
Dehulled, defatted, seed meal	180°C for 5 mins	368.76±1.25	260.01±0.004	29.49(-)	Jimoh *et al.* (2011)
	180°C for 10 mins		274.06±0.002	25.68(-)	
	180°C for 15 mins		261.86±0.01	28.98(-)	
Seed flour	110°C for 30 mins	199.02	165.39	16.89(-)	Adegunwa *et al.* (2012)
Nigerian white seed flour	160°C for 25 mins	464.97±0.68	519.70±0.57	10.53(+)	Makinde and Akinoso (2014)
Seed flour	75-85ºC for 20 mins	439.25±1.00 (Roasted Sesame Flour)	445.02±0.58 (Open pan Roasted)	1.29(+)	Makinde *et al.* (2016)
	Medium power (665W) for 10 mins		442.27±0.43 (Microwave Roasted)	0.68(+)	
Brown	180ºC for 10 mins	2017.89±17.00	2741.75±31.00	26.40(+)	Tenyang *et al.* (2017)
White	180ºC for 10 mins	985.54±15.00	1077.29±12.01	8.51(+)	

Effect of fermentation					
Sesame type	Duration	Calcium (mg/100 g)			References
		Raw	Fermented	% Deviation	
White dehulled		443.67±3.20			Makinde *et al.* (2013)
	Fermentation in banana Leaf (Day 7)		7479.00±1.00	94.06(+)	
	Fermentation in a plastic bowl (Day 7)		521.33±1.37	14.89(+)	
Whole seed	Fermentation: 48 hrs	429±0.82	316±0.31	26.34(-)	Olagunju and Ifesan (2013)
Nigerian white seed flour	Fermentation: 7 days	464.97±0.68	567.91±0.43	18.12(+)	Makinde and Akinoso (2014)

Effect of germination					
Sesame type	Duration	Calcium (mg/100 g)			References
		Raw	Germination	% Deviation	
Whole seed	Soaking: 12 hrs Germination: 48 hrs		1257.74±0.30		Jain and Joshi (2015)
Dehulled white seed	Germination: 96 hrs	4.72±0.02	7.39±0.05	36.12(+)	Makinde and Victoria (2018)
Raw seed flour	Soaking time: 24 hrs Germination: 48 hrs	70.07±0.11	166.36±1.17	137.41(+)	Didier *et al.* (2020)

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Table 6. Effect of processing on iron in sesame.

Effect of roasting					
Sesame type	Temperature and Duration	Iron (mg/100 g)			References
		Raw	Roasted	% Deviation	
Dehulled, defatted, seed meal	180°C for 5 mins	6.99±0.52	4.03±0.12	42.34(-)	Jimoh *et al.* (2011)
	180°C for 10 mins		3.65±0.003	47.78(-)	
	180°C for 15 mins		4.19±0.01	40.05(-)	
Seed flour	110°C for 30 mins	1.29	1.90	32.10(+)	Adegunwa *et al.* (2012)
Nigerian white seed flour	160°C for 25 mins	6.42±0.02	7.08±0.12	9.32(+)	Makinde and Akinoso (2014)
Seed flour	Open pan roasted at 75-85ºC for 20 mins	6.42±0.02	4.98±0.04	9.32(-)	Makinde *et al.* (2016)
	Microwave roasted at medium power (665W) for 10 mins		3.06±0.03	52.33(-)	
Brown	180°C for 10 mins	11.20±1.00	14.34±0.40	21.89(+)	Tenyang *et al.* (2017)
White	180°C for 10 mins	9.83±0.40	14.08±0.08	30.18(+)	

Effect of fermentation					
Sesame type	Duration	Iron (mg/100 g)			References
		Raw	Fermented	% Deviation	
White dehulled		6.13±0.5			Makinde *et al.* (2013)
	Fermentation in Banana Leaf Day 7		6.31±0.03	2.85(+)	
	Fermentation in Plastic Bowl Day 7		6.30±0.12	2.69(+)	
Whole seed	Fermentation: 96 hrs	109±03	99.35±0.03	8.85(-)	Olagunju and Ifesan (2013)
Nigerian white seed flour	Fermentation: 7 days	6.42±0.02	8.00±0.05	19.75(+)	Makinde and Akinoso (2014)

