Evaluation of Ethiopian Nigerseed (*Guizotia abyssinica* Cass) Production, Seed Storage and Virgin Oil Expression

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Abstract

The aim of this study was to investigate factors influencing seed yield, postharvest handling, and the oil expression efficiency for nigerseed (*Guizotia abbysinica* Cass.). Based on field study on two varieties, two locations, three seed rates and three fertilizer rates the highest mean nigerseed yield was 1384.6 kg ha^{-1} at Adet location (rain fed) followed by location Koga (rain) with 1064.7 kg ha^{-1} and Koga (irrigation) with 967.0 kg ha^{-1} showing significant difference. The oil content by location was 41.54% for Koga (rain) followed by 39.59 and 38.67% for Koga (irrigation) and Adet (rain) respectively showing significant difference whereas the Ash content showed a reverse trend of oil content. Fatty acid composition did not show significant difference in any treatment. Significant mean α-tocopherol of 80 mg/100 g (70 to 89 mg/100 g) was attained for increasing seed and nitrogen rates. Based on two temperatures and seven relative humidities model evaluation and monolayer moisture content estimation, Guggenheim-Anderson-de Boer (GAB) models was found to best suit both varieties as compared to Brunauer-Emmet-Teller (BET), and modified Chung & Pfost. For oil expression efficiency, 90ºC seed conditioning showed significant effect compared to 80 and 70ºC however conditioning times and feed rates did not differ significantly.

Key words: Nigerseed, yield, oil content, fatty acid, α-tocopherol, equilibrium-moisture-contents, equilibrium-relative-humidity, model, oil expression

Zusammenfassung

Das Ziel der experimentellen Arbeit war die Untersuchung der Einflussfaktoren auf den Ertrag, die Saatgutqualität unter verschiedenen Lagerungsbedingungen sowie die Effizienz der Expression von Ramtillkraut (Guizotia abbysinica Cass.). In Feldversuchen wurden folgende Varianten untersucht, Sorten ‚Fogera‘ und ‚Kuyu‘, Saatgutaufwand von 5, 10, 15 kg ha^{-1}, ein Stickstoffaufwand von 13, 23 und 33 kg ha^{-1}, sowie eine differenzierte Wasserversorgung an zwei Standorten (Adet und Koga). In Adet wurde der höchste Saatgut Ertrag mit 1.384,60 kg ha^{-1} ermittelt, Erträgen in Koga (ohne Bewässerung) mit 1.064,72 kg ha^{-1} und 967,00 kg ha^{-1} (mit Bewässerung). Der höchste Ölgehalt wurde im Saatgut aus Koga (ohne Bewässerung) mit 41,54% ermittelt, gefolgt von Koga (mit Bewässerung) 39,59% und Adet mit 38,67%. Signifikante Unterschiede wurden zwischen den N-Aufwandmengen in Koga mit Bewässerung und Saatgutmengen in Adet ermittelt. Die Unterschiede bei den Fettsäuregehalten in Adet waren nicht signifikant. Der α-Tocopherol Gehalt betrug 80 mg pro 100 g bei hoher Saatdichte und hoher N-Düngung. Hinsichtlich des Verfahrens des Ölpressens, wurde ein signifikanter Unterschied zwischen Effizienz und Temperatur ermittelt. Die Dauer der Konditionierung und die Vorschubgeschwindigkeit sind negative korreliert gleichfalls mit der Effizienz der Expression. Die Temperaturen von 70°C und 80°C zeigten keinen signifikanten Einfluss auf die Ölausbeute, dagegen war der der Einfluss von 90°C statistisch signifikant.

Schlagwörter: Ramtillkraut, Ölgehalte, Fettsäuregehalt, α-Tocopherol, Saatgut Lagerungsfeuchte, Effektivität Ölpresse

Acronyms and Abbreviations

AA	Arachidonic acid
ACP	African Caribbean Pacific
AD	Adet (study field location)
ALA	Alpha linolenic acid
BET	Brunauer-Emmet-Teller
CSA	Central Statistical Agency (of Ethiopia)
CoA	Coenzyme A
DAG	Diacyl glycerol
d.b.	Dry basis
DHA	Docosahexaenoic acid
DHAP	Dihydroxyacetyl phosphate
DHHS	Department of Health and Human Services (US)
DPA	Docosapentaenoic acid
EARO	Ethiopian Agricultural Research Organization currently Ethiopian Institute of Agricultural Research
E.C.	Ethiopian calendar
EPA	Eicosapentaenoic acid
ERCA	Ethiopian Revenue and Custom Authority
ES	Ethiopian Standards
ETB	Birr (Ethiopian Currency)
emc	Equilibrium moisture content
erh	Equilibrium relative humidity
EU	European Union
F	Fogera (Nigerseed variety)
FA	Fatty acid
FAS	Foreign Agriculture Service (US)
FAO	Food and Agricultural Organization (UN)
FH	Fertilizer High (nitrogen rate)
FL	Fertilizer Low (nitrogen rate)
FM	Fertilizer Medium (nitrogen rate)

Acronyms and Abbreviations (cont'd)

GAB	Guggenheim-Anderson-de Boer
GAME	Gas Assisted Mechanical Expression (of oil)
Gly	Glycerol
HDL	High-density lipoprotein cholesterol, also called "good" cholesterol
ILO	International Labor Organization (of UN)
ISO	International Standards Organization
K	Kuyu (Nigerseed variety)
KO	Koga (study field location)
LA	Linoleic acid
LDL	Low-density lipoprotein cholesterol, also called "bad" cholesterol
MAG	Monoacylglycerol
Masl	Meter above sea level (altitude)
Meher	The major harvest season of Ethiopia
MUFA	Mono Unsaturated Fatty Acid
Noug	Nigerseed's local name in Ethiopia
NPK	Nitrogen-Phosphorus-Potassium
OAA	Oxaloacetic acid
OECD	Organization for Economic Co-operation and Development
PUFA	Poly Unsaturated Fatty Acid
Quintal	A mass of 100kg
SFA	Saturated Fatty Acid
SH	Seed High (rate)
SL	Seed Low (rate)
SM	Seed Medium (rate)
Suc	Succinic acid
TAG	Triacylglycerol
TFA	Trans-fatty acid
UNIDO	United Nation's Industry Development Organization
USDA	US Department of Agriculture
WHO	World Health Organization

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1. Problem Statement

Surveys indicate that many oil mills in Ethiopia are working under capacity for most of their time (Schenk et al., 2009). According to this survey the mills are operational only for 20-30% of their potential. This under capacity working of the oil mills in Ethiopia is mainly due to shortage of raw material/oilseeds (Schenk et al., 2009; Wijnands et al., 2009). When available the oilseeds are expensive which makes the oil pressed from them less competitive than the imported cheaper ones. Both availability and price of the oilseed are fundamental challenges in Ethiopia (Lefebvre, 2012). As a solution to this pressing problem nigerseed and linseed were selected among the oilseed for edible oil value chain enhancement in Ethiopia (Lefebvre, 2012). It is also known that the small scale oil millers cover about two third of the domestic edible oil production (Wijnands et al., 2009). Therefore the small scale oil mills are selected for the edible oil value chain enhancement program. Despite tremendous advantages of nigerseed which is native to Ethiopia limited formal research has been carried out to improve its agricultural productivity and enhance the value chain (Biodiversity International, 2011).

"An unintended consequence of the green revolution has been a massive reduction in the number of species and diversity of crops. This process of crop replacement is a threat to local and global food security because the replaced indigenous crops often are essential for low input agriculture, have unique nutritional and cultural value, and contain a diversity of locally adapted genotypes with resistance to a wide array of biotic and abiotic stresses. Global climate change and degradation of once-productive lands have further heightened the demand for crops that perform well in harsh and/or changing environments. Research on noug/nigerseed is designed to improve the yield and quality of this neglected and underutilized species so it can contribute to the food security and income of subsistence farmers. More projects of this kind on a wide range of neglected and underutilized species are needed to work towards a sustainable solution for increased food security and poverty alleviation as stated in the United Nations Millennium Development Goals" (Rieseberg lab, 2007)

In Ethiopia, nigerseed is used at house hold level to make oil, to make paste known as '*litlit*' and also paste mix with snacks, which is commonly given to a large family to subdue appetite at extra meal hour. Nigerseed paste mixed with roasted cereals or sandwiched with flat bread or 'injera' is used during holidays in Ethiopia especially in

Northern Ethiopia. The nigerseed roasted and pounded into flour is boiled and inhaled and then drunk as a remedy for common cold. The flour or the meal from the oil press is also used to oil/smoothen heated baking clay pan before baking as '*masesha*'.

Despite its tremendous applications and importance nigerseed has multidimensional problems which can be classified into three major dimensions as seed supply, seed storage, and efficiency of oil expression. The overall source of the problem of the domestic edible industry which is already weak can mainly be ascribed to shortage of oilseeds (quantity and quality) and efficiency which makes those in the business to be unable to compete with the imported edible oils (Lefebvre, 2012).

Although seed supply problem could be further subdivided into many the major problem is its low seed and oil yield (production per hectare). Therefore to make nigerseed more competitive in the market and make a priority crop, agronomic optimization could be one among arrays of alternatives approaches to solution. Agronomic optimization is of obvious need for any crop plant cultivation to select the necessary condition and apply the necessary inputs in an efficient and sustainable way so that full potential of the crop is expressed and the maximum possible yield is obtained. The Ethiopian edible oil industry suffered serious challenge mainly as a result of oilseed shortage and this made the country heavily import dependent for edible oil. Ethiopia is currently dependent on imported edible oil mainly from Asia, for about 80% of its consumption (Wijnands et al., 2009). Import of edible oil, mainly palm and soybean, is increasing rapidly and progressively displacing the local edible oils like nigerseed and linseed oils. This can be clearly seen by the case where sometimes the hard currency obtained from the export of oilseed sesame is nearly totally reinvested to import edible oil (EU All ACP Agricultural Commodities Program, 2009). The second source of challenge is the chance given to the imported edible oil to be free from tax duty and the resulting unbalanced playing field created between the imported and domestically produced edible oil. The seed supply problem might be due to customary prioritization of food grains and less attention given to the oilseed sector. Prioritization has caused change on the Ethiopian farming system which can be a reason for progressive decrease of nigerseed especially by highland farmers (Getnet, 2011). Duty free import might also be a strategy to overcome the acute shortage of edible oil in the domestic market but it plays a significantly negative role on domestic industry (Wijnands, 2009). The third factor can be export of oilseeds because of the attractive foreign currency which the oilseeds earn for government (even though government is said to be restricting export during shortage times). Traditionally even sesame oil was the major edible oil for North and Northwestern Ethiopia however today one can hardly find sesame oil except during harvest which is produced from the surplus around the farming areas. Sometimes the net gain is not clear when the oilseed export revenue and the edible oil import expenditure is compared (EU All ACP Agricultural Commodities Program, 2009; Wijnands, 2009). The forth and the controversial factor could be hoarding of the oilseed/oil speculating higher price which is ever escalating partly complicated with currency devaluation. And in this case problems related to storage and the need to control the quality of the seed must be addressed.

The market competitiveness of the oilseed can be improved through improving seed yield mainly by improved agronomic practices in addition to other multitude of approaches like breeding. In addition to improved seed yield, oil content and nutritive value are factors for a given oilseed to be competitive in the market and of course to be priority crop for cultivation by farmers as compared to any other alternative crops in a given area. Until recently where the influence of imported edible oil became dominant, nigerseed oil used to cover 50 to 60% of the domestic edible oil supply (Getnet and Sharma, 1996). The market competitiveness of nigerseed oil is manifested in that it is more expensive without any scientifically approved special value for premium status (Lefebvre, 2012).

Related to improvement of nigerseed supply factors affecting yield could be mainly improved seed varieties, optimum level of the seed, optimum level of fertilizer and the other factors include water supply mode (irrigation/rain fed) and suitability of locations. Related to seed variety, although there are national released varieties of nigerseed (EARO, 2004), their recommendation based on location, rain-fed and irrigation, and even variety to be available for the farmers is limited or unclear. The released varieties are not either known to the farmers. This situation shows that there is gap between the farmers and the researchers particularly in utilization of research output. It is well known that higher production can be achieved when yield per hectare is increased. This is important as the Ethiopian food demand continues to increase because of population and income growth. It is known that Ethiopia is the second most populous country in Africa. The importance of improving yield and quality of nigerseed is far beyond improving raw material for domestic edible oil mills. It is known that the nigerseed virgin oil had been playing almost irreplaceable role of nourishing the Ethiopian people since time immemorial. The cake/meal, for instance, from the press is an important animal feed. In Ethiopians life nigerseed has many more application other than oil. In particular, the main focus of agriculture for the smallholders (dominant in Ethiopian agriculture) is on food security and oilseeds are one of such important crops for food security generally produced as cash crop. Therefore food security, in this regard can be ensured by enhancing optimum yield and profitability of the oilseeds like nigerseed so that the farmers will be attracted to cultivate and benefit from it supplying both to the domestic industry and export market beyond satisfying their household demand.

The second dimension of the problem is the storage of nigerseed for prolonged time under generally inappropriate conditions which also needs attention. Inappropriate storage is likely to result in quality deterioration of the seed and the oil expressed from it in addition to contributing to seed shortage due to seed hoarding. The problem related to oil quality deterioration resulting from such poor storage is not generally accepted for cold pressed and virgin oil production. This is because the virgin oil production has no refining facility to adjust some of the quality deterioration such as free fatty acid and peroxide which may be formed due to poor storage and handling. Therefore seed supply from a good storage is of paramount importance in the edible oil value chain particularly virgin and cold pressed oil which is ultimate product of small scale oil mill. The storage and handling issue is where the virgin oil millers are challenged by the quality authority in Ethiopia (controlling body). In this regard storage characterization of nigerseed is important as a step towards quality oil especially virgin oil production. A well-handled seed is competitive both in export market and as raw material for domestic edible oil millers. The export market of nigerseed itself is obviously facing more and more intensive competition due to involvement of more Asian countries on the one hand (Burnette, 2010) and the increasing competition from farmers of the USA (major importers). More recently, nigerseed is being introduced/taken in to consideration as a raw material for edible oil in some countries (Burnette, 2010; Francis and Campbell, 2003).

Edible oil millers who produce virgin oil that is served directly to the consumer without refining procedure need quality nigerseed which fulfills some recommended physical and chemical criteria as raw material. The seed or oil with free fatty acid beyond certain level is not acceptable as healthy oil for human consumption. This free fatty acid formation is generally enhanced by poor and uncontrolled seed storage and handling. Larger processors with refining facility may tolerate lower quality seed even though loss of certain volume due to removal of the free fatty acid is inevitable.

The third dimension of the problem is efficiency of oil expression. The Ethiopian edible oil sector consists of the local, small-scale processors who are majority and steadily increasing and a few medium and large-scale enterprises which are rather stagnant (Schenk et al., 2009). Although the local small-scale millers' role is highly important in supplying of edible oil their production efficiency is lower as compared to the larger processors. In addition to their low efficiency of production, they are confronted with difficult options following the government law demanding refining as precondition for marketing their product and this is well explained by business model (Figure 1.1) (Sertse et al., 2011). Refining is imposed as a precondition by quality authority to ensure the quality and safety of edible oil irrespective of the seed quality. In this case it could be possible to make them step specialized if the seed quality is ensured following certain guidelines and safe production procedure rather than imposing criteria of refining that they cannot afford.

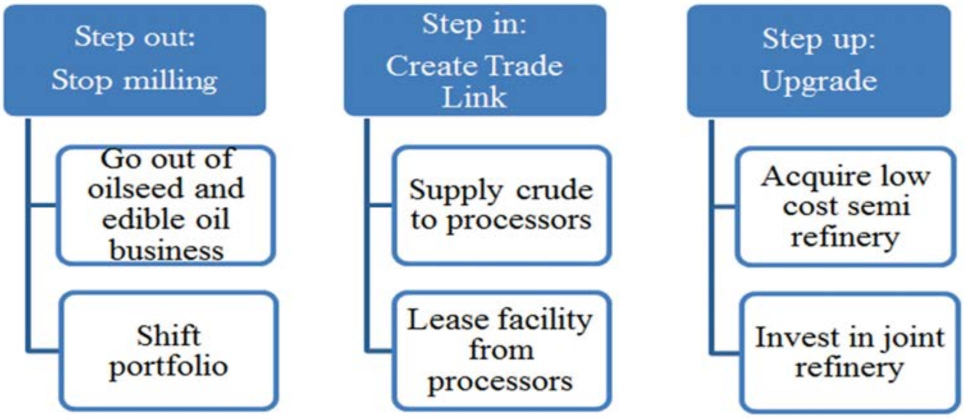


Figure 1.1: Business Options for Edible Oil Millers of Ethiopia (Source: Sertse et al., 2011)

The small scale edible oil millers in Ethiopia mainly depend on nigerseed as raw material for which they are highly known by the local community. Currently the demand for locally produced nigerseed oil is much more than ever since there are lots of complaints related to health on imported palm oil. Related to this nigerseed oil produced locally is sold almost while being expelled from the machine and sometimes it needs to be ordered in advance. The strong demand for tradition of consuming nigerseed oil in the domestic market together with the increasing concern on health is expected to make the market potential for nigerseed oil promising. Despite high, even increasing, and more promising interest for the virgin oil produced by small scale edible oil millers, skill related to training, standardized working condition and operation procedure, and efficiency appears to be the major challenge. One way of dealing with the problem of small scale millers is improving their efficiency. According to the observation and visits to the small scale edible oil millers, improvement in efficiency should be a type that does not require sophistication but is within the reach of the local millers and medium scale processors mainly due to factors related to investment and simplicity of the technology.

Unless it is handled properly, the under capacity working of the oil mills observed today may lead to not only shortage of edible oil but also leaving many people in the value chain jobless. While shortage of oilseed is mainly responsible for shortage of edible oil, prioritizations of cultivation in turn is mainly responsible for shortage of nigerseed. Therefore any effort to improve the oilseeds which are consumed by small scale oil millers (dominant edible oil suppliers) will contribute more significantly to the edible oil supply of Ethiopia. In general improvement of the nigerseed and oil content/yield, determination of storage conditions to maintain quality and standardized seed handling, and improvement of oil expression efficiency particularly for the small scale millers are critically important in dealing with Ethiopia edible oil problem and enhancement of the value chain. The intensive competition of domestic edible oil industry with full time operating, efficient technology of production (energy utilization, oil extraction efficiency, automation … etc.) from supplying countries industry could be challenging to the newly emerging edible oil industry of Ethiopia. The progressive displacement of locally produced edible oil may, in the long run, lead to progressive displacement of value chain of the last resort which is small scale edible oil millers (significant domestic suppliers) and also small holder farmers (major suppliers of oilseed) unless proper measure is taken. Therefore the whole value chain from oilseed to edible oil production and including the market components can curb the problem currently observed in Ethiopia. In this regards independently and sporadically run research and implementation programs need a more coordinated/concerted approach. This could include revision of previous programs and planning new ones based on experiences and new findings.

