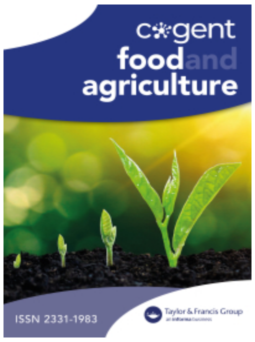

Cogent Food & Agriculture

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/oafa20

Unravelling the potential benefits of sesame (*Sesamum indicum* L.) in cropping systems, nutritional, health, and industrial uses of its seeds – a review

Cosmas Wacal, Simon Peter Musinguzi, Emmanuel Ewaju, Christopher Atibo, Docus Alowo, Jorem Alipa & Daniel Basalirwa

To cite this article: Cosmas Wacal, Simon Peter Musinguzi, Emmanuel Ewaju, Christopher Atibo, Docus Alowo, Jorem Alipa & Daniel Basalirwa (2024) Unravelling the potential benefits of sesame (*Sesamum indicum* L.) in cropping systems, nutritional, health, and industrial uses of its seeds – a review, Cogent Food & Agriculture, 10:1, 2360766, DOI: 10.1080/23311932.2024.2360766

To link to this article: https://doi.org/10.1080/23311932.2024.2360766

Published online: 11 Jun 2024.

COGENT FOOD & AGRICULTURE
2024, VOL. 10, NO. 1, 2360766
https://doi.org/10.1080/23311932.2024.2360766

SOIL & CROP SCIENCES | REVIEW ARTICLE
OPEN ACCESS Check for updates

Unravelling the potential benefits of sesame (*Sesamum indicum* L.) in cropping systems, nutritional, health, and industrial uses of its seeds – a review

Cosmas Wacal[a], Simon Peter Musinguzi[b,c], Emmanuel Ewaju[c], Christopher Atibo[d], Docus Alowo[e], Jorem Alipa[a] and Daniel Basalirwa[f]

[a]Department of Crop and Animal Production, Faculty of Agriculture and Environmental Sciences, Mountains of the Moon University, Fort Portal, Uganda; [b]Department of Agriculture Production, Faculty of Agriculture, Kyambogo University, Kyambogo, Uganda; [c]Department of Agriculture and Natural Sciences, Faculty of Agriculture, Uganda Martyrs University, Kampala, Uganda; [d]Department of Food Science and Postharvest Technology, Faculty of Agriculture and Environment, Gulu University, Gulu, Uganda; [e]Department of Food Innovations and Nutrition, Faculty of Agriculture and Environmental Sciences, Mountains of the Moon University, Fort Portal, Uganda; [f]Department of Soil and Environment, Swedish University of Agricultural Sciences, Uppsala, Sweden

ABSTRACT
Sesame (*Sesamum indicum* L.) is considered as one of the important oilseed crops produced throughout the world especially in the tropical and sub-tropical regions. Sesame crop is grown mainly for its highly nutritious seeds that also offer medicinal value. Sesame seed is rich in edible oil, fatty acids mainly linoleic acid and oleic acid, lignans, tocopherols, phytosterols, phenolic acids, and minerals. Due to these essential contents, the consumption of sesame seeds promotes good health not only in humans but also in livestock. Hence, sesame crop has gained significant attention throughout the world due to its several benefits. Although the global production of sesame is increasing, there is need to understand its various uses right from benefits in cropping systems to nutritional, health and industrial level. Several reviews have been conducted with the central focus on sesame nutritional and health promoting benefits but none has provided a holistic review of its benefits in cropping systems such as intercropping sesame with other crops, inclusion in crop rotation, utilization of its crop residues as nutrient recycling, and nutritional, health and industrial uses of sesame seeds, which this study sought to address.

IMPACT STATEMENT
Sesame is an important oilseed crop cultivated throughout the world especially in the tropical and sub-tropical regions. This study provides a holistic review of potential benefits of sesame in cropping systems, its nutritional, health and industrial uses. Sesame as a plant, plays important role in nutrient cycling, and can potentially be used in the production of bio-pesticide and herbicides for sustainable agriculture. The seeds are rich in minerals and polyunsaturated fatty acids, antioxidants and other ingredients that protect the body against hypertension, cardiovascular diseases, certain types of cancers, as well as treatment of male infertility and menopause, among others. In addition, sesame seed can be a viable and cost-effective alternative to expensive proteins in animal feeds since it has positive effects on growth rate and meat quality of livestock. Overall, the study highlighted the importance of sesame in cropping systems and its seeds in human diet, livestock feeding, and health, cosmetic application and potential uses as biofuel.

ARTICLE HISTORY
Received 11 July 2023
Revised 30 April 2024
Accepted 23 May 2024

KEYWORDS
Sesame oil; cropping system benefits; nutrition; lignans; health benefits; livestock feeds; biodiesel

REVIEWING EDITOR
M. Luisa Escudero-Gilete, Universidad de Sevilla, Spain

SUBJECTS
Agriculture & Environmental Sciences; Botany; Soil Sciences; Entomology; Food Additives & Ingredients

1. Introduction

Sesame, scientifically known as *Sesamum indicum* Linn is considered a very important oilseed crop in the Family *Pedaliacea* produced throughout the world (Bedigan, 2003). The cultivation of sesame crop has spread throughout the subtropical and tropical regions of Asia, Africa, Europe, Carribean and America (Lin et al., 2017; FAO, 2021). In fact, sesame has been cultivated since the ancient times, precisely more than 4,300 years ago (Hwang, 2005). For long, Asia

CONTACT Cosmas Wacal cwacal@gmail.com Department of Crop and Animal Production, Faculty of Agriculture and Environmental Sciences, Mountains of the Moon University, Fort Portal, Uganda

particularly India, and Africa have been reported as the central origin of sesame mainly because in these locations, there are many wild relatives of sesame which include *Sesamum radiatum* ($2n=64$), *Sesamum alatum* ($2n=26$), *Sesamum malabaricum* ($2n=26$) and *Sesamum indicum* var. *yanamalaiensis* ($2n=26$) (Ashri, 2007; Kumar & Hiremath, 2008; Sani et al., 2014; Kumari & Ganesamurthy, 2015). Although these wild species of sesame provide evidence of its origin from Africa or India, it is very difficult to ascertain the precise origin of sesame although it is believed that Africa and Asia are the most important centers of origin of sesame (Bedigian, 2004).

Morphologically, sesame is an annual herbaceous crop that grows in an erect manner with an average plant height of about 50 cm to 200 cm depending on the variety (Langham, 2008). The crop bears opposite leaves that can be as long as 15 cm and with entire margin (Figure 1). The leaves are broad and with lanceolate shape whereas the flowers are bell–shaped, pink, purple or white in colors which appear in the leaf axils (Wacal, 2019). The fruit is a capsule that usually dehiscences upon drying leading to shattering of seeds and this depends on varieties. The color of sesame seeds can be white, black, and yellow or brown which also depends on variety type (Figure 1). Of all the colors, there is a high global demand for white sesame seeds because of its high oil content, with low oxalic acid and reduced rancidity (Agidew et al., 2021; Wei et al., 2022).

Usually, sesame crop grows and matures within 90 to 120 days after sowing and its capsules can be harvested and be processed into paste, oils, used in foods, confectionary and medicinal ingredients. As mentioned earlier, sesame seeds are rich in fatty acids, minerals, proteins, carbohydrates, vitamin E, lignans mainly sesamolin and sesamin (Hassan, 2013; Nzikou et al., 2009; Ünal & Yalçın, 2008; Wu, 2007). These are the major functional ingredients that contribute to the nutraceutical and health benefits of consuming sesame seeds which include protection against hypertension, hypercholesterolemia, carcinogenic substances, neurodegenerative diseases like Alzheimer's disease and dermatological diseases (Kanu et al., 2010; Prasad et al., 2012).

In 2021, the global production of sesame seed was estimated to be 6,354,477 tons produced from 12,507,504 hectares (FAO, 2021). In the same year, the Food and Agriculture Organization statistics indicates that Sudan was the leading sesame seed producer with an annual production of 1,119,026 tons, followed by India (817,000 tons), Republic of

Figure 1. Sesame plants and its seeds (Wacal, 2019).

Tanzania (700,000 tons), Myanmar (641,729.97 tons), China (455,400 tons) and Nigeria (440,000 tons) (FAO, 2021) (Figure 2). Of the top ten producers of sesame seeds, 60% were from Africa indicating that Africa is the largest sesame seed producer in the world (3,362,247 tons) cultivated on over 7,007,345 ha (Table 1). Unfortunately, sesame yield is still lowest in Africa (490 kg/ha) as compared to Europe (1,143 kg/ha) with the smallest land under cultivation (383 ha), and also the seed yield obtained in Asia (588 kg/ha).

Overall, there has been a general increase in the production of sesame over the past years reflected by the rise in the area under cultivation (Figure 3). In 2012, the area under production was 8,542,528 ha producing 5,384,248 tons, but increased to 5,971,045 tons in 2014, was steadily maintained until 2019 when it increased to 6,549,085 tons but this decreased to 6,354,477 tons in 2021 produced from 12,507,504 ha. The decrease in 2021 could be attributed to COVID–19 pandemic that negatively affected global sesame production and trade.

Furthermore, FAO (2021) shows that the top five exporters of sesame seeds in the world are Sudan (289,465 tons), India (260,463 tons), Ethiopia (185,528 tons), Myanmar (171,997 tons) and Pakistan (160,462 tons) earning them 350, 422, 286, 341 and 214 million United States Dollars (USD), respectively (Table 2). On the other hand, China Mainland, Türkiye and Japan are the world's leading importers of sesame importing mainly from Sudan, India, Ethiopia and Myanmar. Generally, the FAO statistics indicate that sesame is important in generating revenue for most African and Asian countries and therefore considered a profitable crop (FAO, 2021; Wacal et al., 2021).

Despite the numerous benefits in terms of nutritional and health values, sesame production has mainly concentrated in Africa and Asia and mostly grown in marginal lands with limited input requirements. Thus sesame is considered a climate smart and high value crop in most countries where it is grown and is able to provide farmers' incomes and livelihoods amidst climate change (Dossa et al., 2017).

Although the global production of sesame is increasing, there is need to understand its various benefits in cropping systems as well as the utilization of its seeds for nutritional, health and industrial purposes. Numerous studies have been conducted to reveal the uses of sesame seeds especially related to nutritional and health promoting benefits (Abbas et al., 2022; Langyan et al., 2022; Mohammed & Pattan, 2022; Pathak et al., 2017; Wei et al., 2022), while others have focused on the level of production, export, import trends as well as challenges in the sesame seed production (Myint et al., 2020; Wacal et al., 2021; Yadav et al., 2022). However, there is still lack of a holistic review of the cropping system benefits derived from intercropping sesame with other crops, its inclusion in crop rotation systems, utilization of its crop residues as nutrient recycling and the overall nutritional, health and industrial benefits of sesame seeds, which this study seeks to address.

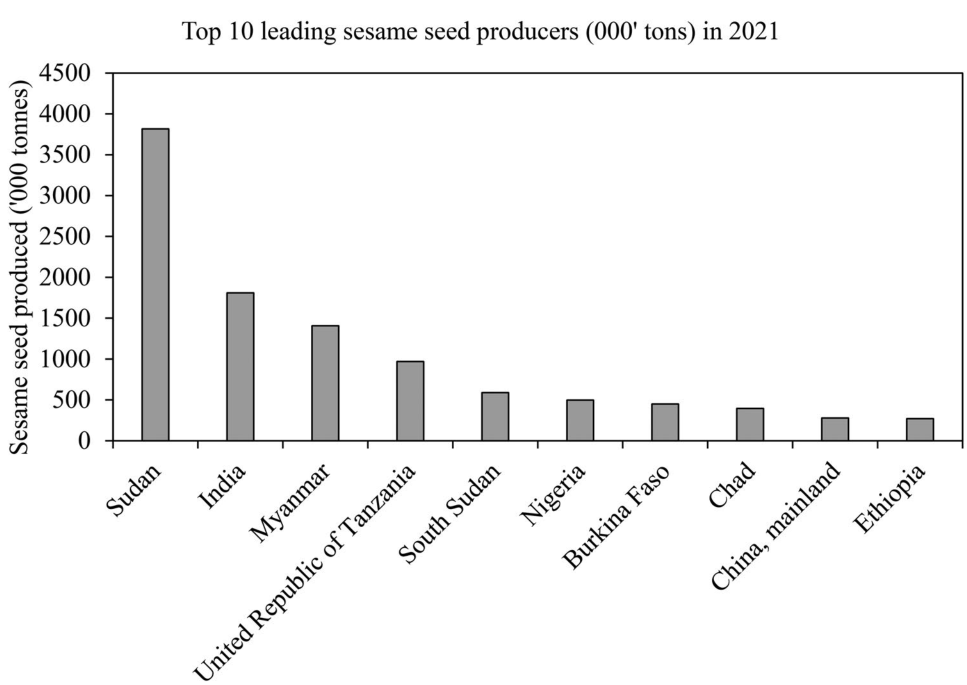

Figure 2. World's top ten leading sesame seed producers in 2021.