Effect of germination					
Sesame type	Duration	Iron (mg/100 g)			References
		Raw	Germination	% Deviation	
Whole seed	Soaking: 12 hrs Germination: 48 hrs		7.83±0.04		Jain and Joshi (2015)
Dehulled white seed	Germination: 96 hrs	0.047±0.002	0.087±0.001	45.97	Makinde and Victoria (2018)
Raw seed flour	Soaking time: 24 hrs Germination: 48 hrs	1.98±0.01	10.72±0.62	441.41	Didier *et al.* (2020)

when roasted at 180ºC for 10 mins, found to be 21.89% and 30.18%, respectively. Due to the roasting of seed flour in the microwave for 10 min, the iron content was reduced by 52.33% (Makinde *et al.* 2016).

Makinde and Akinoso (2014) reported an increase in the iron content of sesame seeds by 19.75% when fermented for 7 days (Table 6).

Makinde and Victoria (2018) reported a 45.97% increase in iron content when the germinated dehulled white seed for 96 hrs. The increase in iron content due to germination was as high as 441.41% (Didier *et al.*, 2020). Germination is the most effective process for increasing the iron content and its availability in sesame seeds. The reduction of oxalates and phytate content due to germination enhances iron availability in the body.

2.6 Effect of processing on zinc

Sesame seeds are rich in zinc, and roasting causes an increase in zinc. Makinde *et al.* (2016) reported a 29.74% increase in zinc content when roasted in a microwave for 10 mins. In contrast, a decrease in zinc content ranges from 40.16% to 73.26% due to roasting at 180ºC for 5-15 mins (Jimoh *et al.*, 2012).

Fermentation increased the zinc values by 30.36% (Makinde and Akinoso, 2014) when fermented for seven days. Germination is the best technique to increase the zinc levels in sesame seeds (Table 7). Zinc increased to 230.52% (Didier *et al.*, 2020) by following the germination of raw seeds by soaking for 24 hrs and incubation for 48 hrs. Whereas dehulled white seed, when germinated for 96 hrs, increases the zinc by 28.26% (Makinde and Victoria, 2018). Following germination, fermentation and roasting can increase the zinc contents (Table 7).

2.7 Effect of processing on magnesium

As reported by different studies, roasting can help increase magnesium levels by 29.78% in white seeds and

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Table 7. Effect of processing on zinc in sesame.

Effect of roasting

Sesame type	Temperature and duration	Zinc (mg/100 g)			Reference
		Raw	Roasted	% Deviation	
Dehulled, defatted, seed meal	180°C for 5 mins	8.64±0.35	5.17±0.002	40.16(-)	Jimoh *et al.* (2011)
	180°C for 10 mins		2.98±0.006	65.50(-)	
	180°C for 15 mins		2.31±0.009	73.26(-)	
Seed flour	110°C for 30 mins	0.49±00.00	0.49±00.01	0.00	Adegunwa *et al.* (2012)
Nigerian white seed flour	160°C for 25 mins	7.97±0.13	10.07±0.03	26.34(+)	Makinde and Akinoso (2014)
Seed flour	Open pan roasted at 75-85°C for 20 mins	2.79±0.04	3.07±0.04	10.03(+)	Makinde *et al.* (2016)
	Microwave roasted at medium power (665W) for 10 mins		3.62±0.05	29.74(+)	
Brown	180°C for 10 mins	11.01±0.08	10.89±0.90	1.08(-)	Tenyang *et al.* (2017)
White	180°C for 10 mins	8.18±0.50	10.27±0.40	25.55(+)	

Effect of fermentation

Sesame type	Duration	Zinc (mg/100 g)			Reference
		Raw	Fermented	% Deviation	
White de-hulled		7.66±0.01			Makinde *et al.* (2013)
	Fermentation in Banana Leaf Day 7		8.57±0.06	11.87(+)	
	Fermentation in Plastic Bowl Day 7		0.07±0.00 (9.07±0.00)	18.40(+)	
Whole seed	Fermentation: 96 hrs	91.1±0.19	88.8±0. 09	2.52(-)	Olagunju and Ifesan (2013)
Nigerian white seed flour	Fermentation: 7 days	7.97±0.13	10.39±0.06	30.36(+)	Makinde and Akinoso (2014)

