Almond oil: powerhouse of nutrients

Akubude, V.C.[1*], Maduako, J.N.[1], Egwuonwu, C. C.[1], Olaniyan, A.M.[2], Ajala, E.O.[3], Ozumba, C.I.[4], Nwosu, C.[4]

(1.Department Agricultural and Bioresource Engineering, Federal University of Technology, Owerri, Imo State, Nigeria
2.Department of Agricultural and Bioresources Engineering, Federal University Oye-Ekitti, Ekiti State, Nigeria.
3.Department of Chemical Engineering, University of Ilorin, Ilorin, Kwara State, Nigeria
4.National Centre for Agricultural Mechanization, Ilorin, Kwara State, Nigeria.)

Abstract: The relative abundance of almond seed in several tropical regions of the world coupled with the little knowledge of its utilization in vegetable oil production prompted the need for this review. The aim is to review almond oil expression through different extraction/expression approach, the economic and health benefits of almond oil, and the challenges and prospects of almond oil extraction in Nigeria. This review covers the recent significant materials found in the literature on almond seed and oil extraction/expression. Almond oil is an essential oil packed with a lot of nutrients that are beneficial to human health. Therefore, it is important to devise better approach for maximum oil extraction/ expression.

Keyword: almond seed, vegetable oil, oil expression/extraction methods, nutritional content

Citation: Akubude, V.C., J. N. Maduako, C. C. Egwuonwu, A. M. Olaniyan, E. O. Ajala, C. I. Ozumba, C. Nwosu. 2020. Almond oil: powerhouse of nutrients. Agricultural Engineering International: CIGR Journal, 22 (3):190-201.

1 Introduction

Oil is substance that does not mix with water and has a greasy feel (Foods Safety and Standards Authority of India, 2010). Fats and oil are substances that can be obtained either from animal or vegetable sources. They are non-volatile and insoluble in water but soluble in organic solvent (Aremu et al., 2015). Oils gotten from plant vegetable are called vegetable oil while those obtained from animals are called animal fats (Aremu et al., 2015). Vegetable oil and animal fats are generally called lipids. These lipids are widely used for our everyday food products. Their applications are increasing day by day for food and industrial purposes (Aremu et al., 2015; Bazlul et al., 2010). Among their industrial applications are manufacturing of soap, detergents, paints, varnishes (Afolabi, 2008), candles, lubricants, linoleum, printing ink, polymers (plastics) (Ibrahim and Onwualu, 2005), some pharmaceutical products (Ajav and Fakayode, 2013), glycerin, fatty acids, cosmetics (Biris et al., 2013), ointments, metal cutting fluids (Olaniyan and Oje, 2007), biofuel (Imane et al., 2014; Giuseppe and Eleonora, 2007) and food items like snacks, cake, margarine (Ibrahim and Onwualu, 2005), salad, cooking oil (Aremu et al., 2015), pastry, mayonnaise (McKevith, 2005). However, there are various sources of vegetable, as some are edible while others are non-edible. The edibility of any vegetable oil is based on its chemical composition, as those containing toxic substances are considered non-edible. Examples of non-edible oil are jatropha curcus, pongamia pinnata, moha, undi, saemaruba . Although, they are non-edible but have found great applications in industries for biofuel production (Bobade and Khyade, 2012). Those that are edible include shea butter, palm oil, palm kernel oil, soybean oil,

Received date: 2019-01-19 **Accepted date:** 2019-01-24

* **Corresponding author: Akubude Vivian Chimezie,** Department Of Agricultural and Bioresource Engineering, Federal University of Technology, Owerri, Imo State, Nigeria. Tel: +23407034325951. E-mail: akubudevivianc@gmail.com.

groundnut oil and almond oil. Among the aforementioned edible oil, almond oil has not been fully utilized because of paucity of information on its potentials. Almond oil is abundant in nature as it is grown as wild tree and can be found mostly in tropical forest.