This paper is organized in such a way that the first chapter briefs on the problems related to the seed supply, storage, and oil expression. The second chapter encompasses the literature review where the trend of production of oilseeds including nigerseed; agronomy; storage; oil expression (background, recent developments, major types of edible oil, major factors affecting yield); small scale edible oil production and its major problems, fat and oil in human nutrition are discussed. The third chapter shows the aim and objectives of the study which is divided into three independent sets experiments: field experiment on nigerseed production, laboratory experiment on nigerseed storage characterization, and oil expression efficiency aspects. The forth chapter is materials and methods based on the three sets of the experiment. The fifth chapter includes the presentation and discussion of the results from the three sets of experiments. Chapter six is a general discussion based on findings from this study and previous works or data. The seventh chapter consists of conclusions from this work and some recommendations which need attention in the future studies on nigerseed and oil production.

2. Literature Review

This chapter encompasses the review of the oilseed cultivation for edible oil production with emphasis on nigerseed (*Guizotia abbysinica* Cass.) and major aspects of the seeds/oilseeds particularly of agronomic practices, seed storage characterization, and optimization of oil expression. In order to address these topics duly, the chapter has been subdivided into seven main sections in which are accommodated the following major topics. The first section deals with the production trend of major oilseeds and edible oils in the global and Ethiopian situation with emphasis on nigerseed. Second section deals with the agronomic aspect of the oilseeds with emphasis on nigerseed including influences of agronomic practices on seed and oil quality. Section three focuses on storage characterization and its importance including validation selected models, and the need for the storage characterization mainly for nigerseed deemed to be used for cold/virgin oil pressing. Section four deals with expression of cold pressed edible oil and its efficiency evaluation with emphasis on small scale mills using screw press. Historical aspects of pressing oil from the past to the current particularly screw presses which this study would like to address will be reviewed. Major factors affecting oil expression as a spring board for selection of experimental variables is discussed briefly in the fifth section. The sixth section discusses small scale edible oil production and its problems in Ethiopia briefly. The seventh section includes the role of fat and oil in human nutrition. Food value chains links agricultural products to consumers through activities from production at the farm through processing, marketing, distribution, and finally to the consumer and has its own dynamicity and peculiarities in developing countries due to population pressure, urbanization, and introduction of global firms (Gomez et al., 2011). Therefore any shock at a point on the value chain will be felt at any other point in one way or another and sometimes in a way difficult to predict. The majority of actors in the value chain are involved in the value chain as a secondary or ready to leave the business when challenges sometime reach maximum (Gomez et al., 2011). Therefore the role of every component and its impact must be seriously addressed supported by evidences.

2.1. Overview of the World and the Ethiopian Oilseed

2.1.1. World Oilseed and Edible Oil

Oilseeds: Oilseeds, such as soybean, cottonseed, rapeseed (canola), sunflower seed and peanut, are the largest sources of vegetable oils in the World (Figure 2.1**)**. The three main edible oils in the World market which represent about 75% of the total production are palm, soybean and rapeseed, (Rosillo-Calle and Pelkmans, 2009). This shows that the global edible oil supply is dependent on a rather limited number of oilseed crops. Therefore there is an obvious need for diversification of oilseeds since relying on a fewer oilseed crops may have its own challenges in many ways including crop failure, exploitation of diverse agro-ecology, climate change, and search for better quality oil such as health oils (Biodiversity International, 2011). Diversification of oilseeds can also be important from point of view of non-food uses of vegetable oil. It is possible to overcome the competition from the non-food use of vegetable oil by exploiting alternative non-edible oilseeds as raw material. Although a more or less steady growth is seen except in 2011/12 (Figure 2.1), the main question is still its utilization aspect.

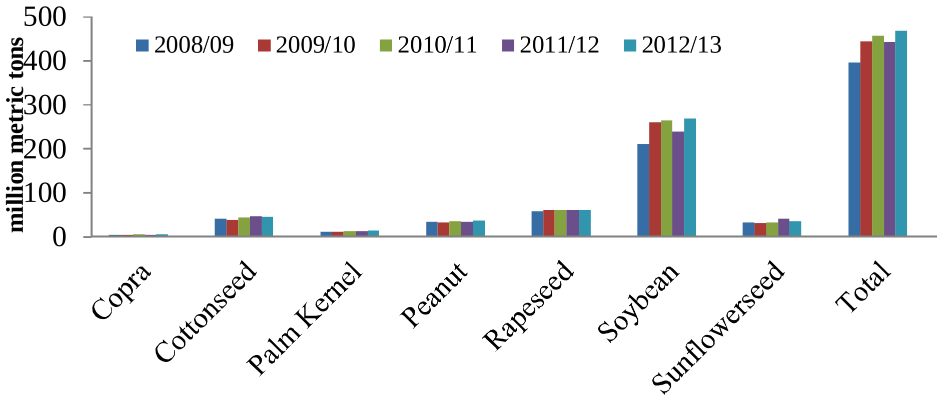


Figure 2.1.: World Production of Major Oilseeds (Source: USDA FAS)

It is known that non-food competition starts from the land and other resources for cultivation such as services for selected seed, fertilizers, crop protection chemicals, and logistics. Therefore regarding vegetable oil consumption, the share of food and non-food use and the changing trend should be clearly understood. From this point of view the trend in the increase of production of oilseeds can be seen as two dimensional.

The first dimension is directed towards satisfying the demand of the growing population/increasing per capita consumption. The second is the trend to use the vegetable oil for non-food application in general and biodiesel in particular. The use of biofuel could be from either environmental concern or tendency to minimize the dependence on mineral fuel or both. And based on these two dimensions, in China and India consumption growth occurs primarily in food use while in the EU and the US biodiesel industry represents a significant source of demand (Rosillo-Calle and Pelkmans, 2009). In general by 2020, biodiesel is expected to increase to 15% of the total consumption as compared to 10% in 2008-10 and particularly the share of biodiesel will reach 50% in the EU (OECD-FAO, 2011).

The shortage of oilseeds and oilseed products is mainly due to global scenario of production-to-utilization difference (Figure 2.2) and stock-to-utilization ratio (Figure 2.3) (USDA FAS, 2013).

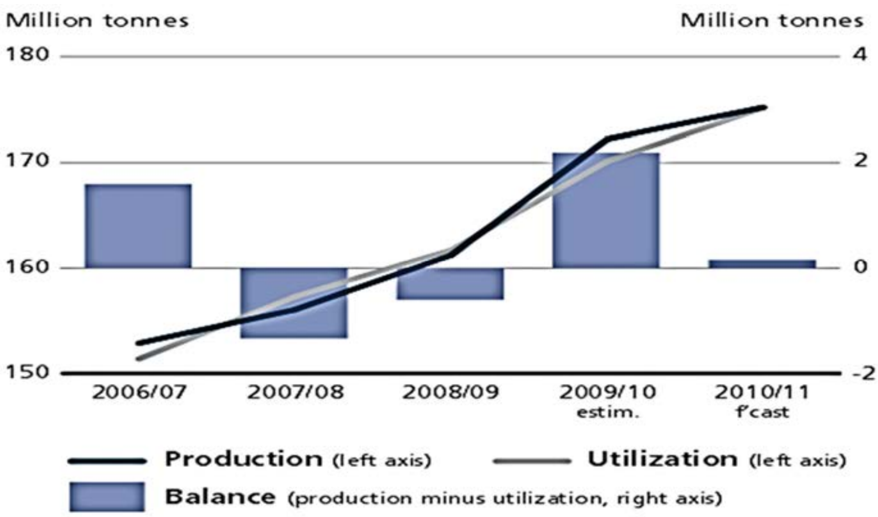


Figure 2.2: Global trend of production and utilization of oilseeds (Source: FAO - Trade and Markets Division, 2012)

This global trend of production and utilization combined with stock to use ratio appears to be somewhat cyclical and the information could be used for preparedness and necessary actions in advance.

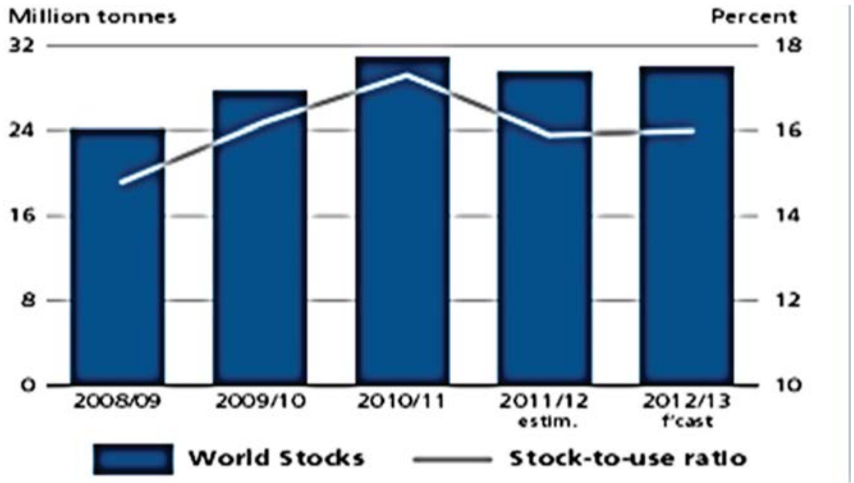


Figure 2.3. World closing stock-to-use ratio of oils/fats (including the oil contained in seeds) (Source: FAO - Trade and Markets Division, 2012)

Several factors are responsible for the global tightening of supply among which are: adverse weather conditions; continued strong import demand for oil crops and derived products by newly emerging economy; demand growth for vegetable oil by the biodiesel industry; and the prospective competition for land among arable crops. Of the two major markets for vegetable oils, food represents over 80% and industrial uses including biodiesel the remaining 20% (OECD/FAO, 2011). Related to its high population and rising per capita consumption, China's vegetable oil import is rapidly increasing significantly affecting the World market. On the other hand, Indonesia, Malaysia, Argentina and Brazil are dominating the World export market compared to the others (USDA FAS, 2013).

Vegetable Oil: Soybean which was not in the list of vegetable oil in significant volume continued to be dominant and similarly the palm oil which was restricted to some parts of Africa and later on Asia showed steady growth taking the Worlds lion`s share of supply. Rapeseed oil showed steadily increasing trend in supplying edible oil to the global market. Sunflower oil is also among those showing steady and relatively fast growth next to rapeseed oil (Figure 2.4). Some oils like cottonseed oil whose raw material supply depends on ginnery industry showed slow but steady growth. Palm kernel oil which is also directly dependent on palm fruit oil production is growing in a similar rate with palm fruit oil but much lower rate due to naturally low kernel/fruit ratio. Coconut, olive, corn, and sesame oil continued with very limited growth for decades either due to their limited expansion or their application for other purposes than edible oil (USDA FAS, 2013).

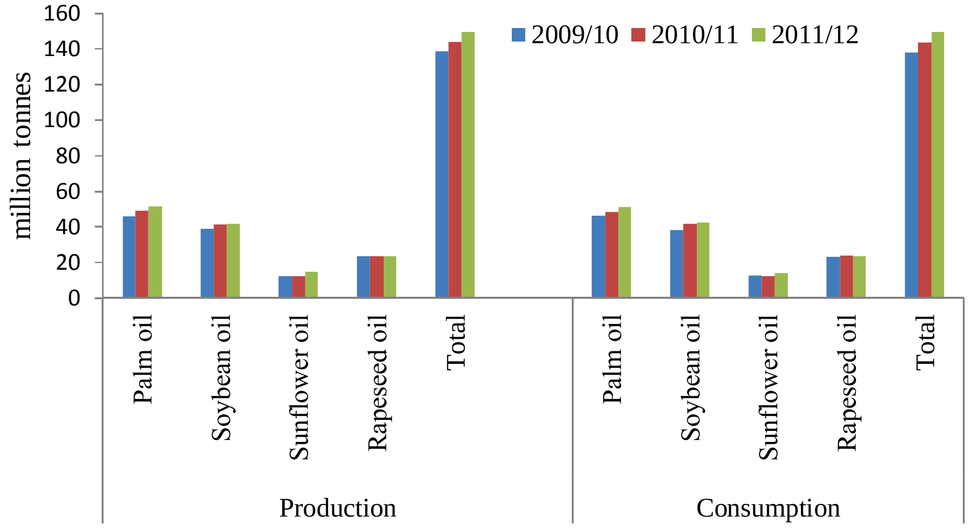


Figure 2.4: World Production and Consumption of oils from different plants (Source: USDA FAS)

Like any other economic cases many developing countries of Africa are unable to meet the demand of their growing population. The weakening of the domestic manufacturing industry and influence of the global economic crisis may be the major factors in this regard. The rate at which sesame is expanding in Ethiopia, for instance, as compared to other oilseed is due the demand in the world market. Therefore it seems obvious that such situation tempts many countries to export oilseeds to earn foreign currency before satisfying the domestic consumption of edible oil. The case of sesame however needs separate treatise since its application in bakery and other product ingredient appears to be more important than raw material of edible oil production elsewhere. Although it is generally said that export of oilseed plays a big role in weakening the domestic industry in Ethiopia the balance need careful scrutiny. If the negative impact is dominating, not only the supply but also the job opportunity across all the value chain may be endangered. The shortage of edible oil supply will additionally affect the nutrition which is obtained from edible oil.

2.1.2. Oilseeds and Edible oil of Ethiopia

The five major cereals in Ethiopia (teff (*Eragrotis tef*), wheat, maize, sorghum and barley) occupy almost three-quarters of total area cultivated, and represent almost 70 percent of total value added in recent years. Teff is a staple cereal crop which is native to Ethiopia to make 'injera', Ethiopian pan cake like food. Moreover, cereal acreage is still increasing, though not as fast as area planted to other crops such as sesame, coffee, chat, vegetables and pulses (Taffesse et al., 2011). The production and % share shows this situation (Table 2.1). Not only the production of oilseed is quite limited but also the trend shows decrease at least for 2009/10 to 2010/11 comparison.

Table 2.1: Total area and production of selected agricultural crops in private farms, 2010/11, Main production season in Ethiopia   Source: (CSA, 2011).

Crop Category	Total area in hectare	%	Total Production (quintal)	(%)
Cereals	9,690,733.96	81.97	177,613,365.84	87.29
Pulses	1,357,522.68	11.48	19,531,935.01	9.60
Oil crops	774,529.55	6.55	6,339,987.49	3.12
Total	11,822,786.19	100	203,485,288.34	100

„The oilseeds value chain makes an important contribution to the Ethiopian economy, accounting for more than twenty percent of the total foreign exchange earnings of the country. It supports the livelihoods of many Ethiopians, particularly small farmers, traders, transporters, and oil millers. The enhanced competitiveness of the value chain hinges on improved efficiency and effective vertical and horizontal integration of different functions, including improved farm practices, input supply, processing, and marketing." UNIDO, FAO, ILO (2011).

The relative economic importance of each type of oilseed of Ethiopia differs. Therefore area of production, total annual product, and yield must be taken into account for prioritization of research or any other attention to the oilseeds. In this regard it can be seen that safflower, linseed, and nigerseed have shown decrease from the highest to the lowest per cent reduction respectively (Table 2.2). Positive change in area of production increased for sesame, groundnut, and safflower with increasing order from 2009/10 to 2010/11.

In Ethiopia, sesame is a priority export crop for government and policy support appears to be the major reason. Groundnut is gaining increasing customer acceptance as a crop with diverse application in food and as a relatively new crop. Groundnut together with safflower is suitable for oil pressing by small scale oil millers in Ethiopia and hence their increasing area of cultivation. Safflower production volume, however, could not similarly increase as compared to sesame and groundnut because of high decline in yield. Linseed showed maximum decrease in area as well as yield which resulted in maximum decrease in production. This shows that little attention is given to linseed by both government and consumers except that its consumption is more important during fasting period of Ethiopian Orthodox Church and its oil in Oromiya state of Ethiopia. Therefore linseed is priority oil crop by small millers of Oromiya state. Although decrease in the area of cultivation as well as yield of nigerseed contributed to its decreased production it is far better than linseed and is even better than safflower due to serious yield problem with safflower. Therefore nigerseed is given relatively better attention and priority especially for small scale edible oil millers. Increasing question on the use of palm oil by the consumer has created favorable condition for nigerseed oil.

Table 2.2: Estimate of Area, Production and Yield for 2009/10 and 2010/11, Ethiopian Major Production Season (Meher in Amharic/Ethiopian language).

Oilseeds	Area (hectare)			Production (quintal)			Yield (kg ha^{-1})		
	2010/11	2009/10	Change (%)	2010/11	2009/10	Change (%)	2010 /11	2009 /10	Change (%)
Total	774,529.6	780,916	-0.82	6,339,987.5	6,436.14	-1.94	NA	NA	NA
Nigerseed	247,611.2	256,794	-3.58	1,448,474.8	1,578,467	-8.24	585	615	-4.88
Linseed	73,687.7	140,801	-47.67	654,205.76	1,506,285	-56.57	888	1074	-17.01
Gr. nuts	49,602.8	41,579	19.30	716,068..3	464,248	54.24	1444	1117	29.27
Safflower	5,489.8	4,653	18.00	50,667.88	55,524	-8.75	923	1193	-22.63
Sesame	384,682.8	315,843	21.80	3,277,409.22	2,605,343	25.80	852	825	3.27
Rapeseed	13,455.1	21,247	-36.67	193,161.43	226,277	-14.63	1436	1065	34.84

Source: CSA (2011), quintal = 100 kg;

Nigerseed alone accounts for about 64% of the land cultivated for oilseed and more than 47% of the production (production year of 2010/11) (sesame excluded) (Table 2.2). Of the land cultivated by nigerseed in Ethiopia, only 0.064% is under irrigation implying that irrigation potential is nearly not exploited. Improved seed utilization for nigerseed is very, about 2.89% is. Similarly about 21.31% of the land on which nigerseed is cultivated was fertilizer applied (CSA, 2011). In Ethiopia the medium and large commercial farms as compared to private small holders are not only limited in numbers in crop cultivation but also are not participating in oilseed production (CSA, 2011).

This can be further clearly seen in that while sesame is incomparably the major export oilseed (Figure 2.5).