2. Benefits of sesame in cropping systems

Sesame is a resilient crop with a strong adaptation to different cropping systems and numerous benefits and that have been reported on the uses of plant parts or whole plant, in intercropping, crop rotation and soil fertility improvement (Couch et al., 2017; Hussain et al., 2017; Morini et al., 2005). For instance, the inclusion of sesame in cropping systems is one way of reducing weeds, since the crop vigorously outcompetes weeds (Creamer & Baldwin, 2000). This is mainly attributed to the allelopathy activity of sesame plants in which it inhibits the growth of weeds (Shah et al., 2016). Research shows that sesame exudes allelochemicals with phytotoxic effects on the growth of purple nutsedge (*Cyperus rotundus*) (Hussain et al., 2017). Hussain et al. tested sesame leaf extracts at concentrations of 50% and 100% on germination, growth and physiological processes in purple nut sedge weed. They found that sesame extracts at 100% significantly inhibited sprouting of nut sedge tubers, plant height, dry weight, chlorophyll and carotenoid as well as protein contents. The study revealed the potential of sesame root exudates to inhibit the photosynthetic capacity of the weeds as well as its establishment through the release of allelochemicals, a defensive mechanism to deter growth of other plants by sesame. Similarly, Kumar and Varshney (2008) isolated root exudates from sesame plants and tested different concentrations of 40, 80, 120, 160, 200 and 240 μg/g soil) on the seedling

Table 1. The area harvest, production and yield by continent in 2021.

Continent	Area harvested (ha)	Production (tons)	Yield (kg/ha)
Africa	7,007,345	336,2247	490
Asia	3,985,070	2,343,395	588
America	335,665	214,976	647
Caribbean	15,364	4,127	269
Europe	383	451	1,143

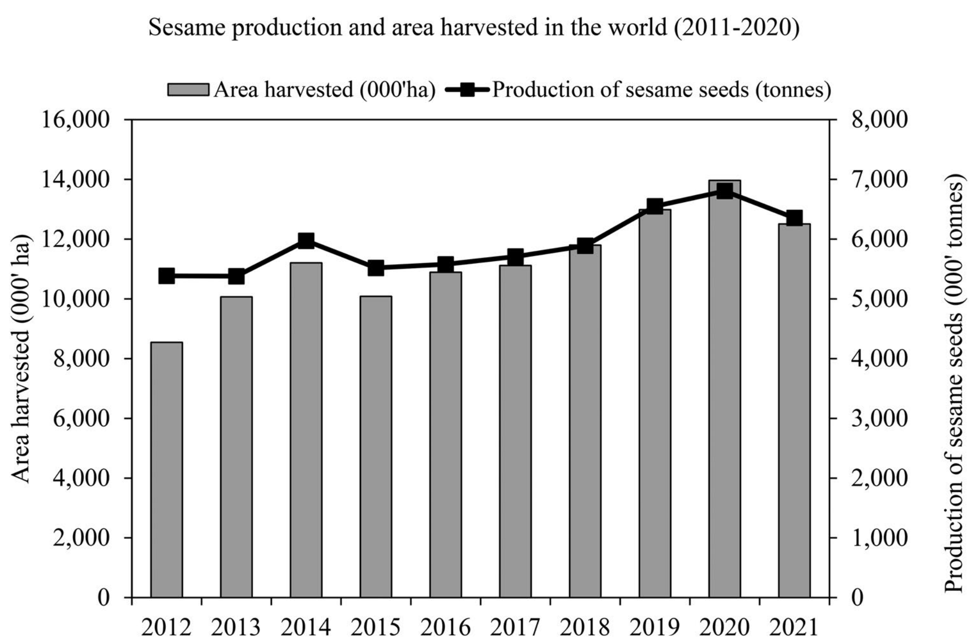

Figure 3. Trends in sesame production and area harvested in the world between 2012 and 2021.

Table 2. The top 10 world leading sesame seed exporters and importers in 2021.

Exporters			Importers		
Country	Export quantity (tons)	Export value (1000 USD)	Country	Import quantity (tons)	Import value (1000 USD)
Sudan	289,465	350,112	China, mainland	1,173,618	1,541,153
India	260,463	421,536	Türkiye	202,614	284,816
Ethiopia	185,528	286,042	Japan	150,975	213,148
Myanmar	171,997	341,791	Republic of Korea	86,923	151,900
Pakistan	160,428	214,098	Israel	66,770	101,779
Nigeria	138,333	170,996	Iran (Islamic Republic of)	60,700	90,000
United Republic of Tanzania	133,462	149,326	Saudi Arabia	48,274	67,611
Chad	91,940	116,970	Viet Nam	44,538	69,247
Mozambique	89,710	83,960	China, Taiwan Province of	43,142	62,791
Brazil	65,103	79,639	Germany	40,932	83,555

germination and growth of purple nut sedge. It was found that germination and growth of purple nut sedge decreased with increasing concentrations of root exudates and the concentration of 240 µg/g significantly inhibited shoots and root biomass by 81.3 and 91.9%, respectively over control. It was presumed that allelochemicals released naturally from roots of sesame as exudates have greater ability to suppress and degrade roots of purple nut sedge confirming the presence of active but unknown molecules in sesame root exudates which is still unclear. Furthermore, Zhao et al. (2022) tested different concentrations sesame plant extracts (of stem, leaf and roots) prepared at 0, 25, 50, 75 and 100 mg mL-1 on the germination and seedling growth of moso bamboo (*Phyllostachys edulis*). It was found that the germination time, radicle and plumule lengths were significantly decreased with increasing concentrations of extracts and the leaf extracts had the highest inhibition rates compared to the stem and root extracts. The authors isolated the allelochemicals and used high performance liquid chromatograph (HPLC), identifying nine compounds which included phenolics, alkaloids, terpenoids, flavonoids, steroid and its derivatives, coumarins, quinines, hydroxyl and substituted benzoic acids, and cinnamic acid and its derivatives. These studies reveal that sesame allelochemicals could be exploited in the development of novel bio-herbicides that are environmentally friendly and promote sustainable agriculture.

Research also indicates that sesame plants have high concentrations of lignans in the leaves, stems and seeds (Hata et al., 2010), which could be extracted and used for insecticide (Wu et al., 2007; Andargie et al., 2021). A study by Sintim et al. (2009) reported that whole leaves or vegetative parts of sesame extracts from selected sesame cultivars exhibited phototoxic effects against cotton leaf worm (*Spodoptera litura*). This is attributed to the phytotoxic substances found in sesame plants which include flavanoids, saponins, phenols, and other organic acids responsible for the insect repellency the (Laurentin et al., 2003). Furthermore, Morini et al. (2005) observed phytotoxic effects of sesame extracts against ant species (*Atta sexdens rubropilosa*) and revealed that the lignans i.e. sesamin and sesamolin were responsible for the phytotoxicity against the ants. According to Taverner et al. (2001), the extracts cause phytotoxicity effects through the blockage of spiracles suffocating the ants upon the oil traversing the hemolymph system of the insects. These studies indicate that sesame could be exploited in the development of cheap and are environmentally friendly bio-pesticides. However, more studies are need to isolate the bioactive compounds from sesame and test their efficacies on management of major insect pests in agriculture.

Studies also indicate that sesame plays important roles in intercropping and crop rotation systems (Tong et al., 2015; Yogranjan et al., 2014). For instance, higher crop yields have been reported in intercropping sesame with sunflower, maize and peanuts (Ijoyah et al., 2016; Olowe & Adeyemo, 2009). There are a number of mechanisms through which sesame crop increase crop yields. For instance, intercropping sesame with millet reduces the infestations of striga weeds (*Striga hermonthica* L.) as compared to mono-cropping of millet (Hess & Dodo, 2004; Wacal et al., 2021). In such intercropping systems, sesame exudate allelochemicals which inhibit the growth and establishment of parasitic weeds in a similar manner in which the "push and pull" technology works (Khan et al., 2010). The "push and pull" in weed control operates on the principle of allelopathy in which a plant e.g., silver leaf desmodium included in a cereal based intercropping system releases allelochemicals to inhibit the growth of *striga*. Since sesame exhibits a similar allelopathic activity towards striga, it could be important to explore the inclusion of sesame in the "push and pull" weed management technology. Furthermore, sesame plays an important role in management of plant pathogens such as *Fusarium oxysporum* f. sp., *Macrophomina phaseolina* due to the release of allelochemicals whose active ingredients have been cited as Chlorosesamone, hydroxysesamone and 2,3–epoxysesamone (Hasan et al., 2001; Syed et al., 2015). Additionally, sesame is known to reduce the detrimental effects of root–knot nematode when intercropped with cotton (Heuzé et al., 2016). These studies reveal that sesame plant as an intercrop, has the potential to reduce the negative effects of weeds and diseases increasing yields of other crops and overall productivity, thus considered important in a wide range of cropping systems. More still, intercropping sesame with broccoli has been shown to promote arbuscular mycorrhizal fungi colonization as it plays the role of a host plant (Tong et al., 2015). Arbuscular mycorrhizal fungi plays a significant role in nutrient acquisition and uptake from soils and enhancing resistance to stress (Bi et al., 2019; Gupta, 2020; Hu et al., 2022; Smith & Read, 2008). Thus, sesame has the potential to improve the productivity of several crops in varying cropping systems. However, studies are needed to demonstrate these mechanisms in different cropping systems where sesame is produced on poorly infertile soils with limited inputs under intercropping systems.

Nutrient recycling is an important aspect in promoting sustainability of cropping systems. Research indicates that sesame has extensive root system which recycles nutrients from the deep layer of soil to the top, and the plant provides valuable cover to the soil while at the same time exhibiting a positive effect on soil structure, moisture retention and tilth (Langham, 2008; Heuzé et al., 2016). Additionally, the above ground of sesame plants after harvest particularly stover, provide good source of nutrients for the succeeding crop. For instance, Langham (2020) reported that for every 1000 kg ha^{-1} of seed harvested, the remaining stover may contain up to 60 kg N, 11 kg P, and 94 kg K, while the leaves contain 16 kg N, 2 kg P, and 18 kg K. Thus, incorporation of sesame stover and leaves could play important role in recycling nutrients. However, the high nutrient content of sesame residues reported by Langham (2020) implies that it may also exhaust the soil available nutrient almost like cereal crops leading to decline in fertility. A study by Wacal et al. (2019b) reported that continuous mono-cropping of sesame without residue return to the fields led to significant decrease in soil organic nitrogen, carbon results and consequently low yield. Therefore, it is recommended that sesame crop residues should be incorporated in the soil to replenish the nutrients lost through harvest and maintain soil fertility.

More still, sesame stover can be converted to biochar, a soil amendment prepared from thermal degradation of crop residues and is known to improve soil fertility, crop growth and yield (Basalirwa et al., 2020; Park et al., 2015; Wacal et al., 2019a; Woldetsadik et al., 2018; Zheng et al., 2010). In addition, it has been reported that biochar prepared from sesame straw and applied in soils improved soil bulk density and also exhibited the potential of reducing N_2O gas emission (Kang et al., 2016). These studies show that sesame straw biochar can be use in agriculture to improve soil conditions, particularly soil fertility as well as mitigate climate change in various cropping systems. Overall, the use of sesame straw for biochar production could be a cheap and eco–friendly approach for soil fertility management in sesame producing regions. However, more studies are still needed to understand the quality of biochar from sesame residues, C sequestration potential and overall agronomic performances of crops cultivated on soils amended with biochar derived from sesame residues. Finally, research has shown that fermented sesame meal can be applied as an organic fertilizer for crop production since it may contain 5.9% nitrogen (N), 3.3% phosphoric acid (P), and 1.5% potassium oxide (K) (Wei et al., 2022). This kind of sesame meal could be a source of nutrients for the production of vegetables, such as watermelon, strawberries, and grapes. The benefit of using such fermented sesame meal an organic fertilizer lies in the proliferation of beneficial soil microorganisms such as bacteria and actinomycetes which enhance nutrient release in soil and thus improve soil fertility (Ma and Fang (2019). However, more studies are needed to understand the potential use of sesame meal as a biofertilizer for crop production.