Almond tree is one of the versatile tree nut (Clyde et al., 2004), perennial in nature, usually grown within the cold and temperate regions (Mirzabe et al., 2013) mainly as shade during hot weather (Agatemor, 2006) or as orchard crop (Agunbiade and Olanlokun, 2006) or for ornamental purposes (Apata, 2011; Nwosu et al., 2008). There are basically two varieties of almond: sweet and bitter almond (Akpabio, 2012; Akpakpan and Akpabio, 2012; Hari and Lakshmi, 2012; Annongu, 2006; Karatay et al., 2014; Aregbesola et al., 2012, Agunbiade and Olanlokun, 2006). Studies have shown that each variety of almond tree has a conservative estimated yield of 75 kg of fruits per year (Apata, 2011). The almond fruit contains seed that house the almond oil. Like any other vegetable seed, almond seed contains three layers: the outer part, the fleshy pulp and relatively hard shell known as green epicarp, mesocarp and endocarp respectively. The endocarp contains embryo known as kernel (Ajala et al., 2016)

The seed being small in size and difficult to extract, is rich in oil (Sovilj, 2010) ranging between 50%-60% total weight of the seed and is located as intracellular oil bodies of diameter size ranging from ~1 to 5 μm (Ellis et al., 2015) and can be preserved up to a year by either drying or smoking before storage (Adu et al., 2013). Garcıa-Pascual et al (2003) confirms that the classical way of storing almonds nuts is to keep them in their shell after natural drying until their consumption or use in industry.

The vast majority of almonds are sold shelled; shelled almonds may be sold as whole natural almonds or may be processed into numerous forms (Clyde et al., 2004) in countries where almonds are produced for commercial purposes. In some countries like Nigeria, production is not yet at commercial level (Aregbesola et al., 2012); in fact, almonds are not sold in Nigeria market in fresh form except for the processed ones imported from other countries, yet there are vast of the trees in almost every state of the country. This shows the high level of under-utilization (Adu et al., 2013) and the need to create awareness in that area to encourage farmers into its production for commercialization. Therefore, the aim of this study was to review the almond oil expression through different extraction/expression approach, the economic and health benefits of almond oil

2 Nutritional content of almond oil

Almond seed is a nutritious oil seed, rich in fiber, calcium, vitamin E and protein content. Chemical profile as was reported by Bolaji et al. (2013) further confirmed almond oil is highly nutritious with high phytochemical content. The phytochemical has been reported to treat coronary artery disease (CAD) (Ellis et al., 2015). Almonds provide a nutrient-dense source of vitamin E, manganese, magnesium, copper, phosphorus, fiber, riboflavin, monounsaturated fatty acid, protein (Ehsan et al., 2009), folic acid, alpha tocopherol, zinc and vitamins A, B1, B2, B6 (Blanca, 2007). Almonds have been identified as good sources of natural antioxidants with bioactive properties (Hanine et al., 2014). Tables 1 and 2 give a highlight of the mineral content and proximate composition of almond seed.

Table 1 Proximate composition of almond seed (Akpabio, 2012)

Composition	Composition
Moisture (%)	25.229
Ash (%)	5.00
Lipid (%)	32.73
Crude Protein (%)	33.69
Crude Fibre (%)	3.11
Carbohydrate (%)	25.47
Caloric value (Kcal)	534.20

Table 2 Mineral contents of Indian almond nut (dmb) (Agunbiade and Olanlokun, 2006)

Element	Composition%
Phosphorus	0.19
Potassium	0.17
Magnesium	0.25
Sodium (ppm)	245.65
Calcium (ppm)	845.45
Manganese(ppm)	10.24
Zinc (ppm)	92.12
Iron (ppm)	70.62
Copper (ppm)	9.21

The chemical composition of bitter almond essential oil was analyzed by gas chromatography–mass spectrometry (GC–MS), twenty-one different components representing 99.9% of the total essential oil were identified of which benzaldehyde (62.52%), benzoic acid (14.80%) and hexadecane (3.97%) were the most abundant components (Geng et al., 2016).