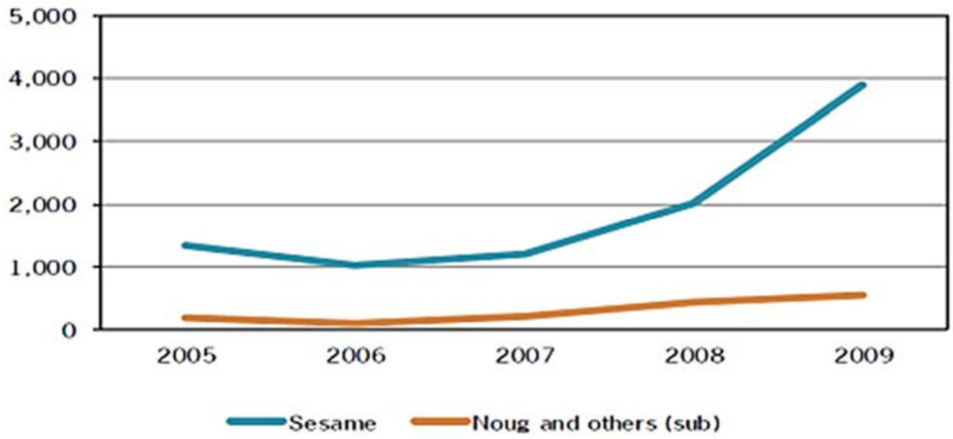


Figure 2.5: Export value of major oilseeds in Ethiopia, 2005-2009 (in million ETB) ERCA (2010) (compiled by Sertse et al., 2011**)**

The fact that the production area coverage is increasing implies that there is certain degree of improvement in cultivation of oilseeds. Although Ethiopia is known to earn about 20% of its foreign exchange from oilseed, by and large this earning is dependent on sesame (Figure 2.5). The other major bottle neck on the seed supply is hesitation of medium and large commercial farms from which significant change expected.

The low improved seed utilization shows that very low national yield estimate was based on the low yielding local cultivars. The low fertilizer utilization is expected because the tradition of considering nigerseed as a marginal crop is still persisting even though the market value of nigerseed has shown dramatic change overtime. Customarily neither fertilizer is applied nor cultivated by irrigation when the crop is marginal in nature. The land preparation and care taken including weeding is very low for marginal crops. Currently since nigerseed oil is gaining more and more value as compared to imported edible oils in Ethiopia, some farmers are improving their fertilizer use as well as land preparation. From this changing trend irrigation cultivation is also expected to increase if encouraging yield is attained. Even though its productivity is still very low, today the market value of nigerseed is very encouraging.

Nigerseed is the major oilseed for crushing (Figure 2.6) and this is why nigerseed together with linseed is selected for edible oil value enhancement program in Ethiopia (Lefebvre, 2012).

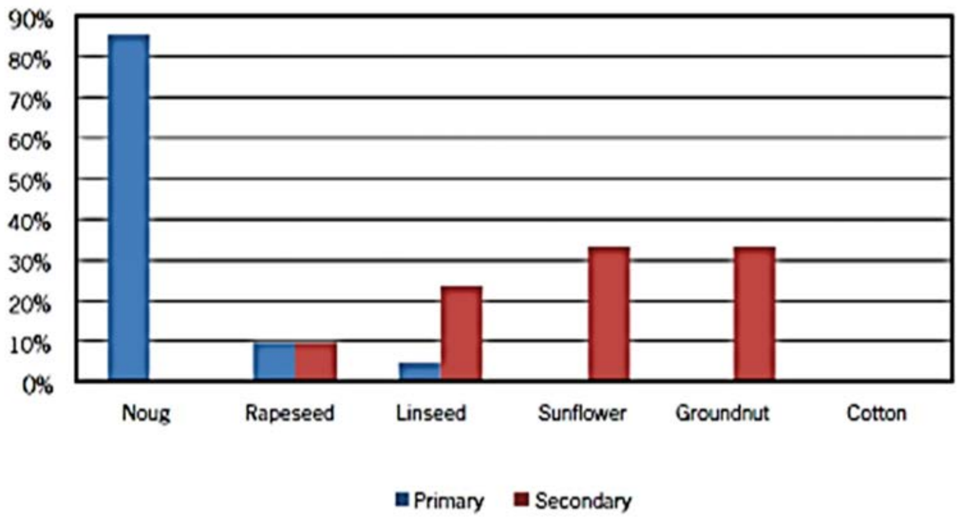


Figure 2.6: Major Oilseeds Crushed by the Millers (Source: clipped from (Sertse et al., 2011).

Edible Oil: It is already described that the main constraint in edible oil production in Ethiopia, irrespective of the production scale (small millers, medium and large processors), is shortage of oilseeds although seed quality, pressing machine, spare parts, finance and workers' skill may exacerbate the problem. Severity of the problem with regard to edible oil/fat can be seen in terms of supply. The fat supply in general is very low in Sub Saharan African as compared to the rest of the World. The gram per capita per day is not only small but also remained nearly stagnant in three decades as compared to reasonable changes in the rest of the World (Figure 2.7).

In this figure is visible that China, East and South East Asia, and South Asia whose per capita supply was much less than Sub-Sahara Africa later on showed remarkable change in about three decades (WHO/FAO, 2003).

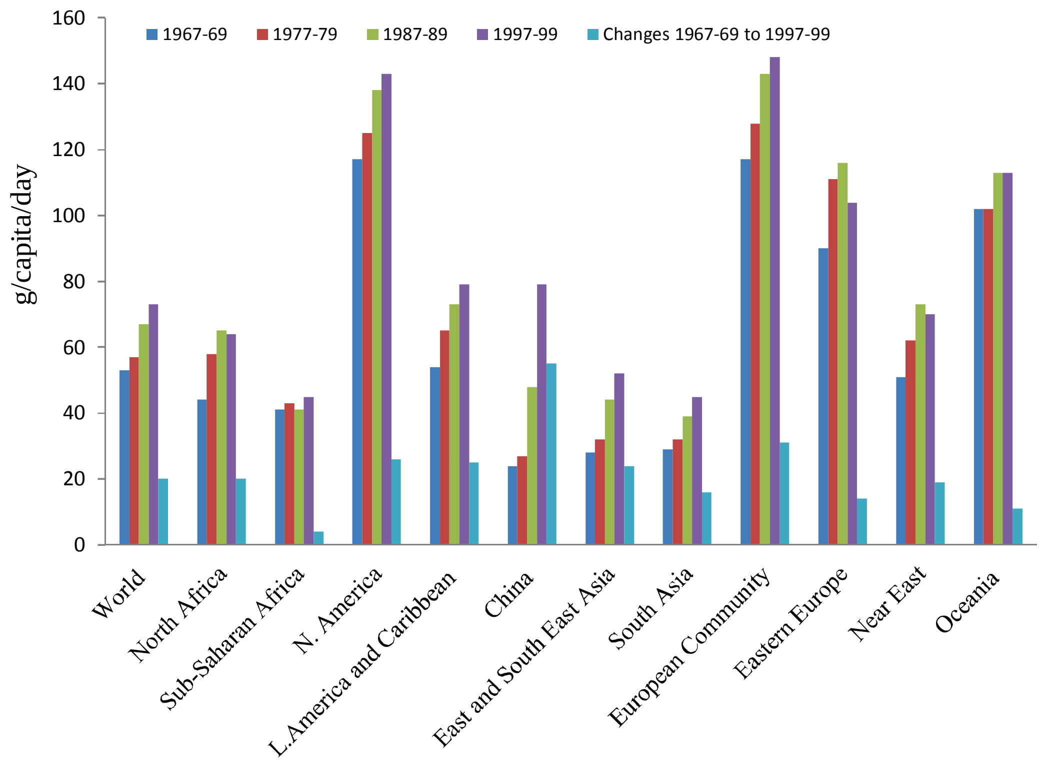


Figure 2.7: Trends of the global supply of fat (Source: WHO/FAO, 2003)

Availability of oilseed to the domestic edible oil producers is always in a challenging and tough competition with oilseed export. The rate at which palm oil import grew when the average of 2001-2003 is compared with the average of 2008-2010, the difference was 1,380% (Figure 2.8) and as a result palm oil alone became major import commodity mainly for Ethiopia.

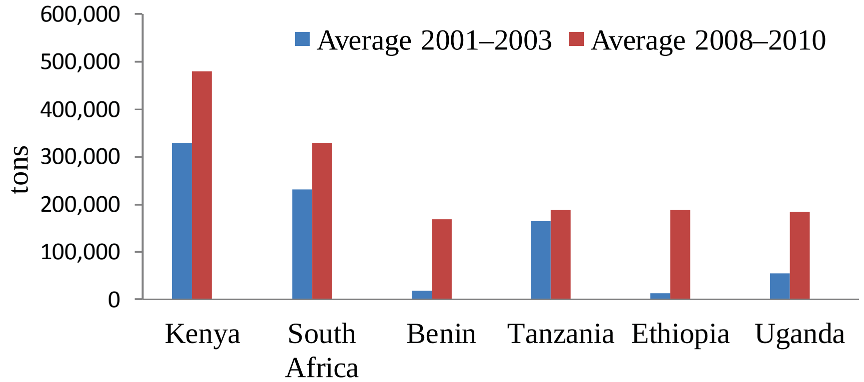


Figure 2.8: Main ACP palm oil importers and volumes imported (Source: USDA FAS, 2013).

Although Ethiopia's palm oil import is highly accelerating to the contrary soybean oil import is decelerating (Sertse et al., 2011) which can be due hesitation of consumers on soybean smell (HighQuest Partners, 2011). Due to continued increase in vegetable oil import, Ethiopia is currently generally classified as edible oil importer and even considered to be high potential country in the sub-Saharan African for soybean oil market by US soybean export council (HighQuest Partners, 2011).

The current trend in Ethiopia seems to be comparable to situations that existed in some other countries of the World from which Ethiopia can adapt success stories and learn from the failure stories. Related to this the major factors responsible for the high consumption and import of edible oil in India, for instance, were increase in per capita consumption and population, change in tastes and preferences, low productivity in the domestic oilseed sector, and liberal policies for edible oil imports (Ghosh, 2009). These trends appear to be similar to the today's situation in Ethiopia except probably that the Ethiopian consumers are generally hardly attracted by tastes and preferences towards imported edible oil. In Ethiopia while population and per capita also appears to be contributing factors, low productivity of domestic oilseeds and policies for edible oil import seem to be major factors responsible for deteriorating domestic edible oil production capacity and progressive dependence on imported edible oil. Under those acute shortage situations, India was a destination for over 15% of global vegetable oil import which accounts for around 55% of the country's edible oil consumption and about half the value of its total agricultural imports in 2002–03 (Ghosh, 2009). In this regard, the situation in Ethiopia seems more serious than that of India since Ethiopia is importing more than 80% domestic edible oil consumption with an even deteriorating situation (Wijnands, 2009). In particular, oilseed yields in India had been among the lowest in the world. The demand for oilseed generally emerges from either edible oil or oil meal production or both. However, oilseed cultivation in India became increasingly unattractive due to low and unstable yields, and due to decreasing edible oil prices and the area under oilseed cultivation had stagnated over several years. This resulted in serious concerns over the future of oilseed production because of this stagnation and also food grains prioritization in government policies. Consequently, imports rapidly increased encouraged by tariff liberalization to meet the ever increasing national demand (Ghosh, 2009).

The currently prevailing situation in Ethiopia is nearly the same to the tariff liberalization action taken in India. Food grain prioritization policy is also similarly typical of countries trying to ensure food self-sufficiency. Therefore it is possible to minimize dependence on imported edible oil by working from both raw material supply and oil production sides and also improved and properly designed stock handling system. The oilseed marketing aspect is also very crucial and at its infancy in all sectors in Ethiopia and needs due attention and separate treatise to facilitate a conducive environment for the true actors in the value chain and discourage the non-value adding intermediates. The work from the raw material side can be improved mainly by encouraging the farmers to produce oilseeds based on the preferences of the domestic market and oil mills. This can be achieved by increasing both cultivated area and the seed yield. The improved yield will particularly be attractive to the farmers since it improves their competitiveness as compared to cultivating other crops because there is limited land for expansion as population increases. This need be supported by improved input supply, agricultural extension services, and also market system to create stable relationship between the farmers and the oil millers.

The crop agriculture in Ethiopia is dominated by numerous small holder farmers in the country cultivating mainly cereals for both household consumption and sells the remaining. Since smallholders account for about 97 % of the total area cultivated and more than 96 % of the overall agricultural production in Ethiopia (CSA, 2011), their decision of whether to produce oil seed or any other crop based on very limited information they have or experience is the other big challenge on the supply side. Contractual agreement is either not known or hard for them to practice since both the farmers and the seed collectors are uncertain about the seed price and forecast is in general very poor or even not existing or not accessible to them and the market is unstable in general. The rate at which the currency is devaluating, which is not known to the general public, is another source of confusion and instability of the market and source of price speculation. As is true for many developing countries, small holder farmers are nearly major sources of agricultural products and this is true in Ethiopia too (CSA, 2011). The oil millers and the seed collectors therefore need an organized approach to deal with the individual farmers and unions to establish a thrust worthy relationship that can solve the problem in a sustainable way (Lefebvre, 2012).

Regarding the oilseed and yield improvement, in Ethiopia, research and development strategy for oilseeds is already in place which classifies oilseeds according to agro-ecology and includes socioeconomics, extension/support and marketing systems (Alemu and Teklewold, 2011) although the achievements from the strategy may be in question. The productivity of the oilseed in general and that of nigerseed in particular appears to be almost stagnant over years (Table 2.2). Since there are various factors contributing to productivity both positively and negatively repeated field experimental data can better explain if these productivities or the changes over the year are characteristics of the crop/oilseed/nigerseed and to design the approach among to improve yield.

2.2. Agronomy and Yield of Nigerseed (*Guizotia abbysinica* Cass.)

Lack of competitiveness of Nigerseed compared to other oilseeds particularly in the domestic market is reflected almost across all the value chain. The main challenges, for instance, to the oil-crushing sector in Ethiopia are to ensure adequate and steady supply of oilseeds and to compete with world market prices mainly due to high price of nigerseed. The imported edible oil are flooding the domestic market by enjoying the opportunity of duty free by Government of Ethiopia to ensure enough supply for the increasing domestic demand (Schenk et al., 2009; Wijnands, 2009). In Ethiopia, oilseed being the mainstay of national economy is the second largest export earner next to coffee (USDA FAS, 2010). More than three million small holders are already involved in their own production of oilseeds. Therefore improvement in oilseed sector significantly contributes to the national as well as local; and family economy (Fikre, 2011).

2.2.1. Botanical Description and Cultivars

Nigerseed belongs to the family compositae and is an annual dicotyledonous herb. Germination is epigeal and seedlings have pale green to brownish hypocotyls and cotyledons (Seegeler 1983 in Getnet and Sharma, 1996). The genus Guizotia consists of six species, of which five, including nigerseed, are native to the Ethiopian highlands. It is a dicotyledonous herb, moderately to well branched and grows up to 2 m tall. Leaves are 100 to 200 mm long and 30 to 50 mm wide. Five of the six species of Guizotia are found in Ethiopia. Of the six species G. *reptans* is not present in Ethiopia. Of the five nigerseed is known to be oilseed and other are not of obvious importance. G.abyssinica (L.f.) Cass. which is oilseed is known by its local name ‘noug’; G. scabra (Vis.) Chiov.

subsp. scabra, G. scabra (Vis.) Chiov. subsp. schimperi (Sch.Bip.) Baagoe the local name is 'mech' (Amharic). Nigerseed plant flower is yellow and heads are 15 to 50 mm in diameter with 5 to 20 mm long ray florets (Getnet and Sharma, 1996; Alemaw and Wold, 1995). The plants depend on cross pollination as they are mostly self-incompatible and insects are the major pollinating agents (Sujatha, 1993; Ramachandran and Menon, 1979 in Agegnehu, 2011). Nigerseed plant is indigenous to Ethiopia where it is grown in rotation with cereals and pulses. The gene pools have diverged into distinct types as Ethiopian and Indian also in America like early bird type. This trend may continue wherever nigerseed is introduced. The Ethiopian germplasm is collected from fields of farmers and does not include breeding lines. Nigerseed plant stems are hollow and break easily. The number of branches per plant varies from five to twelve and in very dense plant stands fewer branches are formed. The color of the stem varies from dark purple to light green and the stem is about 1.5 cm in diameter at the base (Getnet and Sharma, 1996). It was found that fatty acid profile was typical of compositae family (Alemaw and Wold, 1995; Quinn and Myers, 2002).

2.2.2. Land use suitability for Nigerseed

In Ethiopia, nigerseed is cultivated generally on waterlogged soils where most crops and all other oilseeds fail to grow and this contributes a great deal to soil conservation and land rehabilitation (Getnet and Sharma, 1996). But nigerseed grows on almost any soil as long as it is not coarse-textured or extremely heavy. It is usually sown in areas with a rather poor soil or on heavy clay soil under poor cultural conditions. It grows well at pH values between 5.2 and 7.3. Nigerseed is extraordinarily resistant to poor oxygen supply in soil (Prinz 1976 in Getnet and Sharma, 1996). Nigerseed is salt tolerant (Abebe, 1975 in Getnet and Sharma, 1996) but flowering is delayed with increasing salinity (Getnet and Sharma, 1996). Crops following nigerseed grow well and inoculation of soil with soil in which nigerseed was grown resulted in increased growth due to microorganism involved in mycorrhiza association, *Glomus macrocarpus* (Yantasath, 1975 in Getnet and Sharma, 1996). The indigenous knowledge in Ethiopia on nigerseed cultivation is of paramount importance in addition to the formal research being conducted. Farmers, for instance, often report that nigerseed is a good precursor for cereals since crops following nigerseed have less weed infestation and gives better yield. This was later confirmed in crop rotation trials where high yields of cereals were obtained following nigerseed cultivation. Preliminary investigations at Holeta Agricultural Research Center

(Ethiopia) showed that a water-extract from nigerseed plant inhibited the germination of monocotyledonous weeds (Getnet and Sharma, 1996). Nigerseed is a good precursor for cereals, pulses and oilseeds because crops following nigerseed have less weed infestation (Getnet and Sharma, 1996). The highest maize yield (6140 kg ha^{-1}) was attained without fertilizer following nigerseed cultivation (Agegnehu, 2011). Nigerseed crop generally plays an important role to push into unused mostly marginal lands preparing the land for other crops.

2.2.3. Cultivation Method

Agronomic characterization plays vital role in increasing yield based on knowledge gained and experiences developed in variety selection and their agronomic practice determination (Weyesa et al., 2011). Nigerseed is sown generally following of one or two times ploughing and without fertilizer or herbicide (Getnet and Sharma, 1996). Sometimes sowing without fertilizer appears to be justifiable. Comparing the average return and input utilized hesitation of the farmers to use very limited or no fertilizer is a reality particularly when rainfall is unreliable, local varieties and mixtures are less risky than purchased varietal-pure seed (Ffolliot and Thames, 1986). However it is also true that farmers in Ethiopia increasingly apply fertilizer to nigerseed as the promise of return is growing. Threshing the mature and dried nigerseed is easy due to the shattering nature. It is recommended that 45-50% moisture content of the seed or when the buds turn from yellow to brown yellow is the optimum stage (Belaynesh, 1987 in Getnet and Sharma, 1996). In India it is harvested when the leaves dry up and the head turns black (ICAR 1992 in Getnet and Sharma, 1996). During harvesting, plants are stacked, dried and taken to threshing ground in a way shattering is minimum. While ploughing the threshing ground is left free (not ploughed) at the center. It is commonly threshed using sticks and cleaned from the chaffs by manual winnowing. In some areas farmers take to the threshing ground early in the morning before the sun rises to minimize shattering.