Effect of germination

Sesame type	Duration	Zinc (mg/100 g)			Reference
		Raw	Germination	% Deviation	
Dehulled white seed	Germination: 96 hrs	0.46±0.01	0.59±0.01	28.26(+)	Makinde and Victoria (2018)
Raw seed flour	Soaking time: 24 hrs Germination: 48 hrs	0.95±0.01	3.14±0.20	230.52(+)	Didier *et al.* (2020)

18.22% for brown seeds when roasted at 180ºC for 10 mins (Tenyang *et al.*, 2017). Jimoh *et al.* (2012) reported a decrease in magnesium levels in the range of 51.59-55.54% when roasted at 180ºC in 5-15 mins. Through open pan roasting at 75-85ºC for 20 mins, magnesium increased to 8.43% (Makinde *et al.*, 2016).

Fermentation of sesame for seven days caused an increase in magnesium content by 14.02% (Makinde and Akinoso, 2014). Makinde *et al.* (2013) reported an increase of 5.39% in magnesium levels when fermented white dehulled sesame for seven days.

Germination increased the magnesium content highest at 80.17% when germinated dehulled white sesame for 96 hrs (Makinde and Victoria, 2018) (Table 8).

4. Conclusion

The processing methods reviewed in this paper, *i.e.* roasting, fermentation, and germination effectively reduced the antinutrients like oxalates, phytates and tannins. The various studies included the processing of seeds, dehulled seeds of sesame, and defatted sesame flour, thereby increasing the bioavailability of nutrients.

The roasting of sesame seeds caused a reduction in the antinutritional factors, and it was lowest after soaking seeds in water for five or more hours and then germinating for 48 to 96 hrs. The soaking of sesame seeds in a container and discarding the remaining water may result in removing water-soluble oxalates from the seeds. During germination, the endogenous enzymes get activated helps degrade antinutritional factors and enhance mineral content. The fermentation process leads to decreased antinutritional content and increased iron, calcium, magnesium, and zinc. The increase in mineral content and availability is likely due to dry matter loss as microbes degrade oxalates and phytates. The high content of phytic acid and oxalic acid in sesame seed hinders the bioavailability of calcium, iron and zinc.

There was a deviation in mineral contents in sesame seeds, viz. calcium, iron, zinc, and magnesium. If antinutrients are decreasing, the availability of the

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Table 8. Effect of processing on magnesium in sesame.

Sesame type	Temperature And duration	Magnesium (mg/100 g)			References
		Raw	Roasted	% Deviation	
Effect of roasting					
Dehulled, defatted, seed meal	180°C for 5 mins	672.45±20.94	298.93±0.75	55.54(-)	Jimoh *et al.* (2011)
	180°C for 10 mins		300.0±0.002	55.38(-)	
	180°C for 15 mins		325.53±0.004	51.59(-)	
Seed flour	110°C for 30 mins	34.75	39.33	13.17(+)	Adegunwa *et al.* (2012)
Nigerian white seed flour	160°C for 25 mins	399.65±1.00	429.43	7.45(+)	Makinde and Akinoso (2014)
Seed flour	Open pan-roasted at 75-85ºC for 20 mins	357.38±0.54	365.95±0.51	8.43(+)	Makinde *et al.* (2016)
	Microwave roasted at medium power (665W) for 10 mins		364.03±0.63	2.39(+)	
Brown	180°C for 10 mins	466.64±5.00	551.6970±4.70	18.22(+)	Tenyang *et al.* (2017)
White	180°C for 10 mins	445.16±5.06	577.74±10.00	29.78(+)	