2.1 Global production

On a global basis, almonds rank first in tree nut production (Roux et al., 2001). The world's production of this fruits is about 700,000 tons annually (Nwosu et al., 2008; Annongu et al., 2006; Bolaji et al., 2013) and studies showed that Nigeria produces approximately 14% of the worlds production (100000 tons) annually (Annongu et al., 2006; Bolaji et al., 2013) as shown in the Figure 1.

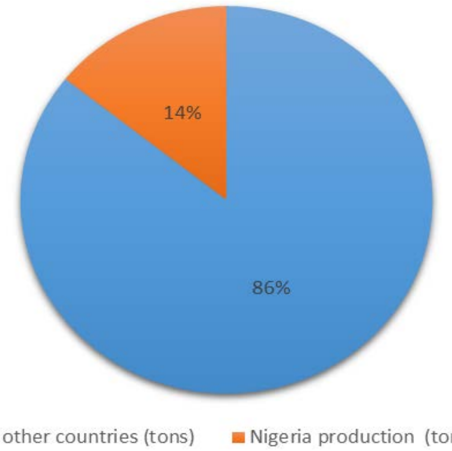


Figure 1 Annual world almond production (tons)

The major countries growing this plant include Italy, Spain, Morocco, France, Greece, and Iran. Its flowers appear between April and May and between September and October. The fruiting season is from October to April (Akpabio, 2012).

Several varieties of almond fruit exist in countries where almond production is at its commercial level like in California. Such varieties include Carmel, Mission, Neplus, Nonpareil, and Peerless (Roux et al., 2001). The most important being the ''Nonpareil'' which accounts for over 50% of the total California production (Clyde et al., 2004).

3 Almond oil extraction methods

The production of oil from oilseeds is an important business, and several researches had been carried out to investigate ways to improve the oil output of the seeds as well as ways to control the composition of the oil (Knowles and Richter, 2013). Numerous methods of separating or removing oil from oilseeds exist and these processes are very important (Biris et al., 2013). The choice of the method is most times influenced by the end use and cost implication as it has effect on the quantity and quality of oil (Biris et al., 2013) as well as the stability characteristics of the oils (Tasan et al., 2011). The separation of oil from oilseeds is painstaking and energy intensive irrespective of the method used (Kalia et al., 2002). Two terms that are frequently used to describe the separation processes are extraction and expression. Extraction is the process of separating a liquid from a liquid-solid system with the use of a solvent while expression is the process of mechanically pressing liquid out of liquid-containing solids. Though they have their little differences but have been used interchangeably in literature (Biris et al., 2013).

The popularly used methods include emulsion method, pressure method and solvent extraction method. Martins et al. (2013) recorded that there are two traditional methods for the extraction of vegetable oils: physical and chemical or solvent., they could also be classified as traditional method, mechanical method, solvent extraction method, supercritical fluid extraction method (Aremu et al., 2015), distillation (Biris et al., 2013), hot water flotation (Fellows and Axtell, 2012), cold percolation method (Kalia et al., 2002), gas assisted mechanical method (Willem, 2007). Despite the several approach in literature, this review classified the methods into two broad classifications, namely: traditional methods and improved methods.

3.1 Traditional method

This method involves several manual steps which vary from place to place. It involves decorating, winnowing, grinding using mortar and pestle, kneading to press out the oil and then heating extracted oil to remove any traces of moisture (Ibrahim and Onwualu, 2005). In Nigeria, individuals extracted oil by reducing the size of the dried seeds using mortar and pestle, after which it is heated and pressed manually using muslin cloth. Some limitations of traditional methods are time consuming, low expression efficiencies which is mainly due to inefficient pounding and grinding (Fellows and Axtell, 2012), tedious, environmentally unfriendly, energy sapping, low yield and poor quality (Olaniyan and Oje, 2007). However, despite the limitations these simple traditional processing methods continue to be used because the cost of equipment is low (Fellows and Axtell, 2012).