2.2.4. Factors on Yield and Quality of Nigerseed

Unlike the earlier times where expansion of area plays the major role for increasing the production of cereals, later on yield became responsible for half of the increase in production. Yield continues to progressively contribute more and more to increase of production (Taffesse, 2011; van Meijerink et al., 2011). As a raw material for domestic industry for edible oil production in Ethiopia and for export, improving yield appears to be priority if nigerseed has to be competitive in both domestic and International markets. In earlier times farmers used to cultivate nigerseed mainly as a fallow crop rather than its commercial value and therefore yield was not given much attention for cultivation prioritization.

Because of the limited research to improve yield, the edible oil and oilseed sector in Ethiopia is facing several challenges mainly as oilseed cultivation has become increasingly unattractive to the farmer because of low and unstable yields exacerbated by unstable market. Varieties of the seed, fertilizer rate, seed rate, soil, weather/climate, sowing time, and harvest time are among the factors influencing yield of crops in general. Farmers' farming practice, genetic less responsiveness and social or policy issues are among the major factors influencing nigerseed yield in Ethiopia (Nigussie and Yeshanew, 1992 in Agegnehu, 2011). Marginal land allocation, poor and below standard crop management, and lack of efficient and sustainable seed supply are among additional factors influencing nigerseed yield (Fikre, 2011).

In Ethiopia, one of the remarkable progresses in the area of nigerseed research was where the seeds were studied in more details to characterize and classify them on varietal bases. In this regard development and release was possible including for other oilseeds: 4 nigerseed, 8 linseed, 8 Ethiopian mustard, 12 sesame, 13 soybean and 16 ground nut varieties. This is an effort which took 40 to 50 years although their productivity remained far below the potential or necessary to be competitive (Jarso et al., 2011). In this regard, four nigerseed varieties approved by the Ethiopia national variety approval committee along with the recommended cultural practices was a remarkable achievement. Fogera, Este, Kuyu, and Shambu were the Ethiopian nigerseed varieties officially released. The seed yield reported varies from variety to variety 911 kg ha^{-1} (Este), 1100-1300 kg ha^{-1} (Kuyu), 911 (Fogera), and 947 kg ha^{-1} (Shambu). The oil content also varies similarly 37.41% (Este), 38.39% (Kuyu), 37.41% (Fogera), and 39.3% (Shambu) (EARO, 2004). From figures of 2000/01, world average oil contents are: soybean (18.3%); rapeseed (38.6%); sunflower (40.9%); groundnut (40.3%); cottonseed (15.1%); coconut (62.4%); palm kernel (44.6%); sesame (42.4%); linseed (33.5%); average for all oilseeds (25.8%). In addition, yields from palm fruit (45–50%), olive (25–30%) and corn (about 5%) (Gunstone, 2002). From this oil content comparison it seems that the oil content of nigerseed is comparable with internationally marketed oilseeds for production of oil. This implies that seed yield is the bottleneck and merits prime consideration as compared to oil yield. Although limited research had been undertaken on nigerseed in Ethiopia in general, its agronomy aspect was given a better attention. Yields of oilseeds are influenced by cultural practices such as plant density, planting time, weeding and harvesting stage. Sowing nigerseed between late June to early July for higher altitudes (> 2000 masl) mid to late June for the lower altitudes (< 2000 masl) areas in the central highlands, mid-July for the Western and Southwestern, and early to mid-July for the North Western were found optimum for the production of late maturing nigerseed ecotypes. A range of seed rate had little or no effect on seed yield however higher seed rates of 10-15 kg ha^{-1} is required under late planting (Hiruy, 1988; Nigussie and Yeshanew, 1992 in Alemaw, 2011). Choferie et al. (2011) also shows that late June to mid-July shows relatively better yield performance (Figure 2.9). Such data could be more informative if it includes comparison of multiple locations from different agro-ecological zones in Ethiopia.

"In Ethiopia nigerseed yields vary from 200–500 kg ha^{-1} but yields of 1000 kg ha^{-1} have also been obtained. Improved cultivars in combination with improved agronomic practices can attain yields of 1000 kg ha^{-1}. In India nigerseed yields of 250–400 kg ha^{-1} are common, but they increase to 500–600 kg ha^{-1} when it is grown in moderately fertile soils." (Bulcha, 2007).

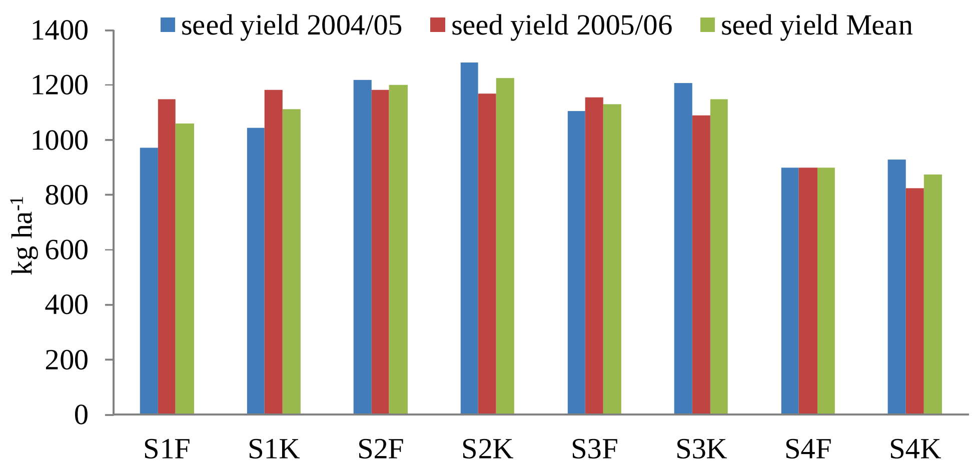


Figure 2.9: Comparison of seed yield (kg ha^{-1}) of two nigerseed varieties on four planting date over two years (Sagure, Oromiya). (K, Kuyu variety; F, Fogera variety; S1, mid-June; S2, late-June S3, mid-July and S4, late July). (Source: Choferie et al., 2011)

Regarding the cultural practice the released varieties influencing yield, seed rates range from 6 to 10 kg ha^{-1} and 12 to 15 kg ha^{-1} for early and late sowing respectively and fertilizer rate 23/23 (N/P_2O_5) kg ha^{-1}. Harvesting days for the varieties are 130-200 days (Este), 136-175 days (Fogera), 130-200 days (Kuyu), 144 days (Shambu). The area of adaptation is 1600 to 2700 m above sea level and demanding rainfall of 600-1000 mm (EARO, 2004).

Comparative study conducted on the Indian and the Ethiopian nigerseed showed that the cultivars differ significantly, with the Ethiopian cultivar being taller, late maturing and higher yielding than the Indian cultivar (Getnet and Sharma, 1996). After importing nigerseed as bird feed, the United States of America has also put considerable efforts to improve the seed through various field experiments. In Indiana, Illinois, and Missouri, for instance, sixteen nigerseed accessions were evaluated in 2001. In this study it was found that several accessions flowered and matured similar to a commercial field that yielded 480 kg ha^{-1} (Quinn and Myers, 2002). An early maturing nigerseed cultivar, supposed to have potential to grow on Northern Great Plains of the United States which were evaluated for seed yield, test weight, plant height and pest incidence based on eight to ten seeding rates showed the maximum yield across for 10 kg ha^{-1} seed rate but 90% of the maximum yields corresponded to 6.7 kg ha^{-1} seed rate which also showed more heads per plant and higher above-ground biomass. Finally the 6.7 kg ha^{-1} seed rate was then recommended for production purposes as better yielding with early canopy closure and uniform seed maturity (Kandel et al., 2004). In a more recent study Randomly Amplified Polymorphic DNA marker analysis made for 18 Indian nigerseed cultivars and evaluated using a Squared Euclidean Distance matrix. A cluster analysis based on the distance showed that the 18 cultivars can be grouped into two distinct groups of early and late maturing cultivars (Nagella et al., 2008). In Ethiopia, India, and United State, it seems common to classify nigerseed as early and late maturing. In a similar manner variety development may continue based on different targets. Variety development as one way of improving oil yield can be achieved through increasing the oil content in the oil bearing part or reduction of hull like with sunflower and safflower, or reduction/elimination of shattering like in sesame and nigerseed. Development of early maturing and less moisture requiring variety is also another possibility (FAO, 1980).

In addition to mere yield improvement by variety development, the adaptation research is important where new hybrid seeds or varieties which are very sensitive to specific local conditions need further research and experimentation to adapt to specific temperature, soil, and water conditions (Dahlman, 2007). Despite development of and adoption of new varieties the lack of success seen in Africa as compared to Asia mainly appears to be due to continued dependence on rain fed and low input agriculture (Byerlee et al, 2005). In such adaptive research activities, evaluation of the final result and in the way forward to practical application, involvement of the farmers and extension workers is very important and the project on sunflower to encourage as cash crop in Kenya can be a good example (Okoko et al., 2008). Due to high dependence on rain, low in put utilization, limited adaptive research and if at all limited or no involvement of farmers and extension workers yield, total production, and area cultivated is sometimes either not increasing or even declining and this is the trend observed the Ethiopian oilseed (CSA, 2010). Not only yield but also fatty acid composition of oilseeds is known to be altered by climate (temperature) of the environment. For sunflower, for instance, linoleic acid decreases and oleic acid increases radically as the temperature increases from 10 to 30°C and similar changes take place in safflower but only slightly (Belitz et al., 2009).

On the other hand various studies revealed that nigerseed yield is affected by seed rate and sowing time (Agegnehu, 2011; Getnet and Sharma 1996). Effects of nitrogen and row spacing had also been studied (Kandel et al., 2004; Bhagwan 2002; Getnet and Sharma, 1996) and it was observed that the denser the plants the fewer the branches and capitulates (heads) and the taller the plants are.

Vegetative growth generally increases in nigerseed plant when more than 30 kg ha^{-1} nitrogen fertilizer is applied. Higher nitrogen levels may cause lodging and shattering which reduces the yield (Getnet and Sharma, 1996; Weyesa et al., 2011). In this regard search for non-shattering variety should be given high emphasis if postharvest loss is to be minimized substantially. Agegnehu (2011) showed location, soil nitrogen and phosphorous, and applied nitrogen and phosphorous and the yield response (Table 2.3). From this observation it seems that the nitrogen and phosphorous content of the soil contributed more to a better yield when comparing the yields with and without the fertilizers.

Although yield continues to be the major concern as both production and research agenda for many reasons, quality should also be part and parcel. In this regard, several efforts are underway to mitigate not only the shortage of oilseed necessary for edible oil production quality aspects.

For nigerseed, linseed and Ethiopian mustard, 36 pre-basic and 236 farmers' representative seeds were collected and analyzed according to procedure described by International Seed Testing Association (ISTA) to get a good quality seed (Gorfu and Wakjira, 2011).

Table 2.3: Seed yield of nigerseed grown with and without nitrogen/phosphorus (N/P) fertilizer at different locations in Ethiopia (Source: Agegnehu, 2011)

Locations (Ethiopia)	Region	Soil analysis			Seed yield ($kg\ ha^{-1}$)	Applied N/P
		pH	N (%)	P (ppm)	($kg\ ha^{-1}$)	23/10 ($Kg\ ha^{-1}$)
Gohatsion	Oromiya	4.7	0.62	15.5	767	932
Bichena	Amhara	6.1	0.07	3.1	569	720
Mota	Amhara	5.3	0.15	2.0	668	738
Shambu	Oromiya	5.2	0.07	5.0	580	523
Tefki	Oromiya	6.5	0.70	8.5	547	916
Weldiya	Amhara	6.8	0.11	5.0	490	610
Mean		5.8	0.29	6.5	604	740

It is well known that the value of a given type of oilseed depends on its oil content, nutritional composition and other quality parameters and may include minor health components if specialty oil is desired. According to the characterization studies conducted, the nutritional value of nigerseed oil has been found to be very attractive that nigerseed has a good potential to join the global edible oil market (Marini et al, 2003; Ramadan and Moersel, 2003; Ramadan and Moersel, 2002; Dutta et al., 1994). Fatty acid, triacylglycerol, and different kinds of phytosterols composition in nigerseed were found to be promising for human health (Dutta et al., 1994; Ramadan and Moersel, 2003). But it is generally known that the Ethiopian variety is superior in alpha-tocopherol (vitamin E) content (Dutta et al., 1994; Marini et al., 2003). The linoleic acid of the Ethiopian cultivar is about 20% higher and the oleic acid content of the Indian cultivar is about 20% higher (Getnet and Sharma, 1996).

In Ethiopia where agro-ecological diversity is very high, adaptive study appears to be a good approach in yield improvement. Therefore adaptive research, input supply system, and irrigation scheme development could be taken as a continuation of variety development in order to see the final fruit of variety development and impact of other factors. Until recently, the even limited research on oilseeds in Ethiopia is biased towards yield based on meeting the target for food security or self-sufficiency and therefore no doubt the quality aspect was almost made secondary or undermined even though the quantity aspect itself is not so promising.

Generally small sized oilseeds such as nigerseed and linseed are the major preferences for small scale oil millers because the use of larger sized seeds will require additional investment for additional processes like cracking, dehulling, size reduction, flaking which require other machineries, working space, additional skill and electric power. Therefore improving yield and hence competitiveness of nigerseed is of paramount importance both to the small scale farmers and small scale edible oil millers and also all other actors in the value chain and finally the consumers.

Therefore due to the growing interest in nigerseed as raw material for edible oil (domestic) and bird feed (export) improvement of yield is of paramount importance. As the nutritional quality of nigerseed is more and more unraveled, its demand as edible oil is also likely to cross its traditional borders. Research conducted to assess/characterize the existing seed and improve agronomic practices is relatively short time in Ethiopia. The economic importance of nigerseed/noug/ is not only to the small scale farmers but also to the small scale oil millers since it is the major raw material option supplemented by other oilseeds such as linseed and Ethiopian mustard seed and currently also emerging groundnuts.

For other various oilseeds than nigerseed, effect of agronomic parameters had been studied in more detail and many different ways of combinations like location, cultivars and interaction showing significant effect on oil content and fatty acid composition for canola cultivars (Fayyaz-ul-Hassan et al., 2005). Similar studies which showed effect on oil content and to a limited extent on fatty acid composition was observed for controlled temperature environments for corn (germ and endosperm) oil (Thompson et al., 1973). Similar studies for safflower (Koutroubas et al., 2008; Elfadl et al., 2009) which is relative of nigerseed. Laribi, 2009 has shown effect of water stress on fatty acid profile of caraway to be significant.

2.3. Storage Characteristics of Seeds

Although a given oilseed may have inherent quality characteristics of its own this natural quality can deteriorate in a short time unless it is handled properly. The handling includes protecting it from impact of physical environment and attack of biological systems in the seeds themselves like on activities of enzymes, microbes and insects. The seed quality, therefore, may start to deteriorate from the time it is received fresh. Depending on the physical environment to which it is exposed and protection given from external damaging microbes or insects, the seed may be kept longer in a more or less natural healthy and intact state. In Ethiopia, oilseeds are mostly stored close to the expellers and almost all oil mills in Ethiopia have no bins and store their raw material in substandard conditions (Schenk et al. 2009).

"Nigerseed is stored in sacks and other containers. It should be protected from storage pests and transported to bulk storage facilities as soon as possible. The moisture content of stored seed must be less than 8% to prevent damage by storage pests, especially molds. Usually, locally-extracted oil has a poor storage life, but heating and storing in airtight containers can prolong it." (Bulcha, 2007)

Generally storage and handling should create an environment under which the seed can keep well for as long as possible with little or no loss of its natural quality.

Deterioration of oilseed quality specially refers to the state of oil naturally contained in the oil bodies of the seed. Triacylglycerol (TAGs) are accumulated in specialized structures of organism or cell and designated ''lipid droplets'' in adipocytes, ''lipid particles'' in yeast, or ''oil bodies'' or ''oleosomes'' in plants (Quettier and Eastmund, 2009). An oil body has a matrix of triacylglycerol, which is surrounded by phospholipids and alkaline proteins, termed oleosins and the physiological significance of maintaining the oil bodies as small entities is to provide ample surface areas for the attachment of lipase to the organelles during post germination growth so that the reserve TAG can be mobilized rapidly (Tzen and Huang, 1992; Tzen et al., 1993). Susceptibility to quality damage also depends on the nature of the seed (cereal, pulse, oilseed …) or more specifically on the seed species or variety (Vertucci and Roos, 1990;

Li et al., 2011). Any biological, chemical or physical or any combination of these factors can mobilize the triacylglycerol leading to deterioration of the oil contained in the oilseed. During storage, physical conditions such as temperature, moisture, and relative humidity are mainly responsible for quality as these are important parameters for germination and post germination growth of plants. The extent to which the storage can maintain the triacylglycerol and all components of oil associated with it depends on the biological, chemical and physical environments which are highly interrelated. Therefore quality is ensured through maintaining these conditions within certain limit depending on the requirement/susceptibility nature of the seed.

2.3.1. Storage and Seed/Oil Quality Deterioration

Quality starting raw material is critical for quality and safety of a processed product especially products with relatively uncomplicated process such as virgin edible oil. The lower the starting raw material quality is the more complex the process will be to attain quality final product. Handling and storage are thus fundamental to knowledge based effective management and utilization of a given raw material/seed especially over extended period of time and extreme environmental conditions. Storage is necessary for production during off season where seed is either unavailable or more expensive. Deterioration may be a serious problem depending on the nature of the seed, method of handling, environmental influence and the duration of handling. It is generally understood that dry and cold conditions will increase shelf life of biological material but the optimum conditions such as moisture and temperature need to be defined. The period of storage is in one way or another is determined by the rate at which the seed quality deteriorates which can be measured using indicator of deterioration.

Deterioration of oilseeds is accompanied by respiration or carbon dioxide evolution and heat generation by oxidation reactions. Sound, intact seeds may release less than 10 cubic centimeters of carbon dioxide per gram of seed per day, while damaged, high moisture seeds may release 50 cubic centimeters or more of carbon dioxide per gram of seed per day. Furthermore, heat generation by oxidation reactions may increase the temperature of stored seed, accelerating deterioration even to the point of charring the seeds (Alemaw, 2011).