3.1. Nutritional composition of sesame and its uses

3.1.1. Proximate analysis

Sesame is rich in dietary components such as crude protein, fats and carbohydrates (Hassan, 2012; Wada et al., 2021; Zebib et al., 2015). The seeds are rich in crude protein (average 24.79%), crude fat (average 49.81%) and carbohydrate (average 9.12%) (Table 3). The crude fiber, ash and moisture contents are present in lower and comparable proportions, 5.95, 5.62 and 3.46%, respectively, in the seeds. The above studies suggest that sesame is rich in crude fat and crude protein which makes it a functional food.

3.1.2. Seed mineral content

The mineral contents of sesame seeds are shown in (Table 4). On average, sesame seeds provide a good source of P (597.83 mg/100 g), K (623.84 mg/100 g), Ca (779.02 mg/100 g), Mg (408.95 mg/100 g), Fe (9.03 mg/100 g), Cu (1.51 mg/100 g), Zn (6.97 mg/100 g) and Mn (3.16 mg/100 g) (Deme et al., 2017; Makinde & Akinoso, 2014; Tenyang et al., 2016; Wacal et al., 2019c). These minerals are important for various physiological functions in the body (Pathak et al., 2014).

Table 3. Seed proximate composition of sesame grown in different parts of the world.

Crude protein (%)	Crude fat (%)	Carbohydrate (%)	Crude fiber (%)	Ash (%)	Moisture (%)	Reference
23.11	51.58	10.46	5.98	5.36	3.51	Zebib et al. (2015)
37.24	47.18	1.60	4.03	8.82	3.71	El–Khier et al. (2008)
22.30	58.52	5.64	7.03	3.25	2.96	Hassan (2012)
26.23	52.70	9.77	3.56	5.83	1.91	Olagunju & Ifesan (2013)
20.55	–	–	3.30	4.27	4.21	Asghar et al. (2014)
19.31	39.08	18.11	11.82	6.20	4.47	Wada et al. (2021)
24.79	49.81	9.12	5.95	5.62	3.46	Mean

3.1.3. Oil and fatty acid content

Sesame oil is a major source of fatty acid both essential and non-essential. For instance, Zahran et al. (2020) reported on average, oil content range of 39.56 to 54.64% among sesame genotypes of Egypt whereas Ünal and Yalçın (2008) reported on average 54.26% among Turkish sesame seeds. Kancharla and Arumugam (2020) also analyzed the oil content of forty-five different sesame accessions consisting of white brown and black sesame seeds and reported that oil content ranged from 44.89 to 48.00% in the white, 38.89 to 49.67% in the brown and 41.33 to 44.11% in the black sesame seeds. Similarly, Dar et al. (2019) studied the variability in fatty acid content of forty-three different accessions of sesame in India and found that oleic and linoleic acids the dominant fatty acid constituents of sesame seeds, ranged from 34.71 to 45.61% and 38.49 to 49.60% respectively. On average, the fatty acids are palmitic (8.42%), linolenic (0.6%), linoleic (41.16%), oleic (39.56%), stearic (5.55%), and arachidic (0.6%) (Table 5).

3.1.4. Amino acid composition of sesame seeds

The most common essential amino acids in sesame seeds include phenylalanine, methionine, threonine, valine, and histidine (Ahmed et al., 2020; Nweke et al., 2011; Yüzer & Gençcelep, 2023). On average, alanine (4.77), aspartic (3.73%), arginine (3.69%) and leucine (3.08%) are contained in high amounts (Table 6).

3.1.5. Ligans, tocopherols and phytosterols of sesame seeds

Sesame seeds contain important plant based lignans that majorly include sesamin, sesamolin and sesaminol. These lignans are responsible for the antioxidant properties of sesame oil (Wu, 2007; Li et al., 2023). On average sesame contains 3.14 mg/g of sesamin, 1.08 mg/g of sesamolin and 0.37 mg/g sesamol, with a total of 6.15 mg/g of lignans (Table 7). The seeds are also important source of tocopherols, precursors of vitamin E which are also related to the antioxidant properties of sesame oil. Research also show that sesame seeds is rich in γ-tocopherol and α-tocopherol which are the two major forms of vitamin E (Wan et al., 2015). The total tocopherols in sesame seeds varies with variety and locations. For instance Matthäus & Özcan (2018) valued the tocopherol levels of sesame seeds from eleven different countries and found 34.07 mg/100g γ-tocopherol and 0.134 mg/100g α-tocopherol. Similarly, Williamson et al. (2008) evaluated the contents of tocopherols in sesame seeds from 11 different genotypes from eight countries and found on average 7.81 mg/100g γ-tocopherol and 0.026 mg/100g α-tocopherol. On average, the γ-tocopherol may be found in the range of 8.12 mg/100g to 53.1 mg/100g while α-tocopherol is 0.14 to 18.01 mg/100g in sesame seeds (Aued-Pimentel

Table 4. Mineral content of different Sesame seeds (mg/100 g) across the world.

P	K	Ca	Mg	Fe	Cu	Zn	Mn	Reference
442.94	336.75	464.97	399.65	6.42	–	7.97	1.5	Makinde and Akinoso (2014)
784.64	743.50	424.66	313.08	10.26	1.02	3.80	3.46	Deme et al. (2017)
645.10	686.08	1501.72	455.90	10.52	2.10	9.60	5.30	Tenyang et al. (2016)
518.65	729.05	724.75	467.15	8.91	1.42	6.51	2.40	Wacal et al. (2019c)
597.83	623.84	779.02	408.95	9.03	1.51	6.97	3.16	Mean

Table 5. Fatty acid composition (%) of sesame seeds across the world.

Palmitic (%) (C16:0)	Stearic (%) (C18:0)	Oleic (%) (C18:1)	Linoleic (%) (C18:2)	Linolenic (%) (C18:3)	Arachidic (%) (C20:0)	SFA (%)	MUFA (%)	PUFA (%)	References
5.60	5.30	40.30	46.10	0.40	0.50	12.8	40.70	46.50	Hama (2017)
10.10	4.72	41.06	43.24	0.36	0.50	15.23	41.30	43.60	Dar et al. (2019)
6.70	–	33.65	34.00	1.38	–	9.95	17.85	18.70	Wacal et al. (2019d)
8.25	4.89	37.60	47.77	0.45	0.50	–	–	–	Were et al. (2006)
8.65	5.45	43.02	46.25	–	0.85	–	–	–	Nzikou et al. (2009)
10.07	6.38	38.35	44.00	–	0.61	–	–	–	Agidew et al. (2021)
8.27	5.69	39.34	43.85	0.36	0.61	–	–	–	Matthäus & Özcan (2018)
9.44	5.28	39.32	43.08	0.32	0.55	–	–	–	Kurt (2018)
8.72	6.69	43.42	40.14	0.91	0.64	15.94	43.77	40.29	Zahran et al. (2020)
8.42	5.55	39.56	43.16	0.60	0.60	13.48	35.91	37.27	Mean

Table 6. Amino acid profile of Sesame seeds.

S/N	Amino (%)	Nweke et al. (2011)	Ahmed et al. (2020)	Yüzer and Gençcelep (2023)	Mean
1	Arginine	4.31	2.43	4.33	3.69
2	Alanine	1.56	0.90	11.86	4.77
3	Aspartic	2.65	1.63	6.92	3.73
4	Cysteine	0.16	0.40	1.57	0.71
5	Glutamic	7.12	3.52	17.78	9.47
6	Glycine	1.70	0.98	2.26	1.65
7	Histidine	0.87	0.48	2.51	1.29
8	Isoleucine	1.30	0.73	2.32	1.45
9	Leucine	2.25	1.32	5.68	3.08
10	Lysine	0.91	0.58	2.82	1.44
11	Methionine	0.93	0.64	2.78	1.45
12	Ornithine	–	0.01	–	0.01
13	Phenylalanine	1.55	0.86	4.47	2.29
14	Proline	1.20	0.68	3.55	1.81
15	Serine	1.52	0.89	4.21	2.21
16	Threonine	1.19	–	3.45	2.32
17	Tyrosine	1.27	0.64	2.90	1.60
18	Tryptophan	–	0.13	–	0.13
19	Valine	1.60	0.90	3.52	2.01

Table 7. Sesame lignin contents in seeds.

Sesamin (mg/g)	Sesamolin (mg/g)	Sesamol (mg/g)	Total lignin (mg/g)	References
9.47	1.74	0.30	11.51	Wu, 2007
2.65	1.65	0.44	4.74	Dar et al., 2015
0.78	0.23	–	8.18	Kim et al., 2014
1.26	1.18	–	4.15	Shi et al., 2017
1.55	0.62	–	2.17	Rangkadilok et al., 2010
3.14	1.08	0.37	6.15	Mean

et al., 2006; Matthäus & Özcan, 2018; Williamson et al., 2008).

Sesame seeds also contain high amounts of phytosterol which can range from 231.7 to 305.2 mg/100 g with β-sitosterol the predominant phytosterol, followed by campesterol and stigmasterol (Pathak et al., 2014). In addition, a study by Deme *et* al. (2021) investigated the contents of phytosterol and found that β-sitosterol constituted 927.42 mg/kg followed by campesterol and stigmasterol comprising 351.23 and 125.73 mg/kg, respectively and these sterols made up 85% of the sterol content of sesame oil. It is these phystoterols that are responsible for lowering cholesterol level in the blood when sesame is consumed in the diet reducing the risk of certain cancers (Pathak et al., 2014). Furthermore, sesame is rich in phenolic and flavonoid compounds. Agidew et al. (2021) investigate the contents of total phenolic and flavonoids in black and white sesame varieties and found that the total phenolic content ranged from 2.95 to 6.96 mgGAE/g of seeds while total flavonoid content ranged from 2.13 to 4.99 mgCE/g. These phenolic and flavonoids play a key role in antioxidant activity and anti-carcinogenic properties when sesame is included in the diet (Lin et al., 2017).

3.2. Nutritional uses of sesame

3.2.1. Human nutrition

Due to the nutritional compositions of sesame seeds aforementioned, sesame has been used in confectionery and food in different parts of the world. Sesame seeds are potential ingredients in the development of healthy snacks and confectioneries that can substitute the ultra–processed cereal–based confectioneries. Sesame seeds have low sugar content, thus its products like biscuits, cookies are considered low glycemic confectionaries (de Carvalho et al., 2023). The authors reported high scores for the different sensory attributes of confectionery developed from sesame. Similarly, Alobo (2001) reported that sesame can be used instead of millet flour to prepare biscuits. Moreover, sesame seeds have been included in flour formulation to develop nutritious complementary flour as a sustainable strategy to curb the persistent prevalence of malnutrition (Alowo et al., 2018; Gernah et al., 2012; Ikujenlola, 2014). Further processing of sesame seeds such as oil extraction provides sesame oil that is used in preparation of other diets and meals (Bedigan, 2018).

The tender leaves of sesame plants are also consumed as a delicious vegetable prepared as a mucilaginous sauce in some African countries such as Uganda (East Africa) and Ivory Coast (West Africa) (Aworh, 2018; Bedigan, 2018). This is attributed to the high nutritive values such as carbohydrates, proteins, minerals and fiber highly recommended for human consumptions. In addition, there are important phytochemicals in sesame leaves found in greater amounts include flavonoids and alkaloids whereas tanins, phenols and phytates being anti-nutritional factors are in low contents (Mbaebie et al., 2010). The flavonoids and phenolic compounds are very important for antioxidant activities when sesame leaves are consumed in the diet (Lin et al., 2017). In some communities of developing countries such as Uganda, sesame seeds may be washed, dried and pounded in a motor using a pestle and cooked with dry fish or smoked meat providing carbohydrates, fats and oils, minerals, protein and fibre like the vegetables (Alowo et al., 2018).

These studies reveal the different ways sesame seeds are consumed as foods across the world. This also suggests sesame is a nutrient dense food with adequately balanced nutritional contents that offer an alternative to fight malnutrition (Wei et al., 2022). Therefore, advocating for the inclusion of sesame in different diets and menus is crucial in curbing the double burden of malnutrition in developing countries (Reardon et al., 2021).