Sesame type	Duration	Magnesium (mg/100 g)			References
		Raw	Fermented	% Deviation	
Effect of fermentation					
White dehulled		341.3±1.50			Makinde *et al.* (2013)
	Fermentation in Banana Leaf Day 7		342.33±1.16	0.30(+)	
	Fermentation in Plastic Bowl Day 7		359.7±0.58	5.39(+)	
Whole seed	Fermentation: 96 hrs	392±0.39	381±0.36	2.80(-)	Olagunju and Ifesan (2013)
Nigerian white seed flour	Fermentation: 7 days	399.65±1.00	455.70±0.53	14.02(+)	Makinde and Akinoso (2014)

Sesame type	Duration	Magnesium (mg/100 g)			References
		Raw	Germination	% Deviation	
Effect of germination					
Dehulled white seed	Germination: 96 hrs	18.66±0.11	33.62±0.03	80.17(+)	Makinde and Victoria (2018)
Raw seed flour	Soaking time: 24 hrs Germination: 48 hrs	12.62±0.08	13.35±0.21	5.78(+)	Didier *et al.* (2020)

minerals becomes higher, which is significantly acceptable. The time, temperature, equipment and variety of seeds may influence the types of processing to improve the nutritional quality of sesame.

Conflict of interest

The authors declare no conflict of interest.

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References

Abbas, S., Sharif, M.K., Sibt-e-Abbas, M., Fikre Teferra, T., Sultan, M.T. and Anwar, M.J. (2022). Nutritional and therapeutic potential of sesame seeds. *Journal of Food Quality*, 2022, 6163753. https://doi.org/10.1155/2022/6163753

Abou-Gharbia, H.A., Shahidi, F., Adel, A., Shehata, Y. and Youssef, M.M. (1997). Effects of processing on oxidative stability of sesame oil extracted from intact and dehulled seeds. *Journal of the American Oil Chemists' Society*, 74(3), 215-221. https://doi.org/10.1007/s11746-997-0126-9

Adegunwa, M.O., Adebowale, A.A. and Solano, E.O. (2012). Effect of thermal processing on the biochemical composition, antinutritional factors and functional properties of benniseed (*Sesamum indicum*) flour. *American Journal of Biochemistry and Molecular Biology*, 2(3), 175-182. https://doi.org/10.3923/ajbmb.2012.175.182

Agidew, M.G., Dubale, A.A., Atlabachew, M. and Abebe, W. (2021). Fatty acid composition, total phenolic contents and antioxidant activity of white and black sesame seed varieties from different localities of Ethiopia. *Chemical and Biological Technologies in Agriculture*, 8, 14. https://

doi.org/10.1186/s40538-021-00215-w

Aglave, H.R. (2018). Physiochemical characteristics of sesame seeds. *Journal of Medicinal Plants Studies*, 6 (1), 64-66. https://doi.org/10.22271/plants.2018.v6.i6b.02

Agrahar-Murugkar, D., Kotwaliwale, N., Kumar, M. and Gupta, C. (2013). Effect of sprouting on rheological properties of soy-butter. *LWT-Food Science and Technology*, 54(1), 95-100. https://doi.org/10.1016/j.lwt.2013.05.010

Ali, A.S. and Elozeiri, A.A. (2017). Metabolic processes during seed germination. Advances in Seed Biology, p.141-166. London, United Kingdom: Intech Open. https://doi.org/10.5772/intechopen.70653

Amandeep, Sharma, M. and Kumar, V. (2019). Enlightening food application and mega health benefits of *Sesamum indicum* L. *International Journal of Current Microbiology and Applied Sciences,* 8(1), 2224-2232. https://doi.org/10.20546/ijcmas.2019.801.232

Anilakumar, K.R., Pal, A., Khanum, F. and Bawa, A.S. (2010). Nutritional, medicinal and industrial uses of sesame (*Sesamum indicum* L.) seeds-an overview. *Agriculturae Conspectus Scientificus*, 75 (4), 159-168.

Asghar, A., Majeed, M.N. and Akhtar, M.N. (2014). A review on the utilization of sesame as functional food. *American Journal of Food and Nutrition*, 4(1), 21-34.