In most cases since the normal seed aging/deterioration takes even years, accelerated storage studies are conducted and then the result (generally germination rate) of the study is extrapolated. In storage studies more theoretical approach on the effect of water content on seed deterioration would alleviate some of the intrinsic difficulties of a purely empirical approach. Therefore using physical principle of Arrhenius equation and moisture contents and relative humidity at which physiological activities are observed for seed species with various chemical compositions had been shown as a basic approach (Vertucci and Roos, 1990). In different studies to compare the moisture contents at which changes in the physical and physiological status of seeds, differences between different species had been observed and it has been shown that moisture contents at which these changes are observed differ among species, and correlate with lipid content of the seed. The lipid content is inversely related with the threshold of respiration and moisture content of storage; seeds with high moisture content adsorb less water. Optimal moisture level for storage can be identified more readily by the relative humidity than the seed moisture content (Vertucci and Roos, 1990). There are several factors affecting storage and interaction of these factors may be much more complex depending on the number of factors involved.

Elias et al. (2012) has classified the major factors and their interactions type of seed, seed moisture content, and initial viability of the seed; storage temperature and relative humidity; duration of storage; protection from storage fungi and insects.

a. Type of seed, moisture content, and initial viability

Some seeds store better than others depending on their inherent nature. In this regard oilseeds, for instance, differ from cereals or legumes due to their chemical nature of the major seed storage reserve material (Vertucci and Roos, 1990). Barton (1961) cited in Shelar et al. (2008) regarded moisture content to be of utmost importance in seed deterioration. Seed deterioration increases as moisture content is increased but the detail needs very close scrutiny of the specific seed as well as the process/conditions of attainment of the ultimate/equilibrium moisture content. As seed deterioration is affected by moisture content, it is important to know what factor affects water absorption and retention of moisture as well as their effects. Seeds absorb or lose moisture until the vapor pressure around the seed and atmospheric moisture reach equilibrium. The seed moisture content attained and maintained under these conditions (equilibration) is referred to as equilibrium moisture content. The equilibrium moisture content in seed at given equilibrium relative humidity decreases slowly with increasing temperature (Shelar et al., 2008) indicating the role of temperature in attainment of equilibrium moisture content. To monitor the moisture of seeds in storage it is possible to measure the moisture content directly, or measure the relative humidity inside the storage.

It is well known that low moisture content in the seed to be stored is the best prevention for all moisture derived multiple problems. The lower the moisture content the longer seeds can be stored provided that the moisture level can be maintained throughout the period of storage. However it is known that the seed moisture content fluctuates with the changes in relative humidity at the immediate vicinity of the seed. The magnitude of these fluctuations can vary with the temperature, the type of storage, type of package used, and the kind of seeds, which influence the migration of moisture from the bulk air to the seed and vice-versa. As a result of their chemical composition, seeds adjust their moisture by their natural tendency to reach equilibrium with the relative humidity of the environment at their immediate vicinity by losing/gaining moisture continuously until equilibrium is achieved. The moisture equilibration may take several days depending on the magnitude of the moisture gradient between the seed mass and the environment it is interacting with, the speed of air movement (air flow rate) through the seed mass, temperature, and mainly the nature of the seed.

In the process of equilibration, temperature plays important role in the determining of how much moisture the air can hold. For an ideal storage condition all seed and their varieties should have an ideal storage characterization which is important to design their storage material and conditions. Of particular reference to oilseeds, quality seed is important to both quality oil and cake. Death of seeds in storage is a symptom that indicates there are causal factors such as starting with poor quality seeds, high moisture content, or high relative humidity and/or temperature which accelerates the deterioration process. To prevent problems, attention must be given to the causal factors first and also it is good to measure the initial status such as viability by tetrazolium test or germination. Some vigor tests such as accelerated aging test, cold test, electric conductivity test and seedling vigor classification test may provide better and earlier picture about the physiological changes happening in the seed. The frequency of such quality test is done depends on the interest, once a year under cold conditions and more often in hot, humid environments (Elias et al., 2012).

b. Storage temperature and duration

The importance of seed storage has been recognized since time immemorial. The duration of storage depends upon why the storage is needed and what the species of the plant is. Farmers need to maintain the seeds from one growing season to the next while seed producers may wish to maintain for several years (Hong et al., 1996). Temperature and moisture content are among the most important factors during storage and, oil seeds should be stored in a cool dry store at moisture content of about 8%. Whole, intact, low-moisture oilseeds (about 8-10 percent moisture) may be stored for an extended time under suitable conditions (Alemaw, 2011). In addition to the temperature of the environment to which the seed is exposed heat is also generated due to metabolic activity in the seed itself. The heat generation by oxidation reactions increases the temperature of stored seed, accelerating deterioration even to the extent of charring the seeds (Alemaw, 2011). Sound, intact seeds may release less than 10 cubic centimeters of carbon dioxide per gram of seed per day, while damaged, high moisture seeds may release 50 cubic centimeters or more of carbon dioxide per gram of seed per day (Alemaw, 2011). Prolonged storage can lead to a gradual loss of vigor and finally a loss of viability. The period in question depends on interaction of all factors and what levels of viability is desired at the end of the storage period. With current technologies and moisture management principles it is possible to have older seeds that germinate at high levels. The longevity also varies among species, varieties, seed lots, and even among individual seeds inside the same package. This is why, within a seed lot, some seeds are alive and others are dead. The relative proportion of these two components by chemical and germination tests (Elias et al., 2012).

c. Protection from storage fungi and insects

Storage fungi have the capacity to grow at very low seed moisture content. They cause seed deterioration by producing toxic substances that destroy the cells of seeds which creates dead tissue to sustain the saprophytic fungi. Insects such as weevils can cause substantial damage to stored seeds (Elias et al., 2012). For sunflower, for instance, as moisture increases mold count and free fatty acid increases particularly with duration of storage and also germination rate decreases (Robertson et al., 1984). The best prevention to these problems is by storing seeds with low moisture, temperature, and shorter duration. The other preventive practice against insects is cleaning the warehouse and avoiding any source of infestation from previous batch of seeds.

2.3.2. Storage Characterization for Nigerseed

The oilseed supply in Ethiopia which is already known to be weak mainly due to low seed yield can be further exacerbated by poor seed handling and storage. As an important industrial edible oilseed particularly in Ethiopia, the problems related to the conditions of Nigerseed storage must be properly addressed before large scale production and large scale global market of the seed is planned. In this regard, nigerseed physical properties related to material handling during storage and processing and processing equipment design had been already well addressed (Solomon and Zewdu, 2009). For nigerseed, determination of storage characteristics is necessary to recommend safe handling and storage condition for both domestic nigerseed oil millers as well as nigerseed exporters. It is well known that the equilibrium relative humidity, in addition to temperature, plays major role in attainment of equilibrium moisture content suitable for storage.

Therefore the relationship between equilibrium moisture content and relative humidity at some given temperatures is critically important before planning to store or dry any the seeds particularly for postharvest large scale production. Moisture content, for instance, is directly related to free fatty acid formation (break down of oil molecule), mold count (multiple problems including toxin formation), and decrease of germination rate (an indicator of low seed quality) (Robertson et al., 1984).

Water activity which is the other form of equilibrium relative humidity is the main factor in post-harvest and food processing operations contributing to the keeping quality of the product such as microbial growth, toxin formation, enzymatic and non-enzymatic reactions (Ragel-Maron et al., 2011).

The adsorption isotherm of a food describes the thermodynamic equilibrium state of water and it can be used to predict the shelf life of packaged product by modeling moisture uptake during food storage and distribution. It is also used to determine the best storage methods, packaging materials, and ingredient selection (Aponte et al., 2011). Oilseeds start new lifecycle by germination using the reserve energy from hydrolysis of fat into fatty acid and glycerol initiated by lipases enzyme (Quettier and Eastmund, 2009) and moisture, oxygen, and temperature are important drivers for this natural process. This natural process which the seed undergoes however means deterioration of quality when their use for human consumption is considered.

Related to this, moisture content is not only an important factor for seed storability but also is in continuous dynamics with humidity (air moisture content) of its immediate vicinity to which it is going to equilibrates. The physical adsorptions of moisture in relation to relative humidity and temperature had been discussed with classifications and data by different authors (Lewicki, 2009). Under storage condition if physical environments are not controlled, an inevitable natural process which leads to tremendous loss of stored product not only in quality but also quantity will result (Simic et al., 2007). And this loss in quantity is about 8 wt. % for nigerseed oil (Sarin et al., 2009). Increased free fatty acid because of poor storage condition decreases the oil yield of nigerseed because the free fatty acid formed by degradation is removed from the oil as soap stock during alkali treatment step of the refining process. Such deteriorated seed could be totally rejected because of quality if it is meant for cold/virgin oil pressing. Sorption isotherm characteristics data is therefore important in understanding conditions for storage stability and acceptability of food products. This includes modeling of the drying process; designing and optimization of the drying and aeration equipment; calculation of moisture changes during storage; and selection of appropriate storage material (Samapundo et al., 2007). Such relationship data application for many seeds of varying chemical and physical properties such as wheat (Li et al., 2011; Henderson and Pixton, 1982; Pixton and Henderson, 1981), sunflower (Robertson et al., 1984; Sergio and Gely, 2005; Chapman Jr. and Robertson, 1987); rapeseed (Pixton and Warburton, 1977), Millet (Raji and Ojediran, 2011) have been well documented.

The quality deterioration, loss of oil, and mold attack can be controlled if moisture content-relative humidity relationship-temperature (sorption isotherm) characteristics is known for a given seed species or variety. It is also obvious that moisture content is one of the critically important parameter in the oil pressing too.

2.3.3. Sorption Isotherm and Model Validation

Water in its ideal condition has a maximum water activity of unity. This water in equilibrium with the surrounding water vapor determines the sorption isotherms of the materials (relationship between the moisture content and water activity at a given temperature) (Blahovec and Yanniotis, 2010). The water activity, however, is always less than unity depending on the material with which it is in a continuous interaction including food materials.

Moist materials including food always tends to equilibrate its moisture content with that of the surrounding atmosphere by either losing or gaining moisture (equilibration) which is manifested as loss or gain of mass respectively at a given temperature. The curve from the data of such moisture and relative humidity relationship at a given temperature is said to be sorption isotherm curve. The sorption isotherm curve of food materials generally have commonly known and classified curves and curve types. The most commonly known one is sigmoid shaped and Type II according to Brunauer's classification (Lewicki, 2009). There are different models developed on the basis of physical phenomena accompanying sorption to approximate experimental data of sorption isotherm. Various models and their suitability to show moisture sorption isotherm have been proposed. Among these models, Brunauer-Emmet-Teller (BET) and Guggenheim-Andersen-de Boer (GAB) are the most commonly used for food materials.

BET equation

$$\mathrm{u} = \frac{\mathrm{u_m c a_w}}{(1-\mathrm{a_w})[1+(\mathrm{c}-1)\mathrm{a_w}} \quad (1)$$

u is the amount adsorbed (kg/kg dry solids)
u_m is the amount of adsorbate filling monolayer (kg/kg dry solids)
a_w is water activity
c is the parameter related to net heat of sorption

GAB equation

$$u = \frac{u_m c k a_w}{(1-a_w)[1+(c-1)k a_w]} \quad (2)$$

k is an additional parameter for GAB.

GAB is a continuation type equation from BET with which it shares parameters of monolayer capacity (u_m) and energy/net heat of sorption (c). GAB has the third additional parameter (k) which corrects the properties of multilayer adsorbed water with respect to the bulk liquid. According to BET, heat of adsorption is limited to the first layer and there are no interactions between adsorbed molecules (Lewicki, 2009). In addition to fitting of model the physical meaning related to the range of the parameters is also very important in model validation. For GAB model, for instance, parameter k>1 means the sorption will become infinite at a value of water activity (a_w) <1 and this is physically meaningless since sorption cannot be infinite. When k=1 the GAB equation will change to BET equation. The parameter k falls in different ranges depending on the type of food material. If the parameters k and c are not maintained in certain ranges, either a_w will go beyond unity which is unrealistic or monolayer capacity estimate will be loaded with large error (Lewicki, 2009). Linearized forms of the equations are very helpful to understand the physical meanings of the parameters more clearly.

The main reason for the popularity of these equations in food technology is because of the water activity range which the isotherms cover. GAB covers the range of $0.05<a_w<0.8$-0.9, which almost completely covering the water range of interest in the field of food technology as compared to that of BET which has limited range of $0.05<a_w<0.3$) (Timmermann, 2003).

The other commonly applicable model is the Chung and Pfost model with initially two parameters which is developed to describe sorption isotherms assuming the way the free energy of sorption changes with the moisture content. The equation of this model is later on modified into an equation with four parameters adding parameters related to temperature and was accepted by the American Society of Agricultural Engineers in 1996 as modified Chung and Pfost (Lewicki, 2009).

Modified Chung and Pfost equation

$$u = E - (F * \ln(-(t + C) * \ln(aw))) \qquad (3)$$

Where

t is temperature (°C)
C, E, and F are adjustable parameters

Fitting of equilibrium relative humidity, equilibrium moisture content and temperature curve in various best fitting models have been evaluated for various seeds (Aviara et al., 2002; Menkov and Durakova, 2005; Garcia et al., 2010). Although physical properties related to material handling during storage and processing and processing equipment design has been reported for nigerseed (Solomon and Zewdu, 2009), the data on equilibrium moisture content-sorption isotherm and related information on model fitting and parameter estimate is lacking.

2.4. Developments in Oil Expression/Extraction

Oil extraction from both animal and plant origin had been known since ancient time. Manual crushing of the seeds using simple available tools, rendering, pressing manually or powered by animals and filtering are among the old methods some of which can still be traced in some parts of the World. Today using high technology seed treatment, pressing, refining, and where necessary modifying the oil by secondary processing, packaging is possible. The current technology has reached high precision taking into account almost all minor but important components in the oil.

2.4.1. Historical Aspect of Oil Extraction

Documented oil extraction dates back to 1650 B.C. when ripened olives were pressed by hand in Egypt using wooden pestles and stone mortars. The extracted olive oil was filtered through goat hair filters and used as a lubricant. Sesame, linseed, and castor oils were recovered in Egypt by hand pressing as far back as 259 B.C. (Kirschenbauer, 1944 in Kemper, 2005). By 184 B.C., the Romans developed more sophisticated technology such as edge runner mills and screw and wedge presses. These technologies combined leverage and the use of animal power to aid in the milling and extraction of the oil. From Roman times until the eighteenth century, similar technology was used for oil extraction (Kirschenbauer, 1944 in Kemper, 2005).

a. Hydraulic Press

In 1795, J. Bramah of England invented the hydraulic press for oil extraction (Kirschenbauer, 1944 cited in Kemper, 2005). For this press oilseeds were milled, cooked, and wrapped in filters cloths woven from horse-hair. The oilseeds wrapped in filter cloths were manually loaded into perforated, horizontal boxes below the head block and above the ram of the press. The boxes were pressed together using upward hydraulic pressure on the ram. The oil was pressed out through the filter cloths surrounding the oilseeds. The filter cloths and spent cake were manually removed from the hydraulic press. The residual oil in spent cake was approximately 10%. Since its discovery various modifications and advancements had been made to hydraulic press from its simplest form to the most advance one. Today, hydraulic press is used only for olive oil and cacao butter pressing (Kemper, 2005). In 1900, Alfred French founded the French Oil Mill Machinery Company in Piqua, Ohio, for the purpose of advancing hydraulic press technology. He was awarded a patent for the automatic cake-trimming machine for automating the sizing of the cakes prior to pressing (Anonymous, May 2000 cited in Kemper, 2005). He also developed and patented the ‘‘change valve’’ in 1905, which allowed the hydraulic press to change pressures near the end of the pressing cycle to squeeze additional oil. The continuous stacked cooker was patented in 1907 along with an innovative cake former. Two pass pressing was another of French’s developments, taking final residual oil in cake below 5% (Kemper, 2005). Depending on the type of material, subsequent process, intended use, quality desired, and efficiency there can be different mechanisms of oil expression from plants (seeds, nuts, fruits…).

Around 1890, oilseeds were pressed in manually loaded batch presses. Oilseed wrapped in filter cloths, separated by stacked layers of plates in hollow perforated cylinder and applied pressure through a manually operated jack screw or a hydraulic cylinder. Oil flows from the compressed material into the hollow plates and then oozes through the perforated side wall of the cylinder. Manually operated jack screw has been used for hundreds of years. With the advent of hydraulic cylinders the presses became more efficient and less labor intensive and also more oil is liberated due to high pressure. In the early 1900s hydraulic presses dominated the oilseed crushing industry. The hydraulic press itself was considered to be labor intensive when continuous screw press was developed. Today, the continuous screw press is the dominant one in mechanical press. The only application still favoring hydraulic press is cocoa butter from cocoa beans where the defatted residue is to be fine-ground into cocoa powder and olive oil. Competition was between limited numbers of companies in the World (Williams, 2005; Bredesen, 1983).

b. Screw Press Extraction

Valerius D. Anderson (Anderson International Corp., Cleveland, Ohio) developed continuous screw press in 1900. He used a continuous press design in 1876 and tested a serious of screw-conveyer like devices that had perforated walls and a flapper-type choke at the discharge end. He later on made a breakthrough discovery providing interruptions to the screw flight i.e. mounted on a central shaft so as to have some unflighted space between the segments (Figure 2.10). This solved the problem of the product spinning with the shaft every time the choke is closed. The shaft is placed in a cylindrical housing with holes drilled throughout to allow oil to escape upon pressing (Kemper, 2005).

c. Solvent Extraction

Solvent extraction is a process in which a solvent (such as hexane) is used to separate the oil from the oil-bearing materials. It is a demanding process, using highly inflammable chemicals, and it is only practiced at a relatively more sophisticated industrial scale. The advantage of solvent extraction is the high efficiency of extraction that can be obtained economically with this method (>99wt. %). But can be at the expense of reduced oil quality resulting from residual solvent chemicals if the technology is not high level (Willems et al., 2008). The advantage of solvent extraction is the high yield/efficiency but this demands high initial investment and skilled technician. Therefore it is less recommended where the technology is not well refined and the skill is not reliable.

2.4.2. Compressive Pressure by Screw Press

A screw press is a mechanical device that accepts a continuous stream of fat bearing material, compresses it under very high pressure to squeeze out the fat, and then discharge a continuous stream of squeezed solids (Williams, 2005).