3.2 Improved methods

3.2.1 Solvent extraction

This has been recorded to be the most efficient oil recovery method from oil seeds. The process is based on the capacity of the solvent to dissolve oils and to extract them from the complete seed (Ricochon and Muniglia, 2010). Therefore, the lipid fraction is removed by means of an apolar solvent, usually hexane (Martins et al., 2013) or other solvents like propane, carbon-dioxide and n-hexane for extraction. It has been employed for extraction from several oil seeds such as shea nut oil (Ikya et al., 2013), neem oil (Liauw et al., 2008; Tunmise and Oladipupo, 2012), mango seed oil (Nzikou et al., 2010), fluted pumpkin (Agatemor 2006), almond seed oil (Agatemor, 2006; Adu et al., 2013; Atsu Barku et al., 2012, Matos et al., 2009), cashew nut oil (Idah et al., 2014), palm kernel oil (Atasie and Akinhanm, 2009), soybean oil (Avram et al., 2014) etc.

The disadvantage with this method is that the oil has to pass through elevated heat treatment for a longer period which may destroy its important nutritional components and the fact that some traces of the solvent used still remains in the oil even after purification (Latif, 2009). Efforts have been made to develop technologies to overcome this challenge through Two-phase solvent extraction, enzyme-assisted solvent extraction (Latif, 2009; Eshtiaghi et al., 2015) or the use of organic solvent (Ferreira-Dias et al., 2003).

3.2.2 Supercritical fluid extraction method

This involves the use of carbon dioxide (SC-CO_2) particularly for isolation of the valuable components from plant materials (Sovilj, 2010). This method helps to produce oil of superior quality but the investment cost is very high (Asoiro and Akubuo, 2011) where any enhancement of extraction efficiency either in terms of extraction rate or yield is economically attractive (Vilkhu et al., 2006). Also, combined action of ultrasound and supercritical carbon dioxide on extraction could be used to significantly improve extraction rate or yield of amaranth oil, almond oil, operating parameters such as temperature, pressure and CO_2 flow for Adlay oil (Vilkhu et al., 2006). Work on optimization of technology for almond oil extraction by supercritical CO_2 showed that the optimum extraction conditions that gave oil yield of 52.98% are as follows: extraction pressure of 36 MPa, extraction temperature of 50^oC, CO_2 flow rate of 24 L h^{-1}, diameter of almond powder 60 mu and extraction time of 2 h (Ma et al., 2007). Supercritical fluid extraction of almond oil has more advantage over Soxhlet extraction method with respect to the quality of the extracts due to high oleic acid content (Natalia et al., 2010). Moreover, oil extracted from crushed almond seeds using supercritical carbon dioxide method at 350 bar and 40^oC gave oil yield values that were very close to that obtained from Soxhlet method (Marrone et al., 1998).