Basso, A.C.D., Machado, P.M.R., Chaves, J.O., Parreiras, P.M. and Menezes, C.C. (2021). Interference of germination on the nutritional composition and antioxidant capacity of black sesame (*Sesamum indicum* L.). *British Food Journal,* 123(11), 3436-3447. https://doi.org/10.1108/bfj-08-2020-0727

Chen, P.R., Chien, K.L., Su, T.C., Chang, C.J., Liu, T.L., Cheng, H. and Tsai, C. (2005). Dietary sesame reduces serum cholesterol and enhances antioxidant capacity in hypercholesterolemia. *Nutrition Research*, 25(6), 559-567. https://doi.org/10.1016/j.nutres.2005.05.007

Deme, T., Haki, G.D., Retta, N., Woldegiorgis, A. and Geleta, M. (2017). Mineral and antinutritional contents of niger seed (*Guizotia abyssinica* (L.f.) Cass., Linseed (*Linum usitatissimum* L.) and sesame (*Sesamum indicum* L.) varieties grown in Ethiopia. *Foods*, 6(4), 27. https:// doi.org/10.3390/foods6040027

Didier, K.I.A., Kwithony, D.W., Thierry, K.F.M., Adaye, Y.K. and Betty, F.M. (2020). Nutritional qualities of germinated sesame (*Sesamum indicum* L.) seeds grown in Côte D'Ivoire. *Annals. Food Science and Technology*, 21(2), 299-309.

Dossa, K., Wei, X., Zhang, Y., Fonceka, D., Yang, W., Diouf, D., Liao, B., Cissé, N. and Zhang, X. (2016). Analysis of genetic diversity and population structure of sesame accessions from Africa and Asia as major centers of its cultivation. *Genes*, 7(4), 14. https://doi.org/10.3390/genes7040014

Dossou, S.S.K., Xu, F., You, J., Zhou, R., Li, D. and Wang, L. (2022). Widely targeted metabolome profiling of different colored sesame (*Sesamum indicum* L.) seeds provides new insight into their antioxidant activities. *Food Research International*, 151, 110850. https://doi.org/10.1016/j.foodres.2021.110850

Dossou, S.S.K., Luo, Z., Wang, Z., Zhou, W., Zhou, R., Zhang, Y., Li, D., Liu, A., Dossa, K., You, J. and Wang, L. (2022). The dark pigment in the sesame (*Sesamum indicum* L.) seed coat: isolation, characterization, and its potential precursors. *Frontiers in Nutrition*, 9, 858673. https://doi.org/10.3389/fnut.2022.858673

El-Geddawy, M.A.U., Sorour, M.A., Abou-El-Hawa, S.H. and Taha, E.M.M. (2019). Effect of domestic processing and microwave heating on phenolic compounds and tannins in some oil seeds. *SVU-International Journal of Agricultural Sciences*, 1(2), 23-32. https://doi.org/10.21608/ svuijas.2019.67094

Elleuch, M., Bedigian, D. and Zitoun, A. (2011). Sesame (*Sesamum indicum* L.) seeds in food, nutrition, and health. Nuts and Seeds in Health and Disease Prevention, p. 1029-1036. USA: Academic Press. https://doi.org/10.1016/B978-0-12-375688-6.10122-7

Embaby, H.E.S. (2010). Effect of heat treatments on certain antinutrients and in vitro protein digestibility of peanut and sesame seeds. *Food Science and Technology Research*, 17(1), 31-38. https://doi.org/10.3136/fstr.17.31

Ertop, M.H. and Bektaş, M. (2018). Enhancement of bioavailable micronutrients and reduction of antinutrients in foods with some processes. *Food and Health*, 4(3), 159-165. https://doi.org/10.3153/fh18016

Gandhi, A.P. and Srivastava, J. (2007). Studies on the production of protein isolates from defatted sesame seed (*Sesamum indicum*) flour and their nutritional profile. *ASEAN Food Journal*, 14(3), 175-180.