3.2.2. Livestock nutrition

Several researches have shown that sesame seeds can be a feed component for fish, chicken, and other livestock (Bonos et al., 2017; Dernekbaşı et al., 2017; Obeidat et al., 2019). An earlier study by Emadi et al. (2014) reported that sesame seeds can be an important ingredient in fish feed, as observed by the increase in the growth rate and weight gain in rainbow trout *Oncorhynchus mykiss* fed on feeds containing 20% sesame seed. Specifically, sesame seed is rich in amino acid methionine which can be a substitute for other plant based fishmeal deficient in this essential amino acid (Enyidi et al., 2014). Thus, sesame meal could be used to enhance fish growth rate and meat quality.

Furthermore, a study indicates that sesame meal can effectively replace soya beans as an alternative source of protein for piglets at critical phase of weaning and at a relatively lower cost (Reis de Souza et al., 2017). The authors reported that sesame meal has the potential of allowing increased utilization of digestible arginine in weaned piglets for enhanced growth performance. Other studies have also revealed that when phytase which is an exogenous enzyme is included in the diet, phytic acid is hydrolyzed to produce evidently higher amounts of calcium, and apparent total tract digestibility, therefore, providing an increased availability for use in pigs (Almeida et al., 2013; Braña et al., 2006).

Research also shows that the inclusion of 12% sesame seed meal in rabbit production significantly improve their growth and carcass quality (Njidda & Isidahomen, 2010). The authors fed New Zealand white breed rabbits on diets mixed with 4, 8 and 12% of sesame seed meal (SSM) and found that the best rate was 12% and attributed this benefits to the abundant protein and fats in sesame seeds.

Sesame seed meal has also been reported to improve the growth of lambs and ewes (Sheep) and even goats as well as reduce cost of feeding (Obeidat et al., 2019; Obeidat & Gharaybeh, 2011; Pérez et al., 2022). Bonos et al. (2017) fed lambs of Pelagonia (comparing sesame seeds mixed at a rate of at 100 g/kg feed and 200 g/kg feed, with conventional feeds for 9 weeks and they observed that lambs fed on sesame hull at 200 g/kg feed had significantly better final body weight, and high quality carcass. Furthermore, sesame seed hulls included up to 12% in broiler chicken feeding has been reported to increase growth rate and meat quality (Mahmoud et al., 2015). These improvements in the growth of livestock upon feeding sesame seed meals are attributed to the existence of polyunsaturated fatty acids in sesame seeds (Wei et al., 2022).

Moreover, sesame meal has been reported to significantly improve milk production. Mitsiopoulou et al. (2021) reported that incorporating whole sesame seeds in the concentrates in goats' diets at 10% non-significantly increased milk yield (1594 g/h/day) compared to feeding only forages without the sesame seeds (1570 g/h/day). The authors also reported that 10% whole sesame seeds significantly increased fat content (4.20%) in milk compared to the control (3.15%). It was also reported that including sesame seeds to replace 10 and 20% of concentrate protein resulted into high milk production of 1523 and 1491 g/h/day respectively compared without sesame seeds (1381 g/day) (Maged et al., 2017). Additionally, the authors observed significantly higher fat percentage in the milk when sesame seeds were included in the rations. Research also indicates that partial substitution (50%) of soybean meal (protein) by inclusion of sesame seed meal in the diet of buffaloes did not have any significant differences in the milk yield (10.7 kg//h/day) when compared to the control (10.4 kg/h/day) (Mahmoud & Ghoneem, 2014). These findings suggest that incorporating sesame seeds into the diet of lactating livestock can improve milk production although more research is needed on other livestock species.

Furthermore, sesame can be used as an additive to make good quality silage with improved palatability in ruminants (Hirano et al., 2005). The plants can be harvested at different phenological stages, including with pod, milky grain, and mature grain, for silage making (de Carvalho et al., 2023). A study by Amorim et al. (2020) showed that sesame silage had a higher crude protein (117.7 g/kg of dry matter, DW) content and lower fiber content (562.4 g/kg DM) compared to corn and millet silages and thus having a better rumen fermentation quality and digestibility when tested in rams (male sheep). These studies provide opportunities to harness sesame as an alternative ingredients in silage making.

Overall, the above studies indicated that sesame seeds can be a viable and cost-effective alternative to expensive proteins in animal feeds since it has positive effects on growth rate and meat quality (Omer et al., 2019).

4. Medicinal uses, and nutraceutical properties

The seeds of sesame provide important nutrients such as the fatty acids, minerals, amino acids and lignans that are beneficial in human nutrition (Tables 3–7). Hence, several studies have reported the health promoting benefits of sesame and its cosmetic uses (Chinweuba & Chendo, 2017; Heidari–Soureshjani et al., 2016; Hsu & Parthasarathy, 2017; Majdalawieh & Mansour, 2019), as discussed below.

4.1. Antihypertension and cardiovascular diseases

Hypertension or high blood pressure is one of the leading causes of cardiovascular diseases (Rapsomaniki et al., 2014). An earlier study by Sudhakar et al. (2011) provided sesame and sunflower oil mixture to patients to consume for 45 days and observed that the Nifedipine and oil–mix patients had significant improvement in the health evidenced by the lowering of the blood pressure compared to those patients treated on nifedipine drug alone. The improvement in hypertension patients due to consumption of sesame-sunflower oil was attributed to the abundance of polyunsaturated fatty acids and ligans such as sesamin and sesamolin that lower the lipid peroxidation as well as decreasing inflammatory effects (Ogunsola & Fasola, 2014; Vennila, 2017).

With the lowering of blood pressure, sesame oil is capable of preventing the occurrence of hypertension and cardiovascular diseases in humans (Hsu & Parthasarathy, 2017). The authors attributed this to the lignan contents such as sesamin and sesamolin with antioxidant and hypocholesterolemic effects. A study by Karatzi et al. (2013) found that after the consumption of sesame oil provided as salad dressing for 60 days, postprandial and flow mediated dilation (FMD) were significantly increased implying reduced risk of cardiovascular disease. Another study showed that ingesting about 2.52 g black sesame meal daily for 4 weeks instead of the sesame oil showed antihypertensive effects, and preventing the risk of cardiovascular disease (Wichitsranoi et al., 2011). Thus, the inclusion of sesame in the diet could play a significant role in reducing hypertension and cardiovascular diseases attributed to antioxidant activities of sesame seeds.

4.2. Anticarcinogenic properties

A study conducted both in vitro and vivo proved the concept that lignans especially sesamin and sesamol from sesame oil contain important anti–carcinogenic properties (Majdalawieh et al., 2017; Majdalawieh & Mansour, 2019). Research reveal that increasing the consumption of sesamin can have a negative effect on tumor cells responsible for various forms of cancer such as colon, prostate, breast, pancreas, and lung cancers (Harikumar et al., 2010). However, further studies need to be done to identify the right quantities of sesame lignans required to completely destroy cancer cells comparable with chemotherapy treatments.

4.3. Knee osteoarthritis

There is also arise in the level of arthritis worldwide especially among the elderly people. Fortunately, sesame in combination with other conventional treatment packages have been associated with reduced effects of osteoarthritis especially on the knee (Eftekhar Sadat et al., 2013). In their study, the authors administered both standard drug therapy and 40 g/day of sesame seeds by oral for 2 months and observed that patients receiving the sesame seeds combination progressively recovered from knee osteoarthritis. This was attributed to the increase in antioxidant enzyme activity and body oxidative status improving clinical signs of knee osteoarthritis.

4.4. Antifungal and antibacterial properties

Sesame oils also possess antifungal and antibacterial thus playing important role in treating wounds (Lavaee et al., 2019; Shittu et al., 2007). This is attributed to the fact that sesame oil inhibits the growth of bacteria and fungi. For instance, a study showed that *staphylococcus aureus* infections can be treated with a minimum concentration of sesame oil of 32 mg/ml (Heidari–Soureshjani et al., 2016). This study shows that sesame oil which has a very effective antibacterial and antifungal activity could be promising agents for the future development of antibiotics and anti-fungal drugs.

4.5. Anti–ulcer properties

Sesame has also been known to protect against ulcers (Mishra et al., 2019). Mishra et al. (2019) conducted a study using rats to determine whether or not the use of sesame plant extracts (0.5 and 1 mg/kg) could heal gastric ulcers and indeed the extracts showed potentials to offer gastroprotective activity against ulcers. The authors showed that sesame, had a remarkable reversal of gastric mucosal damage induced by alendronate. This is because the damaging effects of both ethanol and stress are known to be closely associated with the impairment of mucosal barrier mechanisms and therefore it could be recommended that the consumption of sesame oil offers protection against ulcers.

4.6. Treating infertility

Research also indicates that sesame seed and its oil is capable of treating male fertility when used in combinations with other treatments (Ashamu et al., 2010). Using sesame seeds, a study found that sperm quality (count and mobility) was greatly improved in males who ingested sesame seeds in their diets for 3 months (Khani et al., 2013). In their study, the patients were offered oral powder of sesame sachets, 0.5 mg/kg for 3 months and the result of semen analysis showed an increase in spermatocyte size attributed to the lignans that play important role in eliminating reactive oxygen species responsible for low sperm production. Furthermore, a study of women infertility at post menopause reported that sesame seed ingestion promoted the production of estrogen due to sesame lignan (sesamol), thus reversing menopause (Dar & Arumugam, 2013). All these studies indicate that sesame has potential to treat infertility and reverse menopause in men and women, respectively although there is still need for more research in this area.

4.7. Massage therapy

Sesame oil is also reported to have been applied in massage therapies. A study has shown that sesame oil can be used as a complimentary treatment of pain relief after massage in a clinical trial (Bigdeli Shamloo et al., 2019). In their study, the patients received a five minute massage twice a day for seven consecutive days with sesame oil and had their pains significantly reduced. A similar finding was reported by Nasiri and Farsi (2017) who observed that massaging patients with limb trauma (phlebitis) with sesame oil significantly reduced the pain. The authors attributed this to the analgesic activities of this oil, which due to its chemical composition, could be effective in reducing the pain severity of phlebitis. These important compositions are the unsaturated fatty acids and the lignans that play a vital role in anti–inflammatory activities thereby alleviating pain.

5. Industrial uses

5.1. Cosmetics uses of sesame

Sesame oil also serves as a high quality source of materials for soap and cosmetic production. A study has revealed that sesame oil v has a high nondrying value and has potential use in production of soap and cream (Chinweuba & Chendo, 2017). The authors demonstrated that liquid and solid soaps could be prepared by boiling 50% sodium hydroxide mixed with 14.25% sesame oil in the presence of 35.50% water and 0.02% sodium silicate. The liquid soap was produced from sesame seed oil by saponification of 30% of the oil with 8% potassium hydroxide, 58.8% water and 3.2% alcohol or formaldehyde. When tested, the properties of the soap and body cream were considered high quality comparable to products on the markets.

5.2. Production of biofuel from sesame

There is an increase in the demand for fossil fuel despite its negative impacts of global warming and climate change (Holechek et al., 2022). Alternative sources of fuel preferably renewable energy and biofuels are being sought (Dawodu et al., 2014). Research has shown that sesame oil could offer a suitable raw material for biodiesel production through the process of transesterification of its fatty acid contents (Betiku & Adepoju, 2013; Wakil et al., 2014).

A study by Dawodu et al. (2014) subjected sesame oil to transesterification with methanol in the presence of sodium methoxide and observed a biodiesel yield of 87.80% when optimum condition of 1:6 oil/methanol molar ratio were maintained, in the presence of a catalyst (0.75%) after a reaction time of 30 min was achieved. The selected fuel properties were within the range set by ASTM and EN bodies. Furthermore, Ahmad et al. (2011) demonstrated that sesame oil after undergoing transesterification, biodiesel is obtained. The researchers conducted an acid–base catalyst transesterification of sesame crude oil at 6:1 molar ratio of methanol/oil, respectively, using 0.34%, 0.67%, and 1.35% of sodium hydroxide–potassium hydroxide mixture as a catalyst for the optimization process when the reaction temperature at 60^{0}C was maintained and stirred for 1–30 h with a stirring velocity of 600 rpm. The resultant mixture was cooled at room temperature for the separation of different phases and biodiesel was obtained. The authors successfully produced a biodiesel yield of 92% and the fuel properties of sesame biodiesel met the American Society for Testing Material (ASTM) biodiesel standards. Saydut et al. (2008) also achieved transesterification (i.e., methyl esters) of sesame oil, by mixing the same with methyl alcohol in a molar ratio of 1:6 and catalyst (NaOH) concentration of 0.5% at 600^{0}C which ultimately converts sesame oil to biodiesel. The quality assurance determination revealed that sesame biodiesel produced have similar properties such viscosity and density of the methyl esters with that of petroleum based diesel (Yogranjan et al., 2014). These studies suggested that sesame, which is widely grown for food consumption, can also potentially provide raw materials for biodiesel production (Ahmad et al., 2010), although there is need to understand the cost benefit implications of using sesame plants for biodiesel.