3.2.3 Mechanical method

It is the most common and the oldest method used for oil extraction from seeds (Ajao et al., 2009). This involves the oil seeds being subjected to mechanical forces to enhance seed deformation (Ajav and Fakayode, 2013) and the easy release of oil through pressing. Several machines have been adopted for this method and they include motorized ghani, presses, mechanical oil rig, expellers (Practical Action, 2008; Olaniyan and Oje, 2007). The design process of some of these machines shows that mechanical strength is very important in design of machines for oil extraction from oil seeds as this will determine the force that will be enough for oil optimization (Ozumba et al., 2010) and the power required for it. Also the dehusking process of the whole fruit to get out the seed for extraction is also another vital process and work by Sunmonu et al. (2015) on determination of some mechanical properties of almond seed related to design of food processing machines gave the properties for red and white varieties of almond fruit which will be of great help in designing locally made dehusking machines. There are several researches in this area for some oil seeds (Ajav and Fakayode, 2013; Mirzabe et al., 2013) of locally made oil extraction machines. Also, oil point pressure is very important parameter in mechanical oil extraction as it gives a guide on the pressure range for maximum oil extraction. Work by Aregbesola et al. (2012) on oil point pressure of almond show that oil point pressure reduced with increase in heating temperature and heating time for both coarse and fine particles. Oil point pressure is very important in designing extraction machines for almond seeds as this will serve as a guide to what the minimum and maximum pressure range will be. Investigation carried out on the effect of process parameters on oil yield from sweet almond seed (Terminalia catappia) expressed using a mechanical oil rig shows that the maximum oil yield of 37.138%, was obtained at temperature, pressure, heating time and moisture content of 90°C, 24 KN, 18 minutes and 8% w.b respectively (Akubude et al., 2017).

3.2.4 Aqueous method of oil extraction

This technology was initiated to serve as alternative to solvent method of extraction. It uses the principle of disrupting the tissue of the material by applying heat to allow oil separation. It could be through either dry or wet rendering. Dry rendering is done by heating a material so that the fat melts out and can be separated while wet rendering in terms of aqueous extraction involves three important processes: material crushing, cooking process (which at first development is using heated water) and oil separation either using a pressing or centrifuging (Shende and Sidhu, 2014). Works done using this method include oil extraction from almond seed using methanol-water aqueous layer (Matos et al., 2009), Wheat germ oil (Xie et al., 2012) and breadfruit (Maria et al., 2013) . Also, studies from Sharma and Gupta (2006) recorded that ultrasonic pre-treatment of the almond and apricot seeds before aqueous oil extraction and aqueous enzymatic oil extraction provided significantly higher yield with reduction in extraction time.

4 Factors affecting oil expression

There are several factors affecting oil extraction/expression from oilseeds. For a given specie of oil seed, the main factors influencing the expression process are pressure, temperature, and moisture content. It is important to note that some of these factors are peculiar to a particular extraction/expression method. studies shows that oil extraction process by mechanical method is influenced by particle size, moisture content, heating temperature, heating time, pressing pressure and pressing time (Abidakun et al., 2012; Adekola, 2014).

Common pressures discussed in oil expression are oil point pressure, effective pressure and optimum pressure. Oil point pressure refers to that applied pressure at which the oil comes out of the inter-particle voids or the minimum pressure that must be applied before oil expression commences. Effective pressure is some value above the oil point value. Oil point pressure of almond seed is 1.00 MPa – 2.33MPa for 70^{o}C-115^{o}C, 5%-8% w.b for fine, coarse and particle size (Aregbesola et al., 2012).

Studies on several oil seeds shows that oil recovery increases with decrease in moisture content, increase in temperature, heating time and pressure (Adejumo et al., 2013). But yield tend to level off when the optimum pressure have been reached and yield tend to decrease as the optimum time and temperature is approached and this also tend to have negative effect on the quality of the oil and the cake (Adejumo et al., 2013).

Heating enhances extraction process by reducing the oil viscosity and releasing oil from intact cells, and also reduces moisture in the cells. Temperature is among the key parameters in the seed treatment for mechanical extraction and ensures an effective solvent extraction process by heating the solvent which quickens the extraction process. At the right temperature and moisture content, maximum oil yield is attained (Aremu et al., 2015). Adesina and Bankole (2013) recorded the effect of particle size, applied pressure, pressing time and time on oil yield of almond seed. But there are no works on effect of moisture content and temperature on oil yield and even effect of process parameters on oil quality of mechanically expressed almond seed. Optimum parameters are yet to be established for this method with respect to almond seed.