Gholami, M., Davan, S.T., Gholami, M., Bolandparvaz, S., Gholami, M., Chamanpara, P. and Shayan, L. (2020). Effects of topical sesame oil extracted from Tahini (Ardeh) on pain severity in trauma patients: A randomized double-blinded placebo-controlled clinical trial. *Bulletin of Emergency and Trauma*, 8 (3), 179-185.

Greiner, R. and Konietzny, U. (2006). Phytase for food application. *Food Technology and Biotechnology*, 44 (2), 125-140. https://doi.org/10.1016/j.nbt.2009.06.386

Ha, T.J., Lee, M.H., Seo, W.D., Baek, I.Y., Kang, J.E. and Lee, J.H. (2017). Changes occurring in nutritional components (phytochemicals and free amino acid) of raw and sprouted seeds of white and black sesame (*Sesamum indicum* L.) and screening of their antioxidant activities. *Food Science and Biotechnology*, 26, 71–78. https://doi.org/10.1007/s10068-017-0010-9

Hadeel, S.Y., Khalida, S.A. and Walsh, M.K. (2020). Antioxidant activity of sesame seed lignans in sunflower and flaxseed oils. *Food Research*, 4(3), 612-622. https://doi.org/10.26656/ fr.2017.4(3).331

Hama, J.R. (2017). Comparison of fatty acid profile changes between unroasted and roasted brown sesame (*Sesamum indicum* L.) seeds oil. *International Journal of Food Properties*, 20(5), 957-967. https://doi.org/10.1080/10942912.2016.1190744

Hassan, M.A.M. (2013). Studies on Egyptian sesame seeds (*Sesamum indicum* L.) and its products. 3. Effect of roasting process on gross chemical composition, functional properties, antioxidative components and some minerals of defatted sesame seeds meal (*Sesamum indicum* L.). *World Journal of Dairy and Food Sciences*, 8(1), 51-57.

Jain, R. and Joshi, I. (2015). Nutrient analysis of germinated sesame seeds and development of value added biscuits. *Studies on Home and Community Science*, 9(2-3), 61-64. https://doi.org/10.1080/09737189.2015.11885436

Jannat, B., Oveisi, M., Sadeghi, N., Hajimahmoodi, M., Behzad, M., Choopankari, E. and Behfar, A. (2010). Effects of roasting temperature and time on healthy nutraceuticals of antioxidants and total phenolic content in Iranian sesame seeds (*Sesamum indicum* L.). *Journal of Environmental Health Science and Engineering*, 7(1), 97-102.

Jeong, S.M., Kim, S.Y., Kim, D.R., Nam, K.C., Ahn, D.U. and Lee, S.C. (2004). Effect of seed roasting conditions on the antioxidant activity of defatted sesame meal extracts. *Journal of Food Science*, 69 (5), C377-C381. https://doi.org/10.1111/j.1365-2621.2004.tb10701.x

Jimoh, W.A., Fagbenro, O.A. and Adeparusi, E.O. (2011). Effect of processing on some minerals, antinutrients and nutritional composition of sesame (*Sesamum indicum*) seed meals. *Electronic Journal of Environmental, Agricultural and Food Chemistry*, 10(1),1858-1864.

Kazlauskienė, D., Kasparavičienė, G., Nenortienė, P., Marksa, M., Jukilaitytė, J., Velžienė, S. and Ževžikovas, A. (2021). Determination of fatty acid composition and antioxidant activity in vegetable oils. *Chemija*, 32(1), 17-27. https://doi.org/10.6001/chemija.v32i1.4397

Kumar, V., Sinha, A.K., Makkar, H.P. and Becker, K. (2010). Dietary roles of phytate and phytase in human nutrition: A review. *Food Chemistry*, 120(4), 945-959. https://doi.org/10.1016/j.foodchem.2009.11.052

Langyan, S., Yadava, P., Sharma, S., Gupta, N.C., Bansal, R., Yadav, R. and Kumar, A. (2022). Food and nutraceutical functions of sesame oil: an underutilized crop for nutritional and health benefits. *Food Chemistry*, 389,132990. https://doi.org/10.1016/j.foodchem.2022.132990