The function of a screw press is to separate liquids including oil from solids by expelling the liquids through a screen that surrounds the compression screw. It applies pressure to make the fluid flow through the holes or slots in the screen. As screw presses evolved, a number of mechanisms have been found useful for this separation process (Vincent corporation, 2004) as follows. Firstly the compression can be achieved by gradually increasing the shaft diameter of the screw. This forces the material out against the screen so that liquid is expelled through the screen as the clearance between the wall and the shaft progressively decreases along the length towards the discharge Secondly, compression can be achieved by tightening the pitch of the flighting. As the number of the screw turns per unit length decreases towards the discharge there is more material being forced into the press than is being removed. This results in increase in pressure with decrease of pitch. A third way to achieve compression is to install a cone at the discharge. This cone is also referred to as a choke, stopper or door. In many screw press designs cone is bolted into a fixed position, creating a fixed discharge orifice or changeable cone with varying orifice diameter (Vincent corporation, 2004).

2.4.3. Conditioning of Oilseeds

Conditioning of seeds generally involves heat treatment (temperature and time of heating) in which is also moisture change is included. In the process of oil pressing heating of the raw material like cooking oilseeds is important. Oil droplets in oil bodies of oilseeds are ultramicroscopic and are distributed in the seed and may be concentrated in some parts of the seed like germs of cereals. Cooking causes these minute droplets to coalesce into drops larger and larger droplets until it is large enough to flow from the seed. On the other hand also cooking causes denaturation of proteins mainly those which embed the oil. Before the proteins coagulate through denaturation, the oil droplets are virtually in the form of an emulsion. Coagulation causes the emulsion to break, after which there remains only the problem will be separating gross droplets of oil from the solid material. This is the job of pressing (Williams, 2005). The heat treatment is determined based on time-temperature optimum combination. Therefore conditioning is a process which reduces mechanical oil expression more or less to a solid liquid separation.

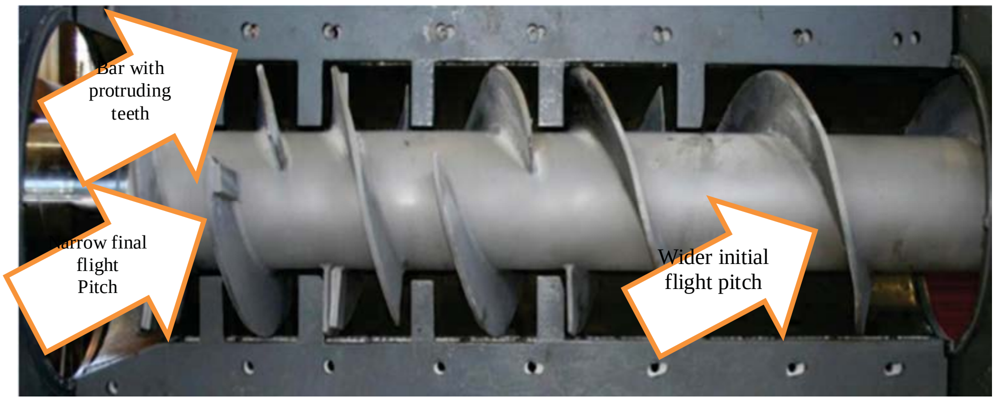


Figure 2.10: Screw with interrupted flight, teeth and bar, and heavy final flight (narrower pitch) (Source: Clipped from Vincent corporation, 2004 and labeled)

The aqueous extraction of oil from oilseed particularly Nigerseed is practiced by the rural society of Northern Ethiopia. The oil produced in this way is called '*qiba noug'* or *tina bug*'. Oil screw expellers with a horizontally rotating screw which feeds raw material into housing made of cages forming shims or barrel with perforated walls is widely practiced in Ethiopia. Hydraulic presses were also used before screw presses became more popular however these types of press are of limited use today. Although, oil can be produced by different methods mechanical press especially screw press is by far the most common by small scale millers for oils pressed from seed. Oil production which is mechanically powered by animals is still common in some parts of India and Ethiopia especially in sesame producing areas in Ethiopia. This type of pressing is used to overcome storage problem during the peak season of production. Such a method of oil pressing is still very important around Metema and Chilga of Amhara Regional State, and Benishangul-Gumuz Regional State (Ethiopia) (Figure 2.11). This device, known in India as "ghani", can be either animal or motor driven.

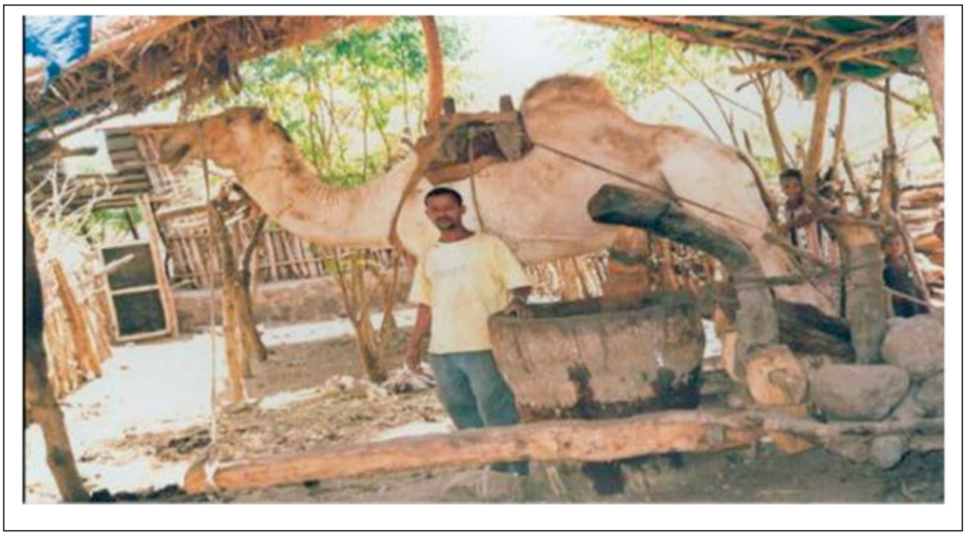


Figure 2.11: Sesame oil expression using animal drag pestle rotating in a stationary mortar in Chilga, Ethiopia).

A motorized oil pressing machine was introduced later on from various countries and the earlier types were generally from Japan and the recent ones are mostly from China (Fig. 2.12) and also from India.

Figure 2.12: A typical motorized small oil mill in Ethiopia (mostly imported from China) and the working premise

2.4.4. Recent Developments in Oil Extraction/Expression

In a more advanced approach supercritical fluid extraction following prepress is also under investigation (del Valle, 2006). Gas assisted oilseed pressing technology is also becoming interesting where dense gas is used so that there would be lower residual oil content during solid-fluid mechanical separation. The gas is contacted with the oilseed before or during pressing in order to achieve high efficiency. Review of recent developments (Dijkstra, 2009) has shown the progresses in the area including evaluation on gas assisted mechanical extraction (GAME) that the high pressure CO_2 released at the nozzle of the press, escapes and dissolves in the oil and thereby reduces its viscosity and entrains so much oil that the residual oil content of the press cake is less than 3%.

A wet extruder can be used to enhance the performance of solvent extraction on soybeans and cottonseed, and a dry extruder can be used to enhance the performance of a full press. A wet extruder is a high-strength cut-flight screw conveyor equipped with steam injection along the housing and a restricted orifice discharge commonly called expander. The oleaginous flakes are heated in the range of 90–110°C temperature from electrically generated and internal friction by the rotating barrel against the wall and live steam heat. High pressure develops as a result of the input flow rate and output flow rate difference and the increased temperature. The steam adds heat as well as moisture. The extrudate which is coming out puffs immediately due to abrupt drop of pressure results in hot, porous and fragile pellet with ruptured of cells. This exposes oil bodies with natured cover protein structure. To enable good solvent extraction performance, the extrudate must be dried to 10% moisture and cooled to 60°C temperature to firm up the soft extrudate and prevent evaporative cooling and re-condensing of moisture go to solvent extraction (Kemper, 2005). Dry extruders are occasionally used ahead of full presses. Dry extruders use electrical power to generate internal friction to heat the product as high as 150°C temperature. When the extruded product exits the dry extruder, it is liquid-like in consistency with thorough cell rupture. When this product is fed to a full press, the press throughput can be increased significantly. The principal advantage of dry extruder preparation is that no expensive stacked tray cookers or steam boiler are required, and the total capital investment for facilities under 100 tons per day in size is significantly less than for traditional full-press or solvent extraction processes (Kemper, 2005).

In recent developments, a new application of twin screw extruder as a machine to conduct a thermo-mechanical pressing and a solvent extraction of sunflower oil in a single step and in a continuous mode was studied using fatty acid methyl ester as a solvent. Parameters studied were screw rotation speed, feed rate, and solvent to solid ratio. As a result an increase of oil extraction was observed as screw rotation speed and feed rate were decreased, and solvent to solid ratio was increased. Highest oil extraction yield of 98% with the best quality oil meal was obtained at 185 rpm speed, 30 kg h^{-1} feed rate, and solvent to solid ratio of 0.55 (Kartika et al., 2005).

2.4.5. Major Types of Edible Oil Products

Based on the degree to which it is processed/the nature of the process edible oil can be classified into two, refined and unrefined. Refined oil refers to those oils where the processes for free fatty acid neutralization, odor removal (deodorization), color correction … are applied after pressing of the oil from the raw material. During hot oil pressing, the level of the undesirable substances is elevated due to high thermal operations associated with raw material pretreatments and high pressure pressing. Therefore the refining process steps are necessitated to adjust the free fatty acid, odor, and color to a standardized level/consistent quality or standard set by standard/quality authorities. Refining prolongs shelf life of the oil and consumers are also attracted by clear and sparkling appearance and moreover the oil is of consistent quality. The terms unrefined oil, raw oil and crude oil are sometimes used interchangeably however the connotation behind the terms is very important. The prefixes raw and crude generally indicate the incompleteness of the process or implying that some processes (refining) is to follow. Therefore using these suffixes for the oil that does not need further process (refining) has negative impact on the product/market. Unrefined oil appears to be a more neutral term for a product that does not need refining step. However these unrefined oils are classified into two as cold pressed and virgin oil depending on the mode of the pressing process. These cold pressed/virgin oils are considered to be types of oil product on their own rather than an incomplete process product. Virgin and cold pressed oil are sometimes used interchangeably but are defined separately Codex Stan 19-1981 (FAO, 1981) with their own standard which is intended for voluntary application by commercial partners. They are defined by the Codex Stan as follows.

> “Virgin fats and oils are edible vegetable fats and oils obtained, without altering the nature of the oil, by mechanical procedures, e.g. expelling or pressing, and the application of heat only. They may be purified by washing with water, settling, filtering and centrifuging only.”

> “Cold pressed fats and oils are edible vegetable fats and oils obtained, without altering the oil, by mechanical procedures, e.g. expelling or pressing, without the application of heat.”

Like the virgin oil, the cold pressed oil may be purified by settling, filtering (Figure 2.13) washing with water and centrifuging (Ferchau, 2000). These virgin/cold pressed oils are highly relevant to the small scale processing because their production step does not include refining instead only pressing and some of the oil cleaning steps mentioned. Since high temperature is not applied formation of free fatty acid, extra natural color, and odoriferous reaction products are minimized in cold pressed/virgin oils (Matthaeus and Bruehl, 2003; Bruehl, 1996).

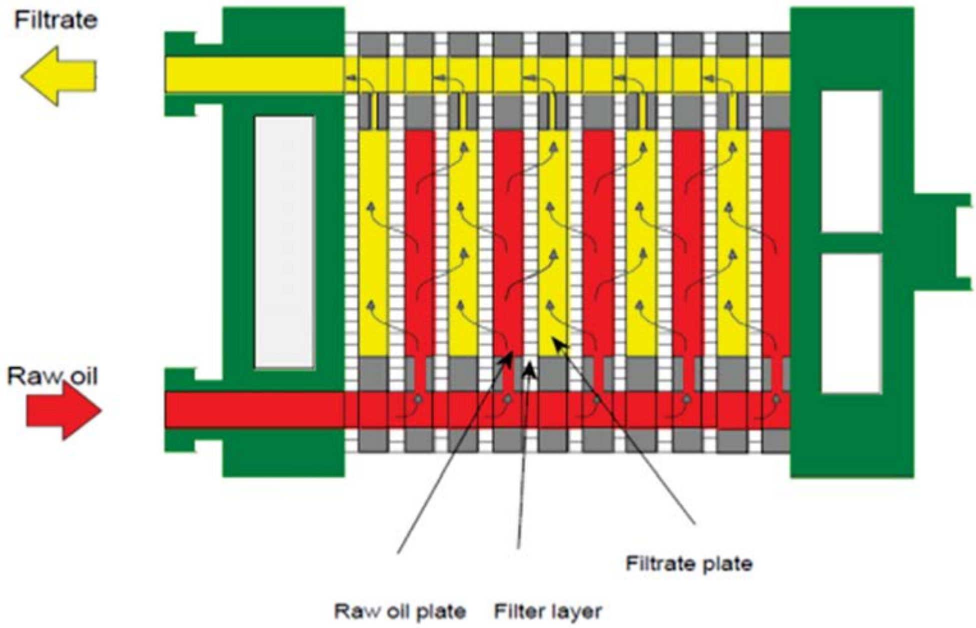


Figure 2.13: Filtration of oil using filter press (lower) (Source: clipped from Ferchau, 2000)

However since these oils are also important to the consumers ensuring their sensory quality appears to be more important (Brühl and Matthaeus, 2008). The main point in the production of cold pressed/virgin oil to minimize undesirable substances in the oil at the stage of raw material handling and pressing since there is no option for further step to remove the undesirable or correct the levels substances to standard set (Matthäus and Bruehl, 2008). Comparison of the quality of cold pressed and virgin rapeseed oils with industrially obtained oils shows certain differences such as loss of tocopherols during deodorization (Wroniak, 2008). Although there is a relatively long tradition that the cold pressed/virgin oil had been with small scale millers there is always a need to give them meaningful and practical technology support (Romijn, 2001). It can also be seen that there is renewed interest in cold pressed oil and they are mushrooming even in economically and technologically powerful countries like Germany (Uhl and Remmele, 2008).

Comparison of refined and non-refined oil demonstrates health advantage of the non-refined ones (Puri, 2004). Although the interest is growing for virgin/cold pressed oil from other sources than the traditionally known ones like olive oil, the advantage and disadvantages (relevance) must be carefully considered (Table 2.4). It is, for instance, worth noticing that virgin oil production is less suitable for large scale production and it is also not suitable for high thermal application or cooking as compared to refined oil. Hot pressing is also comparatively more efficient, multinational and more job creating. The fact that virgin oil is chemical free makes it more attractive.

Table 2.4: Comparison of virgin/cold pressed and hot pressed and /or solvent extracted refined edible oil (Ferchau, 2000) (modified)

Cold Pressed/ Virgin Oil	**Hot Press and /Solvent Extracted Refined Oil**
Small, medium scale private/cooperatives	Large and Multinational
Located near Agricultural Production	Located near cities
Value addition to rural economy	Job creation for cities
Less importance of middle men	With middle men
Low capacity of production	High capacity of production
Low energy consumption	High energy consumption
No use of chemicals	Use of chemicals
Little or no thermal application	High thermal application
Little or no waste	High waste release
Low logistic and security expense	High logistic and security expense
Low investment	High investment

Table 2.4 (cont'd): Comparison of virgin/cold pressed and hot pressed and /or solvent extracted refined edible oil (Ferchau, 2000) (modified)

Cold Pressed/ Virgin Oil	**Hot Press and /Solvent Extracted Refined Oil**
Less efficient (>10%) oil content	High efficiency (<1% oil in the cake)
Less skill requirement	High skill requirement
Intact nutritional components	Removal of some nutritional components
Short shelf life	Long shelf life
Sensitive upon exposure to air and light	Not sensitive to air and light
Not suitable for high temperature cooking/ frying	Suitable for high temperature cooking/ frying

2.5. Small Scale Edible Oil production and its Major Problems in Ethiopia

The Ethiopia's domestic oilseed and edible oil problems that are commonly stated can be summarized as follows: less interest by the investors in both oilseed production and processing; farmers' interest towards cereal grains production due to competitiveness on the market and priority as own food; hoarding of the seed (farmers, intermediaries, union, merchant) due to speculation of rising price irrespective of seed quality deterioration; non-value adding intermediates ; export of oilseeds despite serious shortage for domestic processors; lack of technology support system and training for oil millers' and processors' and imbalance caused by freeing of import oil from duty; and banning (even though not fully enforced) of virgin/cold pressed oil and failure to recognize role of cold pressed/virgin oil in the local market.

Mechanical press is recommended for small scale oil pressers mainly due to capital investment and the skill required (Lefebvre, 2012). While many problems in oil production are more or less common to small, medium and large enterprises there are some problems peculiar to cold the small scale oil millers. The banning of virgin/cold pressed oil is mainly due to the government food law that prohibits unrefined oil production and selling (Sertse et al., 2011; Lefebvre, 2012). The small scale virgin oil millers are targeted because it was generally understood that such oil millers are responsible for adulteration and low quality oil.

Many initiatives in Ethiopia discourage the small scale oil millers directly or indirectly.

The model proposed for the small scale cold pressed/virgin oil millers to apply series of alternative businesses although all are difficult for them (Sertse et al., 2011). Therefore there is a strong demand for support from the small scale edible oil millers who play the dominant role in the domestic edible oil supply, about two third of the nations' supply (Wijnands et al., 2009). Improving the oil expression efficiency based on raw material/nigerseed pretreatment and controlling the mode of pressing operation is particularly of immediate interest to the small scale oil millers. Regarding production of virgin oil by the small scale oil millers, for instance, the quality of oilseed is utmost importance. The main reason to give attention to the seed quality is that the producers have no chance to improve their oil quality once the oil is pressed. Purification by sedimentation or filtration only removes turbid matter, but not chemicals that products of oil degradation (free fatty acids or peroxide value) and reduces quality of the oil. Therefore small mills principally depend on the quality of the raw material, while large-scale facilities can remove free fatty acids, chlorophyll, contaminants or aroma compounds from the oil during the refining process with some losses or higher costs of the production (Bruehl and Matthaeus, 2008). Small scale oil mills are increasing in number not only in developing countries where the main reason is capital for investment but also in industrialized countries where the population is showing more and more interest towards natural, minimally processed, and lowered/none chemical residues (Uhl and Remmele, 2008). It is well known that such virgin oils production system has lower efficiency as compared to the hot pressed and refined ones. The virgin oil has limited application such as only for relatively lower temperature of cooking and not used for frying. Because of the changes that occur during refining, it is always important to note whether compositional data relate to crude/virgin or refined oil (Gunstone, 2002). The natural color, aroma, and flavor of, for instance, Nigerseed oil with which the native consumers had been for a long time is important for people more than any other factor. Therefore improving the efficiency and competitiveness of such small virgin oil millers has both economic and traditional value to the people. The shortage of edible oil currently observed in Ethiopia may be attributed mainly to the global situation but further exacerbated by domestic management of the problem including experts' recommendations to government based on very shallow surveys.