For enzymatic oil extraction studies recorded that the enzyme concentration, enzyme time, type of enzyme (Eshtiaghi et al., 2015), pH and Substrate/Water Ratio (Sant’Anna et al., 2003) affects oil yield.Studies from Sovilj (2010) shows that process parameters affecting supercritical CO_2 extraction method are pressure, temperature, solvent flow rate, diameter of ground materials, and moisture of oil.

5 Quality parameters

Table 3 indicates both chemical and physical properties of almond oil in literature and the method of extraction used.

Table 3 Physiochemical properties of almond oil

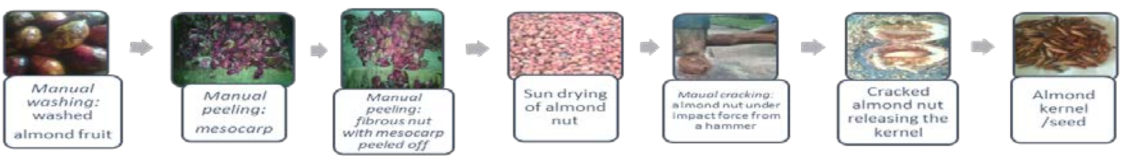
MTE	SG	FFA	SV	IV	PV	VI	PH	RI	FP	FIP	AV	CO	AUTHORS
SE	0.926	-	179.02	85.12	-	-	-	-	-	-	7.59	-	Agatemor (2006)
SE	0.923	0.38	168.27	121.19	4.073			1.465			0.787	Golden	Atsu Barku et al (2012)
SE	-	0.388	163.398	-	-	-	-	-	-	-	0.770	-	Afolabi (2008)
SE	-	20.05	151.55	12.46	2.25	302.39	6.67	1.46	110	220	40.14	Yellow	Ogunsuyi and Daramola (2013)
SE	-	2. 42	207	82.43	0.51	32.92	-	-	-	-	-	-	Mataos et al (2009)

Note: Where RI = Refractive Index, SG = Specific Gravity, VI = Viscosity, AV = Acid Value, SV = Saponification Value, IV = Iodine Value, PV = Peroxide Value, FFA = Free Fatty Acid, FL =Flash point, FIP=Fire point, CO= colour, SE= solvent extraction, MTE= method of extraction, – = Not available.

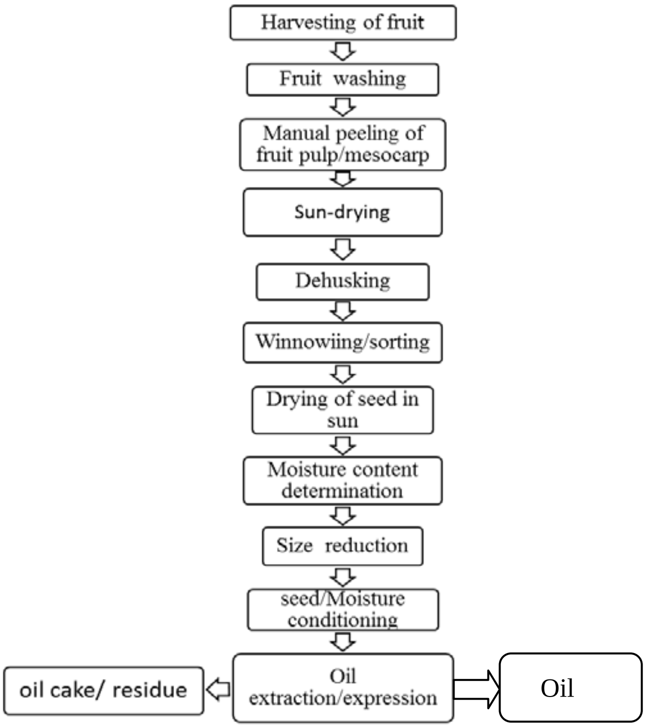
6 Challenges and prospects of almond oil extraction in West Africa