6. Conclusion and future scope

This review unraveled the benefits of sesame in various cropping systems, nutritional, health, and industrial uses of sesame crop. Precisely, this review revealed that sesame plants offers several benefits such as reducing weed and pest infestations in cropping systems which could be exploited in biopesticide and herbicides production for sustainable agriculture. It also plays a role in promoting arbuscular mycorrhizal, nutrient recycling through its crop residues and providing raw materials for biochar and other organic fertilizers production. The seeds are rich in minerals and polyunsaturated fatty acids, antioxidants and other bioactive compounds that protect the body against hypertension, cardiovascular diseases, certain types of cancers, knee osteoarthritis, ulcers, as a massage oil for alleviating pain, as well as treatment of male infertility and menopause, among others. In addition, sesame seed can be a viable and cost-effective alternative to expensive proteins in animal feeds since it has positive effects on growth rate and meat quality of livestock. Overall, the study highlighted the importance of sesame seeds in human diet, livestock feeding, health, and its cosmetic and potential uses as biofuel. However, the use of sesame as raw material for production of biofuel as an alternative energy to fossil fuel requires clear understanding of cost benefit analysis of using sesame compared to other oils. Additionally, more research is needed on sesame production technologies, development of novel livestock feeds and functional health products from sesame seeds that can be marketed globally.

Disclosure statement

The authors declare no conflict of interest.

Funding

The authors received no direct funding for this work.

About the authors

Cosmas Wacal is a Lecturer in the Department of Crop and Animal Production, Faculty of Agriculture and Environmental sciences, Mountains of the Moon University, Uganda. He is an agronomist with core competences in soil science and has several years of experience in conducting research on sesame production. His research interests are in the areas of sustainable crop production, nutrient cycling, soil fertility management, and plant nutrition, utilization of biochar in different cropping systems to enhance crop productivity and carbon sequestration, and as well any studies addressing food insecurity issues.

Simon Peter Musinguzi is a Senior Lecturer of Animal Science in the Department of Agriculture Production, Faculty of Agriculture, Kyambogo University, Uganda and lecturer in the Department of Agriculture and Natural Sciences, Uganda Martyrs University Uganda. His area of expertise is in veterinary Science, parasitology, epidemiology, Microbiology, molecular biology, animal production, livelihoods and food systems, agriculture.

Emmanuel Ewaju is an Assistant Lecturer in the Department of Agriculture and Natural Sciences, Uganda Martyrs University. He is a livestock scientist with key competences in; livestock nutrition, feed resources and utilization; sustainable management of livestock production. His other research areas include; soil- plant - livestock - human nutrient interaction; and indigenous systems in animal genetic resource conservation.

Christopher Atibo is a researcher in the Department of Food Science and Post-harvest Technology, Faculty of Agriculture and Environment, Gulu University, Uganda. He is a Food Security and Nutrition specialist with core competencies in nutrition sensitive and specific areas. Christopher is passionate about agriculture, nutrition and entrepreneurship research.

Docus Alowo is an Assistant Lecturer in the Department of Food Innovation and Nutrition, Faculty of Agriculture and Environmental sciences, Mountains of the Moon University, Uganda. She is a food and Nutrition security specialist with core competences in nutrition research and has several years of experience in food product development using nutrient dense plant-foods such as sesame. Her research interest covers prebiotic and probiotic potential of plant-based foods, food and nutrition security, molecular and precision nutrition to solve emerging food and nutrition challenges at different socio-economic levels.

Alipa Jorem is currently a teaching assistant at Mountains of the Moon University based in Fort portal-Uganda. His area of specialization is Plant Breeding and Seed Systems. He is particularly interested in seed technology, plant pathology, plant breeding and agronomy.

Daniel Basalirwa is a Post-doctoral researcher at the Swedish University of Agricultural Sciences, Uppsala, Sweden. His research interests are mainly in agroecology, soil carbon & nitrogen cycling, soil fertility management, and plant nutrition; including the utilization of biochar in different cropping systems to simultaneously enhance crop productivity, mitigate greenhouse gas (GHG) emissions, and increase resilience to the impacts of climate change.

ORCID

Cosmas Wacal http://orcid.org/0000-0002-4831-3191

Data availability statement

The data supporting the findings of this study are available within the manuscript.

References

Abbas, S., Sharif, K. M., Sibt–e–Abbas, M., Teferra, F. T., Sultan, T. M., & Anwar, J. M. (2022). Nutritional and therapeutic potential of sesame seeds. *Journal of Food Quality*, *2022*, 1–19. https://doi.org/10.1155/2022/6163753

Agidew, M. G., Dubale, A. A., Atlabachew, M., & 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*(1), 10. https://doi.org/10.1186/s40538–021–00215–w

Ahmad, M., Khan, M. A., Zafar, M., & Sultana, S. (2010). Environment friendly renewable energy from sesame biodiesel. *Recovery, Utilization, and Environmental Effects*, *32*(2), 189–196.

Ahmad, M., Ullah, K., Khan, M. A., Ali, S., Zafar, M., & Sultana, S. (2011). Quantitative and qualitative analysis of sesame oil biodiesel. *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, *33*(13), 1239–1249. https://doi.org/10.1080/15567036.2010.531510

Ahmed, I. A. M., AlJuhaimi, F., Özcan, M. M., Ghafoor, K., Şimşek, Ş., Babiker, E. E., Osman, M. A., Gassem, M. A., & Salih, H. A. A. (2020). Evaluation of chemical properties, amino acid contents and fatty acid compositions of sesame seed provided from different locations. *Journal of Oleo Science*, *69*(8), 795–800. https://doi.org/10.5650/jos.ess20041

Almeida, F., Sulabo, R. C., & Stein, H. H. (2013). Effects of a novel bacterial phytase expressed in Aspergillus oryzae on digestibility of calcium and phosphorus in diets fed to weanling or growing pigs. *Journal of Animal Science and Biotechnology*, *4*(1), 8.

Alobo, A. P. (2001). Effect of sesame seed flour on millet biscuit characteristics. *Plant Foods for Human Nutrition (Dordrecht, Netherlands)*, *56*(2), 195–202. https://doi.org/10.1023/A:1011168724195

Alowo, D., Muggaga, C., & Ongeng, D. (2018). The effect of traditional malting technology practiced by an ethnic community in northern Uganda on in–vitro nutrient bioavailability and consumer sensory preference for locally formulated complementary food formulae. *Journal of. Food Science & Nutrition*, *6*(8), 2491–2498. https://doi.org/10.1002/fsn3.856

Amorim, D. S., Edvan, R. L., Rodrigues, R., Bezerra, L. R., Araújo, M. J., De, A., Lopes, F., Mielezrski, S., Nascimento, L. R., Bezerra, M. J., Araújo, L., & De, A. (2020). Fermentation profile and nutritional value of sesame silage compared to usual silages. *Italian Journal of Animal Science*, *19*(1), 230–239. https://doi.org/10.1080/1828051X.2020.1724523

Andargie, M., Vinas, M., Rathgeb, A., Möller, E., & Karlovsky, P. (2021). Lignans of sesame (*Sesamum indicum* L.): A comprehensive review. *Molecules (Basel, Switzerland)*, *26*(4), 883. https://doi.org/10.3390/molecules26040883

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

Ashamu, E., Salawu, E., Oyewo, O., Alhassan, A., Alamu, O., & Adegoke, A. (2010). Efficacy of vitamin C and ethanolic extract of Sesamum indicum in promoting fertility in male Wistar rats. *Journal of Human Reproductive Sciences*, *3*(1), 11–14. https://doi.org/10.4103/0974-1208.63115

Ashri, A. (2007). Sesame (*Sesamum indicum* L.). In R. J. Singh (Ed.) *Genetic resources, chromosome engineering and crop improvement*. *Oilseed crops* (Vol 4, pp. 231–289). CRC.

Aued-Pimentel, S., Takemoto, E., Antoniassi, R., & Badolato, E. S. G. (2006). Composition of tocopherols in sesame seed oil: an indicative of adulteration. *Grasas y Aceites*, *57*(2), 205–210. https://doi.org/10.3989/gya.2006.v57.i2.38

Aworh, O. C. (2018). From lesser–known to super vegetables: The growing profile of African traditional leafy vegetables in promoting food security and wellness. *Journal of the Science of Food and Agriculture*, *98*(10), 3609–3613. https://doi.org/10.1002/jsfa.8902

Basalirwa, D., Sudo, S., Wacal, C., Oo, A. Z., Sasagawa, D., Yamamoto, S., Masunaga, T., & Nishihara, E. (2020). Impact of fresh and aged palm shell biochar on N_2O emissions, soil properties, nutrient content and yield of Komatsuna (*Brassica rapa var. perviridis*) under sandy soil conditions. *Soil Science and Plant Nutrition*, *66*(2), 328–343. https://doi.org/10.1080/00380768.2019.1705737

Bedigan, D. (2003). Evolution of sesame revisited: Domestication, diversity and prospects. *Genetic Resources and Crop Evolution*, *50*, 799–787.

Bedigan, D. (2018). Feeding the forgotten: Wild and cultivated Ceratotheca and Sesamum (Pedaliaceae) that nourish and provide remedies in Africa. *Economic Botany*, *72*, 496–542.

Bedigian, D. (2004). Slimy leaves and oily seeds: distribution and use of wild relatives of sesame in Africa. *Economic Botany*, *58*(sp1), S3–S33. https://doi.org/10.1663/0013-0001(2004)58[S3:SLAOSD]2.0.CO;2

Bertrand, M., & Özcan, M. M. (2021). Fatty acid composition, tocopherol, and sterol contents of sesame, poppy, wheat germ and pecan oils. *Journal of Agroalimentary Processes and Technologies*, *27*(2), 160–163.

Betiku, E., & Adepoju, T. F. (2013). Methanolysis optimization of sesame (*Sesamum indicum*) oil to biodiesel and fuel quality characterization. *International Journal of Energy and Environmental Engineering*, *4*(1), 9. https://doi.org/10.1186/2251–6832–4–9

Bi, Y., Xiao, L., & Sun, J. (2019). An arbuscular mycorrhizal fungus ameliorates plant growth and hormones after moderate root damage due to simulated coal mining subsidence: A microcosm study. *Environmental Science and Pollution Research*, *26*(11), 11053–11061. https://doi.org/10.1007/s11356–019–04559–7

Bigdeli Shamloo, M. B., Nasiri, M., Maneiy, M., Dorchin, M., Mojab, F., Bahrami, H., Naseri, M. S., & Kiarsi, M. (2019). Effects of topical sesame (Sesamum indicum) oil on the pain severity of chemotherapy–induced phlebitis in patients with colorectal cancer: A randomized controlled trial. *Complementary Therapies in Clinical Practice*, *35*, 78–85. https://doi.org/10.1016/j.ctcp.2019.01.016

Bonos, E., Kargopoulos, A., Basdagianni, Z., Mpantis, D., Taskopoulou, E., Tsilofiti, B., & Nikolakakis, I. (2017). Dietary sesame seed hulls utilization on lamb performance, lipid oxidation and fatty acids composition of the meat. *Animal Husbandry, Dairy and Veterinary Science*, *1*(1), 1–5. https://doi.org/10.15761/AHDVS.1000101

Braña, D., Ellis, M., Castañeda, E., Sands, J., & Baker, D. (2006). Effect of a novel phytase on growth performance, bone ash, and mineral digestibility in nursery and grower-finisher pigs. *Journal of Animal Science*, *84*(7), 1839–1849. https://doi.org/10.2527/jas.2005-565

Chinweuba, A. J., & Chendo, M. N. (2017). Extraction, characterisation and industrial applications of Sesamum indicum seed oil. *Modern Chemistry & Applications*, *5*(2), 1–2.