Li, X., Dong, S., Bai, W., Jia, J., Gu, R., Zhao, C., Liu, X. and Wang, Y. (2020). Metabolic and transcriptional regulation of phenolic conversion and tocopherol biosynthesis during germination of sesame (*Sesamum indicum* L.) seeds. *Food and Function*, 11(11), 9848-9857. https://doi.org/10.1039/ d0fo01706j

Liu, B., Guo, X., Zhu, K. and Liu, Y. (2011). Nutritional evaluation and antioxidant activity of sesame sprouts. *Food Chemistry*, 129(3), 799-803. https://doi.org/10.1016/j.foodchem.2011.05.024

Longvah, T., Anantan, I., Bhaskarachary, K., Venkaiah, K. and Longvah, T. (2017). Indian Food Composition Tables. Hyderabad, India: National Institute of Nutrition, Indian Council of Medical Research.

Makinde, F.M. and Akinoso, R. (2013). Nutrient composition and effect of processing treatments on anti-nutritional factors of Nigerian sesame (*Sesamum indicum* L.) cultivars. *International Food Research Journal*, 20(5), 2293-2300.

Makinde, F.M. and Akinoso, R. (2014). Comparison between the nutritional quality of flour obtained from raw, roasted and fermented sesame (*Sesamum indicum* L.) seed grown in Nigeria. *Acta Scientiarum Polonorum Technologia Alimentaria*, 13(3), 309-319. https://doi.org/10.17306/ j.afs.2014.3.9

Makinde, F.M., Adetutu, A.O. and Olorunyomi, G.O. (2016). Influence of roasting techniques on chemical composition and physico-chemical properties of sesame (*Sesamum indicum*) seed flour and oil. *Applied Tropical Agriculture*, 21(2), 25-31.

Makinde, F.M., Akinoso, R. and Adepoju, A.O. (2013). Effect of fermentation containers on the chemical composition of fermented sesame (*Sesamum indicum* L) seeds. *African Journal of Food, Agriculture, Nutrition and Development*, 13(1), 7122-7137. https://doi.org/10.18697/ ajfand.56.11580

Makinde, F.M. and Victoria, A.T. (2018). Changes in Nutritional, Functional and Pasting Properties of Raw and Germinated Seeds of White Sesame (*Sesamum indicum* L.) Grown in Nigeria. *Acta Scientific Nutritional Health,* 2(11), 7-15.

Mares, L.F.D.M., Passos, M.C. and Menezes, C.C. (2017). Interference of germination time on chemical composition and antioxidant capacity of white sesame (*Sesamum indicum*). *Food Science and Technology*, 38(1), 248-253. https://doi.org/10.1590/1678-457x.20217

Mondal, N., Bhat, K.V. and Srivastava, P.S. (2010). Variation in fatty acid composition in Indian germplasm of sesame. *Journal of the American Oil Chemists' Society*, 87(11), 1263-1269. https://doi.org/10.1007/s11746-010-1615-9

Nagendra Prasad, M.N., Sanjay, K.R., Prasad, D.S., Vijay, N., Kothari, R. and Nanjunda Swamy, S. (2012). A review on nutritional and nutraceutical properties of sesame. *Nutrition and Food Science*, 2 (2), 127. https://doi.org/10.4172/2155-9600.1000127

Namiki, M. (2007). Nutraceutical functions of sesame: a review. *Critical Reviews in Food Science and Nutrition*, 47(7), 651-673. https://doi.org/10.1080/10408390600919114

Noonan, S.C. and Savage, G.P. (1999). Oxalate content of foods and its effect on humans. *Asia Pacific Journal of Clinical Nutrition*, 8(1), 64-74. https://doi.org/10.1046/j.1440-6047.1999.00038.x

Obianjunwa, E.I., Adebiyi, F.M. and Omode, P.E. (2005). Determination of essential minerals and trace elements in Nigerian sesame seeds, using TXRF technique. *Pakistan Journal of Nutrition*, 4(6), 393-395. https://doi.org/10.3923/pjn.2005.393.395

Okudu, H.O., Oguizu, A.D. and Nwaokoro, C.F. (2016). Nutrients and anti-nutrients contents of white beniseed caltivar (*Sesamum indicum* L.) in Nigeria. *Direct Research Journal of Agriculture and Food Science*, 4(10), 290-293.