Almond oil extraction process begins from harvesting of the almond fruit as show in Figure 2a and 2b. Though the oil is stored within the almond kernel but to extract the kernel the strong fibrous shell of almond fruit must be carefully cracked to release the seed. The major challenges of almond oil extraction in west Africa particularly Nigeria are experienced during the pre-processing of almond fruit to extract the seed from the almond nut. Operations like harvesting of fruits from the field, de-pulping, winnowing, cracking and sorting are still done manually because there has not been any improved method for carrying out these operations in Nigeria due to the fact that almond processing is still a new venture. Manual cracking using hammer or stone is tedious, time consuming and inefficient since some of the seeds end being broken as a result of application of high impact force. Though almond nut crackers could be imported from some foreign countries but the cost is expensive for small scale businesses that are into almond oil production in Nigeria. Hence, the need for locally made almond nut cracker. Also, reducing the almond kernel to the desired size, heating and pressing out of almond oil is a process that requires a well-controlled mechanical system to achieve. Another, challenge is the availability of the seed in the market. Presently, almond fruits from Nigeria farmland are not sold in Nigeria market because they are allowed to waste in the field. In fact, most of the almond trees are grown for shade and as ornamental trees. Therefore, there is need for creating a market structure for almond sales in Nigeria where farmers are encouraged to cultivate, process, store and sell almond fruits and products in market, this way it becomes available to oil producers that are into almond oil production.

Currently there is research revolution cropping up in Nigeria particularly at University of Uyo and Ghana in view of harnessing the total potentials of almond fruit. The research at Faculty of Agriculture, University of Uyo is presently working on the characterization, selection and breeding of different species. The research is working alongside with National centre for Agricultural mechanization where a prototype machine for almond juice extraction and nut deshelling is being fabricated (AgroNigeria, 2016). Hence, there is hope that through the research results, structures can be set up for almond processing and utilization. This will proffer a bright prospect for the increasing population, solve employment problem, reduce poverty rate and food security problem in Nigeria. This is very possible since the Nigeria soil supports cultivation of almond fruit, and planting of many of this tree plant can help to solve deforestation problem in Nigeria.



(a) Pre-processing of almond fruit before almond oil extraction/expression



(b) Almond oil extraction/expression flow chart

Figure 2 Pre-processing of almond fruit before almond oil extraction/expression and almond oil extraction/expression flow chart

7 Economic and health benefits of almond oil

Almonds tree are nutritional powerhouses with its oil packed with several of helpful nutrients that had contributed to its economic and health importance as shown in Figure 2 and Figure 3. In fact, it has served as natural remedy in many of the external and internal diseases (Safeena et al., 2013). Almond oil contains more vitamin E than most other nut oils, phytosterols, unsaturated fatty acids, mono-unsaturated fatty acids (MUFAs), calcium and magnesium. Its content has triggered the increasing number of natural healthcare products and demand for healthy ingredients. Review work by Akubude et al. (2016) reveals that essential oil of almond can be used for food flavourings and the cosmetics industry. The oil of bitter almonds is also used after the poisonous acid (prussic acid) that gives the bitter taste has been removed. Bitter-almond oil is used as flavouring in foods, soft drinks, and medicines, and as a fragrance for perfume, soaps, cosmetics creams, hair oils, balms, scrubs, massage oils (Safeena et al., 2013). Findings from Geng et al. (2016) revealed that bitter almond oil is a potential botanical and agricultural fungicide that is environmental friendly. Results from work done on almond show that it has high oil yield and is a potential feedstock for biofuel (Ogunsuyi and Daramola, 2013), oleo-chemical production (Amit and Amit, 2012) and aromatherapy (CBI Ministry of Foreign Affair, 2014).