To the small scale oil millers in Ethiopia, support may be given by institutionalized technology support system including preparation of guideline for their production and reversing of any law that influences them based on valid information and best practices elsewhere. Improving their skill through training and standardizing their operations are necessary.

2.6. Major Factors on Yield of Oil Expression/ Screw Press/

The main question next to the amount and quality of oil contained in the raw material is how to express as much as possible of that oil. This maximum possible oil extraction from the raw material is commonly said to be efficiency of expression. The efficiency of expression generally depends on the technology in use. However the efficiency improvement can generally be made for that given technology at different stages in the process i.e. modifying raw material nature, control of operational parameters the pressing machine and improvement of machine design in order of its complexity.

2.6.1. Method of Oil Extraction and Nature of the Raw Material

Before planning any other aspect of edible oil production the method of oil expression must be taken into account i.e. whether it is screw press, hydraulic press or solvent extraction or any combination of these methods. And this consideration is also based on the raw material used like animal flesh, fruit, seed, nut, germ of seed (Williams 2005).

Some materials are more resistant to flow than the others. Hull content of the oilseeds, for instance, increases friction and do not slide easily through the channel in a screw press. Oilseeds with high fiber level can be pressed with shafts of uniform channel depth and uniform pitch. In the prediction of oil expression using time varying properties, for instance, using soy and sunflower. Upon prediction of oil expression by uniaxial compression using time varying oilseed properties sunflower showed significant error as compared soybean due, mainly, to its hull (Bargale et al., 2000). Softer materials have lower friction. A uniform channel depth and a uniform pitch worm shaft generate very little pressure. Transport of material in a single-screw press depends mainly on friction between the material and the barrel’s inner surface and screw surface during screw rotation (Kartica et al., 2005). Therefore material’s resistance to friction is an important factor.

2.6.2. Moisture and Heat for Oil Expression

Control of moisture content is one important way of controlling the nature of raw material for efficient pressing. Controlling temperature of both during raw material pretreatment or pressing is required in the improvement of efficiency of extraction depending on the moisture content. There must not be high moisture to cause protein swelling which in turn decreases flake porosity (Williams, 2005). The optimum moisture depends on the raw material being used and affects quality of the oil expressed (Akinoso et al., 2010). Overcooking (high temperature) causes dark colored oil and cake. Prolonged cooking may affect the nutritional quality of both the oil and the cake. Moisture is set higher than the final considering moisture loss during the final venting. Cooking temperature and time is the most common pretreatment technique known in edible oil processing. It is generally true that oilseeds express their oil more readily to mechanical expression after cooking but complete scientific explanation is lacking due to complex physico-chemical changes. Lowering the viscosity of the ultramicroscopic oil droplets contained in the oil bodies is one objective of heating. The lowered viscosity enables the droplets to flow and coalesce and this process continues further facilitating flow of the oil out of the disrupted oil bodies. Coagulation and denaturation of protein further facilitates permeability to the flowing oil droplets creating more and more coalescence to increase the bulk (Williams, 2005). Seed preheating temperature together with the moisture and oil content has significant effect on efficiency and output (Jacobsen and Baker, 1986; Martinez et al., 2008).

2.6.3. Screw Press and Pressing Operation

There are two main types of screw presses which differ in certain respects like oil and cake outlet as well as the structure of the cake (Ferchau, 2000). These are hole-cylinder type and strainer type. In the hole-cylinder type the screw shaft is housed in a perforated cylinder through which the expressed oil is drained and the press cake is removed at the distal end through a changeable nozzle forming pellet. This type of screw press is generally for small capacity. In the strainer type the housing of the shaft is made of stacking bars with variable thickness spacer between them depending on the type of seed. The cake/meal is removed as thin and flat sheet at the end of the shaft (Figure 2.13).

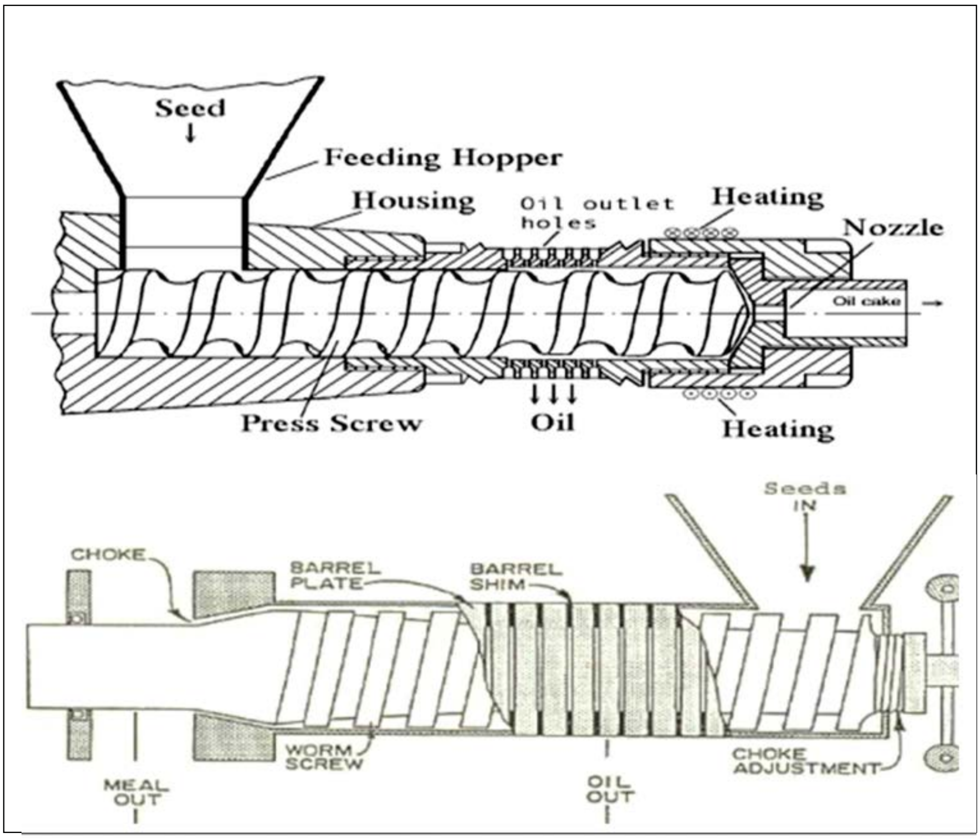


Figure 2.14: Hole-cylinder type (top) and strainer type (bottom) screw presses Source: clipped from (Ferchau, 2000).

During the pressing operation a spring loaded choke creates back pressure against the material which is being pressed. The materials still tend to spin with the flighting but spinning would stop in the areas where there is no flighting. This would allow the shaft to generate enough pressure to push the material against the choking device.

Based on pressure applied, oilseed screw presses fall into two categories: full presses and pre-presses. A full press is designed to generate sufficient pressure to express as much oil as possible. For most oilseeds, the oil level remaining in the press cake can be reduced to 3 -5%. Reducing channel depth (the clearance between the shaft surface and inner wall of the barrel) or decreasing pitch of successive worm flight or reducing the barrel inner wall diameter is the mechanical means for designing positive compaction into the worm shaft. As a result the pressure progressively increases as the matrix is conveyed forward additionally assisted by restricted output through the choke (Vincent corporation, 2004). Models are also attempted based on maximizing pressure considering density, temperature, rate of pressing, dynamic viscosity, moisture content, material property (Willems et al., 2008). Regarding the perforation of the cylindrical wall, the inner wall diameter of the hole is much smaller than its outer wall diameter i.e. it looks like a cut cone. This is so because the inner whole should be as small as possible so that high pressure is built inside. It is possible to see the small the inner diameter the higher the pressure is (Vadke et al., 1988). The steady state screw speed must be adjusted in such a way that the flow of material be sufficiently high to build high pressure but not too high to over choke the cone and cause spinning even though effects like feeding rate, speed of rotation and compressive stress have combined effect (Akinoso et al., 2009).

In an effort to improve the efficiency of oil recovery different types of screw press versions including double stage compression have been developed (Singh and Bargale, 2000). Screw press was generally developed by trial and error approach towards the end of the last century. But nearly all previous attempts were unsuccessful due to lack of data on important parameters such as operating pressure. This in turn limited the effort of screw press designers and gaps in the theory did not allow the theoretical predictions go further (Omobuwajo et al., 1999). Therefore it would still be a good approach to optimize based on screw presses with known specifications for a specific seed.

Control devices like rotational speed, for instance, must be given a wide range of speed to be adjusted depending on the nature of raw material and its possible modifications. The heating ring need be supported by a device to control the temperature which important for both efficiency and quality of oil to be expressed. Screw channel and pitch depth could be more important depending on how hard or soft the oilseed is. The other mechanical device to control pressure for oil expression is cone. Therefore it is possible to vary pressure by varying the cone diameter. Therefore there should be varying option for cone diameter. The barrel perforations may also be modified in many different ways for overall efficiency increase or depending on the raw material nature. Although not common, it is possible to provide barrels with different perforations to be used depending on the raw material nature and its possible modifications.

2.7. Fat and Oil in Human Nutrition

Fat and oil can be obtained from plants and animals. However the plant source is incomparably very high. Fat & oil is one of the three major foodstuffs (Carbohydrate, protein, and Fat &oil). Fat & oil are generally water insoluble organic substances predominantly consisting of triglycerides, glyceryl ester of fatty acids.

A novel definition and comprehensive classification system for lipids are proposed (Fahy et al., 2005). This definition is based on chemical property and defines lipids as 'small hydrophobic or amphipathic (or amphiphilic) molecules that may originate entirely or in part by condensations of thioesters and/or isoprene units'. Ratnayake and Galli (2009) has also made a comprehensive background review on fat, fatty acid terminology, methods of analysis, and fat digestion and metabolism. Generally it is well known that lipids exist as oil (liquid at room temperature and mainly from plant source) and fat (solid at room temperature and mainly from animal source). Lipids are sources of energy and supply more than twice energy per unit mass as compared to carbohydrate due to their more chemically reduced nature i.e. potential to give out more energy by oxidation.

2.7.1. Lipid/fatty acid Classification

Oils and fats (lipids) in human diet are usually classified based on different criteria like their sources, relative composition, function in the source organism, saturation of fatty acids, reaction of their functional groups, chemical structure, molecular size, and their metabolism (FAO, 1980; Belitz et al., 2009; Fahy et al., 2005; Ratnayake and Galli, 2009). Based on their sources, for instance, lipids can be classified as plant/vegetable oils and animal lipids. Vegetable/plant lipids are generally liquid at room temperature (with unsaturated fatty acids) and can be obtained from different parts of the plant including seed, fruit, leaves etc. The animal lipids which are generally solid at room temperature (with saturated fatty acids) and can be obtained from milk, flesh or other part of animals (terrestrial or marine). Lipids can also be obtained from microbial (bacteria, yeasts, molds, and algae) sources. Therefore accordingly the lipids are commonly named based on their respective sources as plant, animal, microbial lipids. Or they can be named more specifically as nigerseed oil (plant), butter or milk lipid (animal) based on the specific source.

Although each and every fatty acid within each broad classification of fatty acids may have unique biological nature and health effects, still the best way to classify them is on the basis of double bond for the sake of clarity and continued common usage. Therefore the grouping of fatty acids into these three broad groups: Saturated Fatty Acid (SFA), Mono-Unsaturated Fatty Acid (MUFA) and Poly-Unsaturated Fatty Acid (PUFA) as follows are recommended (FAO, 2010).

- SFAs are the major fatty acids in human diet, with carbon numbers C14, C16, C18, except in the case of milk and coconut oil where SFA range from C4 to C18 carbon numbers.
- MUFAs are the major fatty acid in Western diets, which is oleic acid (C18:1n-9). Erucic acid (C22:1n-9) also belongs to this group for some population who still consume edible oils derived from Brassica spp. such as rapeseed and mustard seed.
- PUFAs are the major unsaturated fatty acids in human diet, which includes mainly linoleic acid (C18:2n-6), a lower proportion of alpha-linolenic acid (C18:3n-3), and depending on seafood intake a variable but relatively low proportion of long chain PUFA such as AA, EPA, DPA and DHA.
- TFAs are the fatty acids in our diet which are typically isomers of 18:1 *trans* derived from partially hydrogenated vegetable oils.

Although edible fat and oil (lipid) can be obtained from different source those from plant (vegetable oil) is the most dominant source.

2.7.2. Oils in the Seed/Storage lipids/

Seed is a small and dormant form in the life cycle of plants and depends on food reserve, lipid in for oilseed, from the previous generation until it synthesizes its own food to establish as an independent plant of the next generation (Bewley, 1997). Seed food reserves usually consist of seed storage and differ in type and nature from plant to plant in which protein, carbohydrate or lipid may be dominant as in legumes, cereals, and oilseeds respectively. The seed is said to be oilseed where the oil is dominantly reserve in the seed. Of all types of reserves, oil is chemically in its most chemically reduced form to later on accordingly give out the highest amount of energy per unit mass by oxidation (Baud and Lepiniec, 2010). The storage lipids of seeds usually consist of triacylglycerides (TAG). TAGs are by far the most important edible lipids. TAGs are esters of glycerol in which fatty acids are esterified to each of the three hydroxyl groups of a glycerol back bone. The TAGs which are also found in membrane lipids are predominantly palmitate (16:0), stearate (18:0), oleate (18:1), linoleate (18:2), and alpha–linolinate (18:3). Of the numerous fatty acids some are specially modified in some seeds and demanded for special applications other than food (Voelker, 2001 cited in Baud and Lepiniec, 2010). Of these there are specialty oil (unusual forms/chemistry) such as oils in Brassicaceae (*Brassica napus, Arabidopsis thaliana*.), for instance, is rich in elongated acyl chains ranging from 20 to 24 carbons, whereas oil in other families (e.g. Lauraceae) contains shorter acyl chains ranging from 8 to 14 carbons. In caster bean (*Ricinus communis*), a hydroxylated fatty acid species (ricinoleate: $\Delta^{9cis}18{:}1\ OH^{12}$) is predominantly accumulated. Other families have epoxidated or methylated acyl chains in their seed oils (Baud and Lepiniec, 2010).

2.7.3. Vegetable Oils as Sources of Nutrient

In economically underdeveloped countries, shortage of edible oil is beyond a simple demand gap and its significance as a major contributor to nutrition gap is also quite important. Poor nutrition in sub-Saharan Africa, for instance, is often linked to a lack of fat in people's diets. Ten of the 20 countries with the lowest per capita visible oil or fat intake in the world are in eastern and southern Africa to which Ethiopia belongs (WHO, 2003). If these poor countries could produce their own enough oilseeds for edible oil production and ensure sustainable supply for themselves the nutrition problem could be substantially reduced. But practically most of these countries with serious nutrition problem are overly import-dependent for their domestic edible oil supply. About 80% of Ethiopia’s edible oil is imported since earlier than 2009 and the situation is getting worse and worse and per capita edible oil consumption in Ethiopia is only 2 kg (Wijnands et al., 2009) and it is clear that the population, particularly the vulnerable groups, is highly affected. Similarly, in 1987, 80% of the vegetable oil and fat consumed by the population in Kenya was imported. The intake of edible oils remains low, affecting people's nutrition and health (WHO, 2003).

Dietary fat are generally classified as saturated and unsaturated the latter being more important from health point of view (Appendix II). Common dietary fat are identified based on the degree of their saturation. The dietary fat has a number of importance such as energy source, cell structure and membrane function, source of essential fatty acid for prostaglandin synthesis, vehicle and source for oil soluble vitamins (A,D,E and K) and source of phytosterols to control blood cholesterol. In addition, fat and oil improves palatability of food when used in different forms including for cooking (FAO, 1980).

However of particular interest in the lipid aspects of nutrition in addition to energy source are essential fatty acids, tocopherols (vitamin E included), and phytosterols, oil soluble vitamins (vitamins A, D, E, and K).

a. Unsaturated Fatty Acid

As compared to the animal lipids the plant lipids are major sources of unsaturated fatty acids with the exception of coconut and palm oil which are mainly with saturated fatty acids. Since unsaturated fatty acids are currently highly recommended in relation to health concern, the demand for vegetable especially those with high content of unsaturated fatty acid will increase.

The fact that World food price in general and that of oilseed/edible oil in particular is rising may be due to various reasons among which supply is one but the rising consciousness and demand for vegetable oil may contribute to this.

According to FAO there is convincing evidence that replacing SFA with PUFA decreases the risk of CHD, replacing carbohydrates with MUFA increases HDL cholesterol concentrations, replacing SFA (C12:0–C16:0) with MUFA reduces LDL cholesterol concentration and total/HDL cholesterol. There is also convincing and sufficient evidence to set an acceptable intake to meet essential FA needs for linoleic acid (LA) and alpha-linolenic acid (ALA) consumption at a recommended ratio. As these evidences continue to be communicated widely the demand for unsaturated fatty acids/vegetable oil increases in a higher rate (FAO, 2010). It is possible that Nigerseed oil with very high omega-6 (linoleic acid) of about 80% can be preferable edible oil in the World market The new WHO guidelines, for instance, include a specific saturated fat component, specifically that saturated fats should provide no more than 10% of total energy intake (WHO/FAO, 2003). The demands for vegetable oil (mainly unsaturated ones) is expected to increase specially due to the developing tendency to achieve edible oils with certain omega-3/omega-6 ratio taking International recommendation as a reference (WHO, 2000; USDA and USDHHS, 2010).

b. Essential Fatty Acids

Essential fatty acids (precursors for important hormones, prostaglandins) are among substance required in fat and oil. While the glycerol skeleton fat and oils (triglycerides) are generally universal the fatty acids are versatile. Of these fatty acids, essential fatty acids are the most important as nutritional components with direct health implications. Body can synthesize some of the fatty acids however those which cannot be synthesized (essential fatty acids) should essentially be obtained through nutritional intake. These essential fatty acids are linoleic acids (18:2, ω6) which are highly abundant in Nigerseed oil and α-linolenic acids (18:3, ω3) which are highly abundant in linseed oil. Essential fatty acids are required for the normal growth and function of all tissues. Oils containing the polyunsaturated fatty acids: γ-linolenic acid, 18: 3 (ω6); arachidonic acid, 20:4 (ω6); eicosapentaenoic acid, 20:5 (ω3); and docosahexaenoic acid, 22:6 (ω3) are very important. For human adults a dietary in take of 3 energy % as essential fatty acid is recommended although many factors are known to elevate this recommended level (FAO, 1980). The two essential fatty acids known as omega-3 and Omega-6 have a number of clinical/health implications (Mirajkar et al., 2011). *Omega-3* (*ω3*) fatty acids are a family of unsaturated fatty acids that have in common a final carbon-carbon double bond at the *omega*-3 position from methyl end of the fatty acid. Both *omega-3* (α-linolenic acid) and *omega-6* (linoleic acid) fatty acids must be obtained from food. The human body cannot synthesize *omega-3* fatty acids but can form the long chain omega-3 fatty acids from the eighteen-carbon *omega-3* fatty acid (α-linolenic acid) by enzymes called desaturase and elongase. This elongation linolenic acid (*omega-3* fatty acids) occurs competitively with linoleic acid *(omega-6* fatty acids) (Kapoor and Patil, 2011). The dietary intake of linoleic acid (18:2, ω6) of an individual may be estimated by the equations as follows (FAO, 1980). Omega-3 and omega-6 composition is of serious concern and recommended dietary level is included for human being at different age level and sex (Appendix I).

$$\mathrm{Log}_{10^{LA*}} = 0.079[18:2\ (\omega6)\ + 20:4\ (\omega6) - 20:3\ (\omega9)] - 1.9 \qquad (4)$$

Based on this equation the linoleic acid of normal breast fed infant was calculated to be 5.1 energy %. Total ω-6 of serum phospholipid can be used to calculate using the following formula.

$$Log_{10^{LA*}} = 5.8(\log_{10} total\ \omega 6) - 8.5 \qquad (5)$$

***Linoleic acid (LA) is expressed as energy % and the other three fatty acids are expressed as % fatty acid in serum phospholipids of infants for both equations.