Olagunju, A.I. and Ifesan, B.O. (2013). Changes in nutrient and antinutritional contents of sesame seeds during fermentation. *Journal of Microbiology, Biotechnology and Food Sciences*, 2(6), 2407-2410

Popova, A. and Mihaylova, D. (2019). Antinutrients in plant-based foods: A review. *The Open Biotechnology Journal*, 13(1), 68-76. https://doi.org/10.2174/1874070701913010068

Prasad, R. (2002). Textbook of field crops production. New Delhi, India: Indian Council of Agricultural Research,

Ravindran, V., Ravindran, G. and Sivalogan, S. (1994). Total and phytate phosphorus contents of various foods and feedstuffs of plant origin. *Food Chemistry*, 50(2), 133-136. https://doi.org/10.1016/0308-8146(94)90109-0

Rizki, H., Kzaiber, F., Elharfi, M., Ennahli, S. and Hanine, H. (2015). Effects of roasting temperature and time on the physicochemical properties of sesame (*Sesamum indicum*. L) seeds. *International Journal of Innovation and Applied Studies*, 11(1), 148-155.

Sallam, K.I., Abd-Elghany, S.M., Imre, K., Morar, A., Herman, V., Hussein, M.A. and Mahros, M.A. (2021). Ensuring safety and improving keeping quality of meatballs by addition of sesame oil and sesamol as natural antimicrobial and antioxidant agents. *Food Microbiology*, 99, 103834. https://doi.org/10.1016/j.fm.2021.103834

Sharma, L., Saini, C.S., Punia, S., Nain, V. and Sandhu, K.S. (2021). Sesame (*Sesamum indicum*) seed. In Tanwar, B. and Goyal, A. (Eds.) Oilseeds: Health Attributes and Food Applications, p. 305-330. Singapore: Springer. https://doi.org/10.1007/978-981-15-4194-0_12

Tenyang, N., Ponka, R., Tiencheu, B., Djikeng, F.T., Azmeera, T., Karuna, M.S., Prasad, R.B.N. and Womeni, H.M. (2017). Effects of boiling and roasting on proximate composition, lipid oxidation, fatty acid profile and mineral content of two sesame varieties commercialized and consumed in Far-North Region of Cameroon. *Food Chemistry*, 221, 1308-1316. https://doi.org/10.1016/j.foodchem.2016.11.025

Thakur, A., Sharma, V. and Thakur, A. (2019). An overview of antinutritional factors in food. *International Journal of Chemical Studies*, 7 (1), 2472-2479.

Toma, R.B., Tabekhia, M.M. and Williams, J.D. (1979). Phytate and oxalate contents in sesame seed (*Sesamum indicum* L.). *Nutrition Reports International (USA),* 20(1), 25-32.

Toros, H. and Guzmán-Alvarez, R. (2022). Reduction of antinutritional factors of three varieties of sesame (*Sesamum indicum* L.) seeds when applying heat-alkaline treatments". *Acta Scientific Nutritional Health*, 6(3), 59-68. https://doi.org/10.31080/asnh.2022.06.1009

Uzo-Peters, P.I. and Akinola, K.O. (2018). Effects of germination and defatting of the soybean and sesame on the mineral bioavailability and absorption of sweet potato based complementary diets. *African Journal of Food Science*, 12(11), 309-315. https://doi.org/10.5897/ajfs2017.1615

Wan, Y., Li, H., Fu, G., Chen, X., Chen, F. and Xie, M. (2015). The relationship of antioxidant components and antioxidant activity of sesame seed oil. *Journal of the Science of Food and Agriculture*, 95(13), 2571-2578. https://doi.org/10.1002/jsfa.7035

Zebib, H., Bultosa, G. and Abera, S. (2015). Physico-chemical properties of sesame (*Sesamum indicum* L.) varieties grown in Northern Area, Ethiopia. *Agricultural Sciences*, 6(2), 238-246. https://doi.org/10.4236/as.2015.62024