8 Future research needs

Studies on the oil yield of several varieties of almond seed under different process parameters is very essential; more information is needed on the effect of storage methods on the quality of oil produced from several methods. Research on the comparative study of the various methods of oil extraction from almond and their blending compatibility with other vegetable oil is also needed. The effect of process parameters on oil recovery and its quality is also imperative. Study on optimization of oil from almond seed is essential. There is little research on mechanical and physical properties of the several varieties in continents like Africa particularly West Africa and more research is needed in that area which will also serve as a guide to the design and fabrication of locally made machines for the processing of almond fruit into its several products like oil. Also, the market setup for commercialization of almond fruit and its products in countries where they are under-utilized is urgently needed through creating awareness and encouraging farmers to go into its commercial production. And when taken serious, almond will turn to become one of the exported products of any country that goes into its production at commercial level and this will generate income not just for the farmers but the country at large.

Finally, food scientist and chemist are encouraged to research more on the end use of the oil for production of other essential products like cosmetics; mayonnaise, hair cream etc and the federal government alongside with non-governmental organizations need to help out in setting up a research institute to make developmental studies on almond a reality in no distant time.

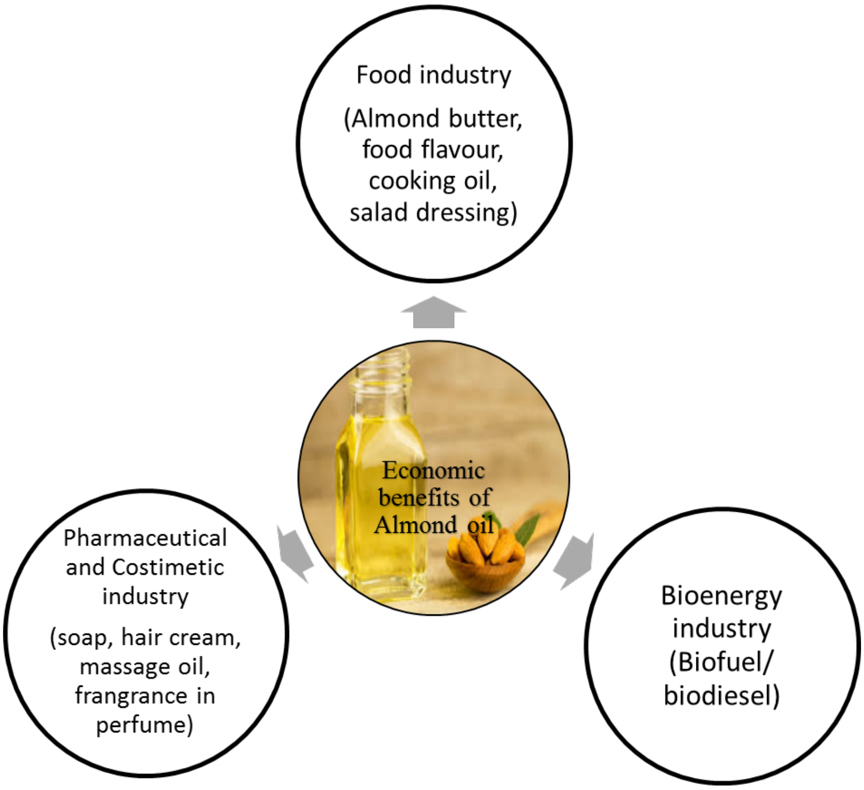


Figure 3 Economic benefits of almond oil

Figure 4 Health benefits of almond oil

9 Conclusion

A review on almond oil has been undertaken. From this study, the following are evident:

1. The most commonly used method of expression for

almond is supercritical carbon dioxide method, hence the need to explore other expression/extraction methods and its combination more deeply.

2. There are data for process optimization for some methods like the mechanical expression using mechanical oil rig and supercritical carbon dioxide method but optimization for other method is yet to be explored.

3. There is need for increased awareness on the nutritional content of almond in countries where it is underutilized since it has great health and economic benefits so that such countries can get involved in commercial production of almond.

4. There are few research works on blending of almond oil with other oils as this can help to enhance its quality and quantity for specific applications.

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