Couch, A., Gloaguen, R. M., Langham, D. R., Hochmuth, G. J., Bennett, J. M., Rowland, D. L., & Sesamum, N. (2017). Non–dehiscent sesame (Sesamum indicum L.): its unique production potential and expansion into the southeastern USA. *Journal of Crop Improvement*, *31*(2), 101–172. https://doi.org/10.1080/15427528.2017.1280575

Creamer, N. G., & Baldwin, K. R. (2000). An evaluation of summer cover crops for use in vegetable production systems in North Carolina. *HortScience*, *35*(4), 600–603. https://doi.org/10.21273/HORTSCI.35.4.600

Dar, A. A., & Arumugam, N. (2013). Lignans of sesame: Purification methods, biological activities and biosynthesis – A review. *Bioorganic Chemistry*, *50*, 1–10. https://doi.org/10.1016/j.bioorg.2013.06.009

Dar, A. A., Kancharla, P. K., Chandra, K., Sodhi, Y. S., & Arumugam, N. (2019). Assessment of variability in lignan and fatty acid content in the germplasm of Sesamum indicum L. *Journal of Food Science and Technology*, *56*(2), 976–986. https://doi.org/10.1007/s13197-018-03564-x

Dar, A. A., Verma, N. K., & Arumugam, N. (2015). An updated method for isolation, purification and characterization of clinically important antioxidant lignans–Sesamin and sesamolin, from sesame oil. *Industrial Crops and Products*, *64*, 201–208. https://doi.org/10.1016/j.indcrop.2014.10.026

Dawodu, F. A., Ayodele, O. O., & Bolanle–Ojo, T. (2014). Biodiesel production from Sesamum indicum L. seed oil: An optimization study. *Egyptian Journal of Petroleum*, *23*(2), 191–199. https://doi.org/10.1016/j.ejpe.2014.05.006

de Carvalho, A. F., de Araújo, M. J., Vallecillo, S. J. A., Neto, J. P. C., de Souza, A. R., Edvan, R. L., Dega, V., & Barbhai, M. D. (2023). Exploring the underutilized novel foods and starches for formulation of low glycemic therapeutic foods: a review. *Frontiers in Nutrition*, *10*, 1162462. https://doi.org/10.3389/fnut.2023.1162462

Deme, T., Haki, G. D., Retta, N., Woldegiorgis, A., & Geleta, M. (2017). Mineral and anti–nutritional contents of niger seed (Guizotia abyssinica (Lf) Cass., linseed (Linumusitatissimum L.) and sesame (Sesamum indicum L.) varieties grown in Ethiopia. *Foods (Basel, Switzerland)*, *6*(4), 27. https://doi.org/10.3390/foods6040027

Deme, T., Haki, G. D., Retta, N., Woldegiorgis, A., Geleta, M., Mateos, H., & Lewandowski, P. A. (2021). Sterols as a biomarker in tracing Niger and sesame seeds oils adulterated with palm oil. *Heliyon*, *7*(4), e06797. https://doi.org/10.1016/j.heliyon.2021.e06797

Dernekbaşı, S., Karayücel, İ., & Akyüz, A. P. (2017). Evaluation of sesame (Sesamum indicum) seed meal as a replacer for soybean meal in the diets of rainbow trout (Oncorhynchus mykiss Walbaum, 1792). *Ege Journal of Fisheries and Aquatic Sciences*, *34*(1), 31–39. https://doi.org/10.12714/egejfas.2017.34.1.05

Dossa, K., Konteye, M., Niang, M., Doumbia, Y., & Cissé, N. (2017). Enhancing sesame production in West Africa's Sahel : A comprehensive insight into the cultivation of this untapped crop in Senegal and Mali. *Agriculture & Food Security*, *6*(1), 1–15. https://doi.org/10.1186/s40066–017–0143–3

Eftekhar Sadat, B., Khadem Haghighian, M., Alipoor, B., Malek Mahdavi, A., Asghari Jafarabadi, M., & Moghaddam, A. (2013). Effects of sesame seed supplementation on clinical signs and symptoms in patients with knee osteoarthritis. *International Journal of Rheumatic Diseases*, *16*(5), 578–582. https://doi.org/10.1111/1756-185X.12133

El–Khier, M. K. S., Ishag, K. E. A., & Yagoub, A. A. (2008). Chemical composition and oil characteristics of sesame seed cultivars grown in Sudan. *Research Journal of Agriculture and Biological Sciences*, *4*(6), 761–766.

Emadi, H., Mokhayer, B., & Faal, M. (2014). Alternative role of sesame seed replacing fish meal in the diet of rainbow trout (*Oncorhynchus mykiss*) fingerlings. *Iranian Journal of Fisheries Sciences*, *13*(3), 608–620.

Enyidi, U. D., Pirhonen, J., & Vielma, J. (2014). Effects of sesame seed meal and bambaranut meal on growth, feed utilization and body composition of juvenile African catfish Clarias gariepinus. *Iranian Journal of Fisheries Sciences*, *13*(4), 998–1013.

FAO (Food and Agriculture Organization). (2021). *Statistical database*. https://www.fao.org/faostat/en/#data/QCL (Accessed on 11th June 2023).

Gernah, D. I., Ariahu, C. C., & Ingbian, E. K. (2012). Nutritional and sensory evaluation of food formulations from malt-

ed and fermented maize fortified with defatted sesame flour. *African Journal of Food Agriculture Nutrition and Development*, *12*(6), 11–16.
Gupta, M. M. (2020). Arbuscular mycorrhizal fungi: The potential soil health indicators. In B. Giri and A. Varma (Ed.), *Soil health* (pp. 183–195). Springer.
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
Harikumar, K. B., Sung, B., Tharakan, S. T., Pandey, M. K., Joy, B., Guha, S., Krishnan, S., & Aggarwal, B. B. (2010). Sesamin manifests chemopreventive effects through the suppression of NF–kappa B–regulated cell survival, proliferation, invasion, and angiogenic gene products. *Molecular Cancer Research*, *8*(5), 751–761. https://doi.org/10.1158/1541-7786.MCR-09-0565
Hasan, A. F., Furumoto, T., Begum, S., & Fukui, H. (2001). Hydroxysesamone and 2, 3-epoxysesamone from roots of Sesamum indicum. *Phytochemistry*, *58*(8), 1225–1228. https://doi.org/10.1016/s0031-9422(01)00357-0
Hassan, A. M. M. (2013). Studies on Egyptian sesame seeds (*Sesamum indicum* L.) and its products. 3. Effect of roasting process on gross chemical composition, functional properties, anti–oxidative components and some minerals of defatted sesame seeds meal (Sesamum indicum L.). *World Journal of Dairy & Food Sciences*, *8*(1), 51–57.
Hassan, M. A. (2012). Studies on Egyptian sesame seeds (Sesamum indicum L.) and its products 1–physicochemical analysis and phenolic acids of roasted Egyptian sesame seeds (Sesamum indicum L.)*World Journal of Dairy & Food Sciences*, *7*(2), 195–201.
Hata, N., Hayashi, Y., Okazawa, A., Ono, E., Satake, H., & Kobayashi, A. (2010). Comparison of sesamin contents and CYP81Q1 gene expressions in aboveground vegetative organs between two Japanese sesame (*Sesamum indicum* L.) varieties differing in seed sesamin contents. *Plant Science*, *178*(6), 510–516. https://doi.org/10.1016/j.plantsci.2010.02.020
Heidari–Soureshjani, R., Gholipour, A., Obeidavi, Z., Jafari, A., Abbasi, S., & Madmoli, Y. (2016). Bactericidal and Bacteriostatic effect of sesame oil, olive oil and their synergism on Escherichia coli in vitro. *Advanced Herbal Medicine*, *2*(3), 13–19.
Hess, D. E., & Dodo, H. (2004). Potential for sesame to contribute to integrated control of Striga hermonthica in the West African Sahel. *Crop Protection*, *23*(6), 515–522. https://doi.org/10.1016/j.cropro.2003.10.008
Heuzé, V., Tran, G., Bastianelli, D., & Lebas, F. (2016). Sesame (Sesamum indicum) seeds and oil meal. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. Retrieved September 9, 2016, from http://www.feedipedia.org/node/26
Hirano, Y., Ito, Y., Inagaki, N., Yamasaki, K., Yokota, H., & Kita, K. (2005). Effect of sesame meal supplemented in Sudangrass silage on fermentation quality and feed intake in goats. *Journal of Applied Animal Research*, *28*(2), 85–88. https://doi.org/10.1080/09712119.2005.9706797
Holechek, J. L., Geli, H. M. E., Sawalhah, M. N., & Valdez, R. (2022). A Global Assessment : Can Renewable Energy Replace Fossil Fuels by 2050 ? *Sustainability*, *14*(8), 4792. https://doi.org/10.3390/su14084792
Hsu, E., & Parthasarathy, S. (2017). Anti–inflammatory and antioxidant effects of sesame oil on atherosclerosis: A descriptive literature review. *Cureus*, *9*(7), e1438. https://doi.org/10.7759/cureus.1438
Hu, Y., Pandey, A. K., Wu, X., Fang, P., & Xu, P. (2022). The role of arbuscular mycorrhiza fungi in drought tolerance in legume crops: A review. *Legume Research-An International Journal*, *45*(1), 1–9.
Hussain, I., Singh, N. B., Singh, A., & Singh, H. (2017). Allelopathic potential of sesame plant leachate against Cyperus rotundus L. *Annals of Agrarian Science*, *15*(1), 141–147. https://doi.org/10.1016/j.aasci.2016.10.003
Hwang, L. S. (2005). Sesame oil. In F. Shahidi (Ed.), *Bailey's industrial oil and fat products* (6th ed., pp. 538–577). John Wiley and SonsInc.
Ijoyah, M. O., Anyogo, J. O., & Ugese, F. D. (2016). Yield response of maize (Zea mays L.) and sesame (Sesamum indicum L.) intercrop as influenced by planting densities and varieties of sesame at Makurdi, Nigeria. *World Scientific News*, *37*(2016), 25–49.
Ikujenlola, V. A. (2014). Chemical and functional properties of complementary food blends from malted and unmalted acha (*Digitaria exilis*), soybean (Glycine max) defatted sesame (Sesamun indicum L.) flours. *African Journal of Food Science*, *8*(7), 361–367. https://doi.org/10.5897/AJFS2014.1173
Kancharla, P. K., & Arumugam, N. (2020). Variation of oil, sesamin, and sesamolin content in the germplasm of the ancient oilseed crop Sesamum indicum L. *Journal of the American Oil Chemists' Society*, *97*(5), 475–483. https://doi.org/10.1002/aocs.12346
Kang, S., Cho, J., Kim, H., Seo, D., & Moon, S. (2016). Effect of sesame straw biochar application on soil physics and nitrous oxide emission in upland soil. 한국토양비료학회지, *49*(3), 259–264. In Korean with English summary).
Kanu, P. J., Bahsoon, J. Z., Kanu, J. B., & Kandeh, J. B. A. (2010). Nutraceutical importance of sesame seed and oil. A review of the contribution of their lignans. *Sierra Leone Journal of Biomedical Research*, *2*(1), 4–16. https://doi.org/10.4314/sljbr.v2i1.56583
Karatzi, K., Stamatelopoulos, K., Lykka, M., Mantzouratou, P., Skalidi, S., Zakopoulos, N., Papamichael, C., & Sidossis, L. S. (2013). Sesame oil consumption exerts a beneficial effect on endothelial function in hypertensive men. *European Journal of Preventive Cardiology*, *20*(2), 202–208. https://doi.org/10.1177/2047487312437625
Khan, Z. R., Midega, C. A., Bruce, T. J., Hooper, A. M., & Pickett, J. A. (2010). Exploiting phytochemicals for developing a 'push–pull' crop protection strategy for cereal farmers in Africa. *Journal of Experimental Botany*, *61*(15), 4185–4196. https://doi.org/10.1093/jxb/erq229
Khani, B., Bidgoli, S. R., Moattar, F., & Hassani, H. (2013). Effect of sesame on sperm quality of infertile men. *Journal of Research in Medical Sciences*, *18*(3), 184–187.
Kim, S.-U., Oh, K.-W., Lee, M.-H., Lee, B.-K., Pae, S.-B., Hwang, C.-D., Kim, M.-S., Baek, I.-Y., & Lee, J.-D. (2014). Variation of lignan content for sesame seed across origin and growing environments. *Korean Journal of Crop Science*, *59*(2), 151–161. https://doi.org/10.7740/kjcs.2014.59.2.151
Kumar, L., & Varshney, J. G. (2008). Allelopathic effect of sesame root exudates against purple nut sedge. *Indian Journal of Weed Science*, *40*(1), &2), 32–36.

Kumar, M. S. A. K., & Hiremath, S. C. (2008). Cytological analysis of interspecific hybrid between Sesamum indicum L. X S. orientale L. Var. malabaricum. *Karnataka Journal of Agricultural Science*, *21*, 498–502.

Kumari, B. M., & Ganesamurthy, K. (2015). Study of reproductive compatibility and morphological characterization of interspecific hybrids in *Sesamum* sp. *African Journal of Agricultural Research*, *10*(9), 911–918. https://doi.org/10.5897/AJAR2014.8592

Kurt, C. E., M., A. L. (2018). Variation in oil content and fatty acid composition of sesame accessions from different origins. *Grasas y Aceites*, *69*(1), e241–e241. https://doi.org/10.3989/gya.0997171

Langham, D. R. (2008). *Growth and development of sesame*. Sesaco Corp. 42 pp. and Technology. Earthscan, London, pp. 1–2.

Langham, D. R. (2020). *Sesame agronomic and administrative descriptors, Part 2 (Sesamum indicum L.)*. Sesame Research.

Langyan, S., Yadava, P., Sharma, S., Gupta, N. C., Bansal, R., Yadav, R., Kalia, S., & 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

Laurentin, H., Pereira, C., & Sanabria, M. (2003). Phytochemical characterization of six sesame (*Sesamum indicum* L.) genotypes and their relationships with resistance against the sweet potato Whitefly *Bemisia tabaci* Gennadius. *Insect Management*, *95*(6), 1577–1582.

Lavaee, F., Moshaverinia, M., MalekHosseini, S. A., Jamshidzade, A., Zarei, M., Jafarian, H., Haddadi, P., & Badiee, P. (2019). Antifungal effect of sesame medicinal herb on Candida Species: original study and mini-review. *Brazilian Journal of Pharmaceutical Sciences*, *55*,e17479. https://doi.org/10.1590/s2175-97902019000117479

Li, M., Luo, J., Nawaz, M. A., Stockmann, R., Buckow, R., Barrow, C., Dunshea, F., & Suleria, H. A. R. (2023). Phytochemistry, bioaccessibility, and bioactivities of sesame seeds: An overview. *Food Reviews International*, 40(1), 1–27. https://doi.org/10.1080/87559129.2023.2168280

Lin, X., Zhou, L., Li, T., Brennan, C., Fu, X., & Liu, R. H. (2017). Phenolic content, antioxidant and antiproliferative activities of six varieties of white sesame seeds (Sesamum indicum L.). *RSC Advances*, *7*(10), 5751–5758. https://doi.org/10.1039/C6RA26596K

Ma, F., & Fang, W. (2019). Research progress of active ingredients and product development of sesame. *Anhui Agron. Bull*, *25*, 46–48.

Maged, G. A., El-Kholany, M. E., El-Emam, G. E., Elsayed, F. A., El-Sawah, T. H., Aboul-Omran, A. O. A., & Al-Mowafy, A. A. (2017). Response of milk production of dairy zaraibi goats to feeding rations containing different levels of sesame seeds unsuitable for manufacturing as an inexpensive and untraditional source of protein. *Journal of Animal and Poultry Production*, *8*(3), 49–54. https://doi.org/10.21608/jappmu.2017.45769

Mahmoud, A. E. M., & Ghoneem, W. M. (2014). Effect of partial substitution of dietary protein by nigella sativa meal and sesame seed meal on performance of Egyptian lactating buffalo. *Asian Journal of Animal and Veterinary Advances*, *9*(8), 489–498. https://doi.org/10.3923/ajava.2014.489.498

Mahmoud, K. Z., Obeidat, B. S., & Ishmais, M. A. (2015). Roasted sesame hulls improve broiler performance without affecting carcass characteristics. *Italian Journal of Animal Science*, *14*(3), 3957. https://doi.org/10.4081/ijas.2015.3957

Majdalawieh, A. F., & Mansour, Z. R. (2019). Sesamol, a major lignan in sesame seeds (*Sesamum indicum*): Anti–cancer properties and mechanisms of action. *European Journal of Pharmacology*, *855*, 75–89. https://doi.org/10.1016/j.ejphar.2019.05.008

Majdalawieh, A. F., Massri, M., & Nasrallah, G. K. (2017). A comprehensive review on the anti–cancer properties and mechanisms of action of sesamin, a lignan in sesame seeds (Sesamum indicum). *European Journal of Pharmacology*, *815*, 512–521. https://doi.org/10.1016/j.ejphar.2017.10.020

Makinde, F. M., & Akinoso, R. (2014). Physical, nutritional and sensory qualities of bread samples made with wheat and black sesame (*Sesamum indicum* Linn) flours. *International Food Research Journal*, *21*(4), 1635.

Matthäus, B., & Özcan, M. M. (2018). Fatty acid composition and tocopherol contents of some sesame seed oils. *Iranian Journal of Chemistry and Chemical Engineering (IJCCE)*, *37*(5), 151–155.

Mbaebie, B., Omosun, G., Uti, A., & Oyedemi, S. (2010). Chemical composition of sesamum indicum L (sesame) grown in southeastern Nigeria and the physicochemical properties of the seed oil. *Seed Science and Biotechnology*, *4*(1), 69–72.

Mishra, S., Balaji, O., Rao, V., & Adiga, S. (2019). Gastroprotective activity of sesame (sesamum indicum) seeds extract in alendronate–induced gastric ulcer in rats. *Asian Journal of Pharmaceutical and Clinical Research 12* (10), 214–217. https://doi.org/10.22159/ajpcr.2019.v12i10.35203

Mitsiopoulou, C., Sotirakoglou, K., Labrou, N. E., & Tsiplakou, E. (2021). The effect of whole sesame seeds on milk chemical composition, fatty acid profile and antioxidant status in goats. *Livestock Science*, *245*, 104452. https://doi.org/10.1016/j.livsci.2021.104452

Mohammed, S., & Pattan, N. (2022). An overview on nutritional composition and therapeutic benefits of sesame seeds (*Sesamum indicum*). *International Journal for Research in Applied Science and Engineering Technology*, *10*(1), 1119–1127. https://doi.org/10.22214/ijraset.2022.40002

Morini, M. S. C., Bueno, O. C., Bueno, F. C., Leite, A. C., Hebling, M. J. A., Pagnocca, F. C., Fernandes, J. B., Vieira, P. C., & Silva, M. F. G. F. (2005). Toxicity of sesame seed to leaf–cutting ant atta sexdens rubropilosa (Hymenoptera: Formicidae). *Sociobiology*, *45*(1), 195–204.

Myint, D., Gilani, S. A., Kawase, M., & Watanabe, K. N. (2020). Sustainable sesame (Sesamum indicum L.) production through improved technology : An overview of production, challenges, and opportunities in Myanmar. *Sustainability*, *12*(9), 3515. https://doi.org/10.3390/su12093515

Nasiri, M., & Farsi, Z. (2017). Effect of light pressure stroking massage with sesame (Sesamum indicum L.) oil on alleviating acute traumatic limbs pain: A triple–blind controlled trial in emergency department. *Complementary Therapies in Medicine*, *32*, 41–48. https://doi.org/10.1016/j.ctim.2017.03.004

Njidda, A. A., & Isidahomen, C., E. (2010). Hematological parameters and carcass characteristics of weanling rabbits fed sesame seed meal (*Sesamum indicum*) in a semi–arid region. *Pakistan Veterinary Journal*, *31*(1), 35–39.

Nweke, F. N., Ubi, B. E., & Kunert, K. J. (2011). Determination of proximate composition and amino acid profile of

Nigerian sesame (Sesamum indicum L.) cultivars. *Nigerian Journal of Biotechnology*, 23, (2011), 5–12.
Nzikou, J. M., Matos, L., Kalou, G. B., Ndangui, C. B., Tobi, N. P. G. P., Kimbonguila, A., Silou, T., Linder, M., & Desobry, S. (2009). Chemical composition on the seeds and oil of sesame (*Sesamum indicum* L.) grown in Congo–Brazaville. *Advance Journal of Food Science and Technology*, *1*(1), 6–11.
Obeidat, B. S., & Gharaybeh, F. F. (2011). Effect of feeding sesame hull on growth performance, nutrient digestibility, and carcass characteristics of black goat kids. *Asian-Australasian Journal of Animal Sciences*, *24*(2), 206–213. https://doi.org/10.5713/ajas.2011.10107
Obeidat, B. S., Kridli, R. T., Mahmoud, K. Z., Obeidat, M. D., Haddad, S. G., Subih, H. S., Ata, M., A., Jamal, A. E., Abu Ghazal, T., A., & Khazáleh, J. M. (2019). Replacing soybean meal with sesame meal in the diets of lactating Awassi Ewes suckling single lambs: Nutrient digestibility, milk production, and lamb growth. *Animals: An Open Access Journal from MDPI*, *9*(4), 157. https://doi.org/10.3390/ani9040157
Ogunsola, O., & Fasola, T. (2014). The antibacterial activities of Sesamum indicum Linn. leaf extracts. *Advances in Life Science and Technology*, *18*, 28–32.
Olagunju, A. I., & Ifesan, B. O., T. (2013). Nutritional composition and acceptability of cookies made from wheat flour and germinated sesame (Sesamum indicum) flour blends. *British Journal of Applied Science & Technology*, *3*(4), 702–713. https://doi.org/10.9734/BJAST/2013/3547
Olowe, V. I. O., & Adeyemo, A. Y. (2009). Enhanced crop productivity and compatibility through intercropping of sesame and sunflower varieties. *Annals of Applied Biology*, *155*(2), 285–291. https://doi.org/10.1111/j.1744-7348.2009.00340.x
Omer, H. A. A., Ahmed, S. M., Abdel–Magid, S. S., Bakry, B. A., E., Karamany, M. F., E., & Sabaawy, E. H. (2019). Nutritional impact of partial or complete replacement of soybean meal by sesame (Sesamum indicum) meal in lambs rations. *Bulletin of the National Research Centre*, *43*(1), 10. https://doi.org/10.1186/s42269–019–0140–8
Park, J. H., Ok, Y. S., Kim, S. H., Cho, J. S., Heo, J. S., Delaune, R. D., & Seo, D. C. (2015). Evaluation of phosphorus adsorption capacity of sesame straw biochar on aqueous solution: Influence of activation methods and pyrolysis temperatures. *Environmental Geochemistry and Health*, *37*(6), 969–983. https://doi.org/10.1007/s10653–015–9709–9
Pathak, K., Rahman, S. W., Bhagawati, S., & Gogoi, B. (2017). Sesame (Sesamum indicum L.), an underexploited oil seed crop : Current status, features and importance – A review. *Agricultural Reviews*, *38*(03), 223–227. https://doi.org/10.18805/ag.v38i03.8982
Pathak, N., Rai, A. K., Kumari, R., & Bhat, K. V. (2014). Value addition in sesame: A perspective on bioactive components for enhancing utility and profitability. *Pharmacognosy Reviews*, *8*(16), 147–155. https://doi.org/10.4103/0973-7847.134249
Pérez, E., Héctor, T., Montemayor, M. A., & Robles, L. E. (2022). Effect of replacing soybean meal (Glycine max) with sesame meal (Sesamum indicum) on productive traits, carcass characteristics, and gross profit margin in fattening lamb's diets. *Tropical Animal Health and Production*, *54*(6), 405. https://doi.org/10.1007/s11250–022–03406–1
Prasad, M., N., N., Sanjay, K. R., Prasad, D. S., Vijay, N., Kothari, R., & Swamy, S. N. (2012). A Review on nutritional and nutraceutical properties of sesame. *Journal of Nutrition & Food Sciences*, *2*(2), 127.
Rangkadilok, N., Pholphana, N., Mahidol, C., Wongyai, W., Saengsooksree, K., Nookabkaew, S., & Satayavivad, J. (2010). Variation of sesamin, sesamolin and tocopherols in sesame (*Sesamum indicum* L.) seeds and oil products in Thailand. *Food Chemistry*, *122*(3), 724–730. https://doi.org/10.1016/j.foodchem.2010.03.044
Rapsomaniki, E., Timmis, A., George, J., Pujades-Rodriguez, M., Shah, A. D., Denaxas, S., White, I. R., Caulfield, M. J., Deanfield, J. E., Smeeth, L., Williams, B., Hingorani, A., & Hemingway, H. (2014). Blood pressure and incidence of twelve cardiovascular diseases: lifetime risks, healthy life–years lost, and age–specific associations in 1· 25 million people. *Lancet (London, England)*, *383*(9932), 1899–1911. https://doi.org/10.1016/S0140-6736(14)60685-1
Reardon, T., Tschirley, D., Liverpool-Tasie, L. S. O., Awokuse, T., Fanzo, J., Minten, B., Vos, R., Dolislager, M., Sauer, C., Dhar, R., Vargas, C., Lartey, A., Raza, A., & Popkin, B. M. (2021). The processed food revolution in African food systems and the double burden of malnutrition. *Global Food Security*, *28*, 100466. https://doi.org/10.1016/j.gfs.2020.100466
Sani, I., Okpalaoka, C. C., Bello, F., Warra, A. A., & Abdulhamid, A. (2014). Flavonoid content and antioxidant potential of white and brown sesame seed oils. *European Journal of Biomedical and Pharmaceutical Sciences*, *1*(3), 56–63.
Saydut, A., Duz, M. Z., Kaya, C., Kafadar, A. B., & Hamamci, C. (2008). Transesterified sesame (Sesamum indicum L.) seed oil as a biodiesel fuel. *Bioresource Technology*, *99*(14), 6656–6660. https://doi.org/10.1016/j.biortech.2007.11.063
Shah, A. N., Iqbal, J., Ullah, A., Yang, G., Yousaf, M., Fahad, S., Tanveer, M., Hassan, W., Tung, S. A., Wang, L., Khan, A., & Wu, Y. (2016). Allelopathic potential of oil seed crops in production of crops: A review. *Environmental Science and Pollution Research*, *23*(15), 14854–14867. https://doi.org/10.1007/s11356-016-6969-6
Shi, L. K., Liu, R. J., Jin, Q. Z., & Wang, X. G. (2017). The contents of lignans in sesame seeds and commercial sesame oils of China. *Journal of the American Oil Chemists' Society*, *94*(8), 1035–1044. https://doi.org/10.1007/s11746-017-3018-7
Shittu, L. A. J., Bankole, M. A., Ahmed, T., Bankole, M. N., Shittu, R. K., Saalu, C. L., & Ashiru, O. A. (2007). Antibacterial and antifungal activities of essential oils of crude extracts of Sesame radiatum against some common pathogenic micro–organisms. *Iranian Journal of Pharmacology and Therapeutics*, *6*(2), 165–170.
Sintim, H. O., Tashiro, T., & Motoyama, N. (2009). Response of the cutworm Spodoptera litura to sesame leaves or crude extracts in diet. *Journal of Insect Science (Online)*, *9*(52), 1–13. https://doi.org/10.1673/031.009.5201
Smith, S. E., & Read, D. J. (2008). *Mycorrhizal Symbiosis*. Academic Press.
Syed, R. N., Laurentin, H., Splivallo, R., & Karlovsky, P. (2015). Antifungal properties of extracts of sesame (Sesamum indicum). *International Journal of Agriculture & Biology*, *17*, 575–581.
Reis de Souza, T. C., Escobar, K., Aguilera, G. A., Ramírez, B. E., & Mariscal-Landín, R. G. (2017). Sesame meal as the first protein source in piglet starter diets and advantages of a phytase: A digestive study. *South African Journal of Animal Science*, *47*(5), 606–615. https://doi.org/10.4314/sajas.v47i5.3
Sudhakar, B., Kalaiarasi, P., Al–Numair, K. S., Chandramohan, G., Rao, R. K., & Pugalendi, K. V. (2011). Effect of combi-

nation of edible oils on blood pressure, lipid profile, lipid peroxidative markers, antioxidant status, and electrolytes in patients with hypertension on nifedipine treatment. *Saudi Medical Journal*, *32*(4), 379–385.

Taverner, P. D., Gunning, R. V., Kolesik, P., Bailey, P. T., Inceoglu, A. B., Hammock, B., & Roush, R. T. (2001). Evidence for direct toxicity of a "light" oil on the peripheral nerves of lightbrown apple moth. *Pesticide Biochemistry and Physiology*, *69*(3), 153–165. https://doi.org/10.1006/pest.2000.2527

Tenyang, N., Ponka, R., Tiencheu, B., Djikeng, F. T., Azmeera, T., Karuna, M. S. L., Prasad, R. B. N., & Womeni, H. M. (2016). 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

Tong, Y., Gabriel–Neumann, E., Krumbein, A., Ngwene, B., George, E., & Schreiner, M. (2015). Interactive effects of arbuscular mycorrhizal fungi and intercropping with sesame (Sesamum indicum) on the glucosinolate profile in broccoli (Brassica oleracea var. Italica). *Environmental and Experimental Botany*, *109*, 288–295. https://doi.org/10.1016/j.envexpbot.2014.06.008

Ünal, M., & Yalçın, H. (2008). Proximate composition of Turkish sesame seeds and characterization of their oils. *Grasas y Aceites*, *59*(1), 23–26. https://doi.org/10.3989/gya.2008.v59.i1.485

Vennila, L. (2017). Cardioprotective effect of sesame oil: A review. *World Journal of Pharmaceutical Research*, *6*(11), 331–341. https://doi.org/10.20959/wjpr201711-9607

Wacal, C. (2019). *A study of continuous monocropping obstacles of sesame (Sesamum indicum L.) for sustainable production on upland field converted paddy*. [Doctoral dissertation: The United Graduate School of Agricultural Sciences]. Tottori University.

Wacal, C., Basalirwa, D., Okello–Anyanga, W., Murongo, M. F., Namirembe, C., & Malingumu, R. (2021). Analysis of sesame seed production and export trends; challenges and strategies towards increasing production in Uganda. *Oilseeds and Fats Crops and Lipids*, *28*, 4.

Wacal, C., Ogata, N., Basalirwa, D., Handa, T., Sasagawa, D., Acidri, R., Ishigaki, T., Kato, M., Masunaga, T., Yamamoto, S., & Nishihara, E. (2019a). Growth, seed yield, mineral nutrients and soil properties of sesame (*Sesamum indicum* L.) as influenced by biochar addition on upland fields converted from paddy. *Agronomy*, *9*(2), 55. https://doi.org/10.3390/agronomy9020055

Wacal, C., Ogata, N., Basalirwa, D., Sasagawa, D., Ishigaki, T., Handa, T., Kato, M., Tenywa M.M., Masunaga, T., Yamamoto, S., Nishihara, E. (2019b). Imbalanced soil chemical properties and mineral nutrition in relation to growth and yield decline of sesame on different continuously cropped upland fields converted paddy. *Agronomy* *9*(4), 184. https://doi.org/10.3390/agronomy9040184

Wacal, C., Ogata, N., Basalirwa, D., Sasagawa, D., Kato, M., Handa, T., Masunaga, T., Yamamoto, S., & Nishihara, E. (2019d). Fatty acid composition of sesame (Sesamum indicum L.) seeds in relation to yield and soil chemical properties on continuously monocropped upland fields converted from paddy fields. *Agronomy*, *9*(12), 801. https://doi.org/10.3390/agronomy9120801

Wacal, C., Ogata, N., Sasagawa, D., Handa, T., Basalirwa, D., Acidri, R., Ishigaki, T., Yamamoto, S., & Nishihara, E. (2019c). Seed yield, crude protein and mineral nutrient contents of sesame during a two–year continuous cropping on upland field converted from a paddy. *Field Crops Research*, *240*, 125–133. https://doi.org/10.1016/j.fcr.2019.06.004

Wada, E., Leja, D., Gogile, A., & Loha, G. (2021). Chemical composition and fatty acid profile of five sesame (*Sesamum indicum* L.) varieties from Wolaita area, Ethiopia. *Journal of Science and Inclusive Development*, *2021*, 41–53.

Wakil, M. A., Kalam, M. A., Masjuki, H. H., Rizwanul Fattah, I. M., & Masum, B. M. (2014). Evaluation of rice bran, sesame and moringa oils as feasible sources of biodiesel and the effect of blending on their physicochemical properties. *RSC Advances*, *4*(100), 56984–56991. https://doi.org/10.1039/C4RA09199J

Wan, Y., Li, H., Fu, G., Chen, X., Chen, F., & 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

Wei, P., Zhao, F., Wang, Z., Wang, Q., Chai, X., Hou, G., & Meng, Q. (2022). Sesame (Sesamum indicum L.): a comprehensive review of nutritional value, phytochemical composition, health benefits, development of food, and industrial applications. *Nutrients*, *14*(19), 4079. https://doi.org/10.3390/nu14194079

Were, B. A., Onkware, A. O., Gudu, S., Welander, M., & Carlsson, A. S. (2006). Seed oil content and fatty acid composition in East African sesame (*Sesamum indicum* L.) accessions evaluated over 3 years. *Field Crops Research*, *97*(2-3), 254–260. https://doi.org/10.1016/j.fcr.2005.10.009

Wichitsranoi, J., Weerapreeyakul, N., Boonsiri, P., Settasatian, C., Settasatian, N., Komanasin, N., Sirijaichingkul, S., Teerajetgul, Y., Rangkadilok, N., & Leelayuwat, N. (2011). Antihypertensive and antioxidant effects of dietary black sesame meal in pre–hypertensive humans. *Nutrition Journal*, *10*(1), 82. https://doi.org/10.1186/1475–2891–10–82

Williamson, K. S., Morris, J. B., Pye, Q. N., Kamat, C. D., & Hensley, K. (2008). A survey of sesamin and composition of tocopherol variability from seeds of eleven diverse sesame (Sesamum indicum L.) genotypes using HPLC-PAD-ECD. *Phytochemical Analysis*, *19*(4), 311–322. https://doi.org/10.1002/pca.1050

Woldetsadik, D., Drechsel, P., Marschner, B., Itanna, F., & Gebrekidan, H. (2018). Effect of biochar derived from faecal matter on yield and nutrient content of lettuce (*Lactuca sativa*) in two contrasting soils. *Environmental Systems Research*, *6*(1), 1–12. https://doi.org/10.1186/s40068–017–00829

Wu, W. H. (2007). The contents of lignans in commercial sesame oils of Taiwan and their changes during heating. *Food Chemistry*, *104*(1), 341–344. https://doi.org/10.1016/j.foodchem.2006.11.055

Yadav, R., Kalia, S., Rangan, P., Pradheep, K., Rao, G. P., Kaur, V., Pandey, R., Rai, V., Vasimalla, C. C., Langyan, S., Sharma, S., Thangavel, B., Rana, V. S., Vishwakarma, H., Shah, A., Saxena, A., Kumar, A., Singh, K., & Siddique, K. H. M. (2022). Current research trends and prospects for yield and quality improvement in sesame, an important oilseed crop. *Frontiers in Plant Science*, *13*, 863521. https://doi.org/10.3389/fpls.2022.863521

Yalcin, H., & Unal, M. K. (2011). Evaluation of tocopherol homologues of Turkish sesame seed (Sesamum indicum) cultivars grown in different locations. *Journal of Applied Botany and Food Quality, 84*, 61–64.

Yogranjan, S., G. K., Marabi, R. S., Mishra, M. K., & Mishra, S. P. (2014). Global resurgence of sesame (*Sesamum indicum* L.) Utilization: a current scenario. *Indo-American Journal of Agricultural and Veterinary Sciences*, *2*(3), 2321–9602.

Yüzer, M. O., & Gençcelep, H. (2023). Sesame seed protein : Amino acid, functional, and physicochemical profiles. *Foods and Raw Materials*, *11*(1), 72–83. https://doi.org/10.21603/2308-4057-2023-1-555

Zahran, H. A., Abd–Elsaber, A., & Tawfeuk, H. Z. (2020). Genetic diversity, chemical composition and oil characteristics of six sesame genotypes. *Oilseeds and Fats Crops and Lipids*, *27*, 39.

Zebib, H., Bultosa, G., & Abera, S. (2015). Physico–chemical properties of sesame (*Sesamum indicum* L.) varieties grown in Northern Area, Ethiopia. *Agricultural Sciences*, *06*(02), 238–246. https://doi.org/10.4236/as.2015.62024

Zhao, J., Yang, Z., Zou, J., & Li, Q. (2022). Allelopathic effects of sesame extracts on seed germination of moso bamboo and identification of potential allelochemicals. *Scientific Reports*, *12*(1), 6661. https://doi.org/10.1038/s41598-022-10695-x

Zheng, W., Sharma, B. K., & Rajagopalan, N. (2010). Using biochar as a soil amendment for sustainable agriculture. *Waste utilization—Biochar*.