Based on this second equation the linoleic acid of normal breast fed infant was calculated to be 4.8 energy %.

Therefore in addition to all efforts to increase yield and other quality parameters of edible oil, omega-3/omega-6 content and ratio are important parameters in determination/selection of quality oil and its seed source. Nigerseed, for instance, is highly rich in omega-6 (about 80%) but poor in omega-3 and linseed is highly rich in omega-3 (about 54%) content and also with a good amount of omega-6. Therefore in addition to search for balanced omega-6 and omoga-3 directly from a single source, blending of different oils (two or more) in a certain ratio based on the relative content of the nutrients in question including omega-6 and omega-3 can be a good strategy.

c. Vitamin E (alpha-tocopherols)

Adequate vitamin E (antioxidant) is required to protect the essential fatty acids other fatty acids from oxidative degradation/deterioration (FAO, 1980). More often in characterization of oils and fats it had been focused only on the principal components which constitute the saponifiable fraction that comprises over 95% of oils and fats. However, it is also generally understood that the minor components which constitute the unsaponifiable matter have nutritional and characteristic compositional properties that determine the quality of individual oils and fats (Mitei et al., 2009). Tocols are generally classified as tocopherols and tocotrienols each of which are again classifieds into four depending on the number and position of methyl on the ring. Tocotrienols differ in chemical structure from tocopherols because of its unsaturated tail (Belitz et al., 2009). Generally tocols (tocopherols and tocotrienols) are natural antioxidants made by plants for protection against oxidative spoilage of plant materials such as oils mainly for lipids which are part of structural/functional components starting from while in the seed/ before extraction and after extraction (Figure 2.14).

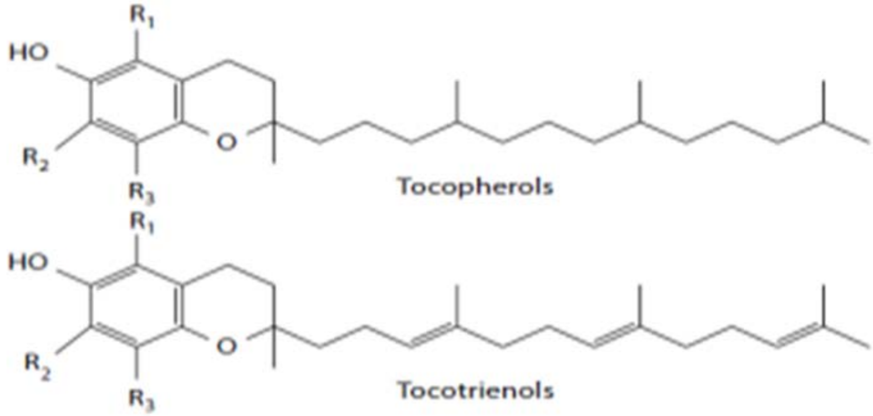


Figure 2.15: Vitamin E structures. The methyl groups on the chromanol head determine whether the molecule is α- (R 1 = CH 3 , R 2 = CH 3 , R 3 = CH 3), ß-(R 1 = CH 3 , R 2 = H, R 3 = CH 3), γ- (R 1 = H, R 2 = CH 3 , R 3 = CH 3) or δ- (R 1 = H, R 2 = H, R 3 = CH 3), while the tail determines whether the molecule is a tocopherol or tocotrienol (Source: Ratnayake and Galli, 2009).

For each plant species, oil expressed from them may have a characteristic compositional ratio as tocopherol/tocotrienol and also as alpha/beta/gamma/delta for each of these substances (Mitei et al., 2009). Alpha tocopherol (vitamin E) is of the major importance in biological system. The role of vitamin E is not limited to stabilization of lipid and membrane structure but also stabilizes other active agents such as vitamin A, hormones, and enzymes. Vitamin E is also involved in conversion of arachidonic acid to prostaglandins and slows down the aggregation of blood platelets. And the main well-known biological function of tocopherols is for protection of polyunsaturated fatty acids (PUFA) against oxidation (Belitz et al., 2009). About 60-70% of the tocopherols are retained during the oil extraction and refining process. Spectrum of tocopherol can be used to distinguish one type of oil from the other having similar fatty acid composition i.e. using characteristic tocopherols and their relative amount in different sources as an indicator (Belitz et al, 2009). Vitamin E (α-tocopherol) compounds constitute, by far, the bulk of the unsaponifiable matter of oil. Vitamin E sources are searched generally from edible oils or their seeds and wherever a good amount is found the oil is usually commercialized as nutraceutical/specialty oil. Edible oils from different sources differ in their vitamin E composition. While some are rich sources other have very low content. Vitamin E content of nigerseed analysis from samples collected all over Ethiopia, for instance, shows 657-853 μg/g or 65.7- 85.3 mg/100g (Dutta et al., 1994). It is noticed that this composition is exceptionally high as compared to any other sources known so far (Ching and Mohamed, 2001; Belitz et al., 2009).

d. Phytosterols

The sterols, and stanols (hydrogenation product of sterols) occurring in plants are known as phytosterols. The phytosterols are of interest from a nutritional and physiological point of view because they lower the concentration of cholesterol and low-density lipoprotein (LDL) in the blood plasma. There are about 44 phytosterols known to exist in plants, the most abundant being ß-sitosterol, campesterol and stigmasterol (Belitz et al., 2009). The food sources with the highest total phytosterol contents, as the sum of these three compounds (in mg/100 g), are the oils of rice bran (1055), corn (952), wheat germ (553), flax seed (338), cottonseed (327), soybean (221), peanut (206) and olive (176) (Kritchevsky, 1997 in Lerma-García et al., 2009). Analysis for nigerseed, black cumin, coriander seed oils showed respectively to be 202.2, 76.3, 179.4mg/100g of which that of nigerseed is much better than others listed here in its phytosterol content (Ramadan and Moersel, 2006). Most phytosterols available today are mainly derived from processing of canola, cottonseed, corn and soybean. An alternative commercial source is tall oil, a by-product of paper mills (Lerma-García et al., 2009).

e. Carriers of Vitamins

In addition to its role as a source of energy and various nutrients, edible oil is also known as a good vehicle for nutrients soluble in it. Vitamins A, D, E, and K are known to be soluble in oil. The role of edible oil as a vehicle for other nutrients can be well depicted by vitamin A. Vitamin A**,** a fat soluble vitamin, has high importance to health, mainly visual problem. Vitamin A deficiency is the single most important cause of childhood blindness in developing countries and where the deficiency is widespread, the risk of childhood mortality can be reduced on average by 23% through provision of sufficient vitamin A (Bagriansky and Ranum, 1998). Vegetable oil is the best option to deliver vitamin A because the technology of fortification is well established, fairly simple and stability of vitamin A in oil is greater than other currently used food vehicles such as flour, sugar or corn soy blends (Bagriansky and Ranum, 1998).

3. Aim and Objectives

3.1. Aim of the Study

The aim of this study is to contribute to the effort to combat of the problem related to the extreme shortage of edible oil and oilseeds observed in Ethiopia. In addition to the obvious shortage of oil and the resulting nutritional problem, the endangered value chain has strong negative impact on overall life of the population. Based on the national priority by Ethiopian Government, nigerseed and linseed were oilseeds selected for edible oil value chain enhancement (Lefebvre, 2012). And this study aims nigerseed (*Guizotia abbysinica* Cass.) as raw material mainly focusing on small holder farmers of Ethiopia who are responsible for supply of more than 90% of agricultural production for the country (CSA, 2010) and the maximum users of locally crushed nigerseed as edible oil (Sertse et al., 2011). And also includes the improvement of oil expression efficiency mainly targeted the small-scale oil millers in the country who produce virgin edible oil mainly from nigerseed and linseed and play significant role on supply of domestic edible oil.

Therefore the aim of this study is

a) To investigate the relationship of treatment variables: nitrogen fertilizer rate, seed rate, and nigerseed variety and their interaction with the nigerseed yield, oil content and in particular to evaluate the oil quality such as fatty acid and vitamin E composition.

b) To understand the appropriate storage condition for nigerseed by determining the equilibrium moisture content, the equilibrium relative humidity and temperature relationship (sorption isotherm) and validate some selected models for nigerseed storage and handling characterization.

c) To investigate the means of improving oil expression efficiency of the small scale edible oil mill (screw press) through conditioning of raw material and control of pressing operation.

3.2. Objectives of the Study

Based on the above aim of the study which is derived from the problems prevailing in Ethiopia the following general objectives were set.

a) To conduct field experiments for possible improvement of nigerseed yield based on agronomic practices: seed rate, nitrogen fertilizer rate, variety, method of water supply (rain fed/irrigation), and location. And investigation of the relationship between treatment variables and the nigerseed responses such as seed yield, oil content, and also evaluate the oil quality parameters such as fatty acid and vitamin E composition.

b) To experimentally show an improved way of seed storage and handling by determining important characteristics of the seed (adsorption isotherm, model validation and parameter estimation) for improvement of both quality oil and seed.

c) To improve oil expression efficiency of the small scale edible oil mill (screw press) through treatments of raw material and control of pressing operation i.e. determining the effect of conditioning nigerseed on the expressed oil.

The specific objectives are

a) To experimentally determine the method for improvement of seed yield and oil content by agronomic treatments of two selected varieties (Fogera and Kuyu) by varying seed and nitrogen rates at three levels each (triplicating each experiment) at two locations (Koga and Adet) under rain fed condition. In addition to location, comparison of irrigation and rain fed will be done at Koga location for the same experimental treatment.

b) To evaluate the fatty acid and α-tocopherol (vitamin E) profile at Adet location for the same experimental treatment and show their relationship with the experimental treatments under rain fed condition.

c) To experimentally determine the storage conditions (equilibrium moisture content, equilibrium relative humidity, at seven equilibrium relative humidity and two temperatures (including comparison of the two varieties)) for improved nigerseed storage and handling mainly to ensure quality nigerseed oil. Herewith to validate the data from multilayer adsorption isotherm against common models

(BET, GAB, and modified Chung and Pfost) and evaluation of the estimated parameters. The two varieties (Kuyu and Fogera) are compared in these regards.

d) To determine the efficiency of oil expression through raw material (local variety of nigerseed) conditioning at set temperature - time (both at three levels) and control of raw material feed rate (two levels) using small screw press machine.

4. Materials and Methods

The experimental works of this study is divided into three main components as shown below (Figure 4.1). The first component is field experiment for investigation of seed yield and oil content as well as oil quality (vitamin E and fatty acid) for two nigerseed varieties (Fogera and Kuyu). The second component is seed storage characterization and its model validation using the data to be generated on the storage characterization/adsorption isotherm which is again for the two nigerseed varieties. The third component is an experiment on efficiency of oil expression using small screw press and local variety of nigerseed.

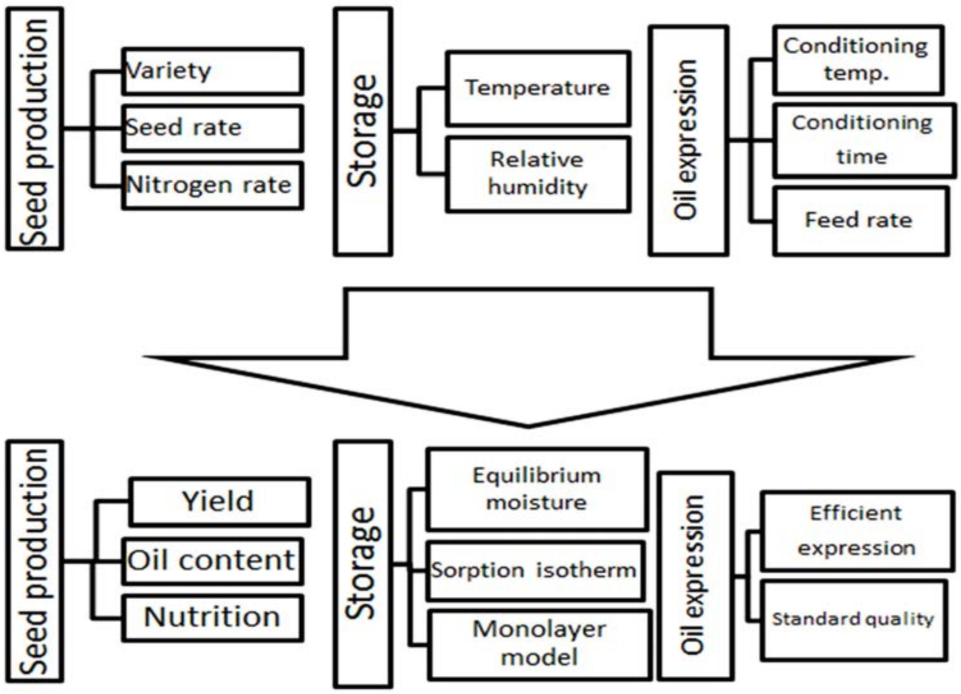


Figure 4.1: The major components of the experimental work and the measured parameters

4.1. Field Experiments on Nigerseed (*Guizotia abbysinica* Cass.)

Improved agronomic practice is one of the components in the effort to ensure sustainable seed supply for the edible oil industry (Figure 4.2). The field experiment was planned and conducted on the Ethiopian highland area which is a native place for nigerseed (*Guizotia abbysinica* Cass.). The field experiment was taken as the first step in dealing with edible oil value chain enhancement to work on the raw material supply aspect of the problem. Experimental approach was adapted from Choferie et al. (2011) and Weyesa et al. (2011).

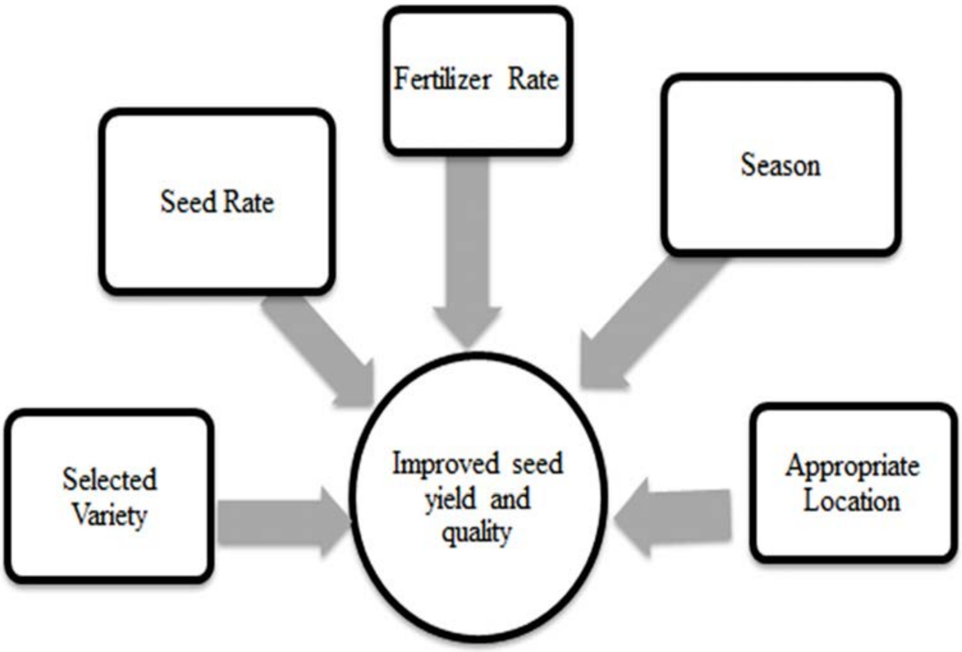


Figure 4.2: The major components and the goal of the planned field experiment

4.1.1. Experimental Factors and Experimental Design

Treatment variables: Seed variety, seed rate, and nitrogen rate were treatment variables for the field experiment. Based on these treatment variables the field experiment was performed at two different locations for location comparison. On one of the locations rain fed and irrigation were also compared while on the other location only rain fed is considered.

Responses variables: Seed yield, oil content, ash content, and thousand seed mass (tsm) were response variables for all treatments of the field experiment (both locations). Fatty acid and vitamin E (α-tocopherol) profile was done for one of the two locations (Adet location) with rain fed cultivation. In addition to determination of effect of different levels of the treatment variables comparison of the responses was also done for the two locations including rain fed and irrigation treatment.

Experimental Design: First the treatment variables were set in full factorial. The experiment was performed in triplicate and was in a completely randomized blocked design (CRBD) for the treatment variables: seed variety, seed rate, and nitrogen fertilizer rate. For the response variables fatty acid profile and α-tocopherol (vitamin E) content the experimental design simply takes the form of completely randomized design as the data was taken only from one of the two locations, Adet location by rain fed (Table 4.1).

Table 4.1. Field Experiment general treatment/response plan

Treatment / Responses	Locations		
	Koga		Adet
Mode of Water supply	Rain fed	Irrigation	Rain fed
Treatment factors (level)	Variety (2), Seed rate and nitrogen rate (3 levels each)	Variety (2), Seed rate and nitrogen rate (3 levels each)	Variety (2), Seed rate and nitrogen rate (3 levels each)
Major Responses	Seed yield, oil content	Seed yield, oil content Phenotypic	Seed yield, oil content, vitamin E and fatty acid profile
Other responses	Thousand seed mass, ash content	Thousand seed mass, ash content	Thousand seed mass, ash content

4.1.2. Locations for the Field Experiments

Field experiments were planned to be at two locations called Koga and Adet for location comparison at the Ethiopian highland area of Amhara Region (Figure 4.3). Selection of the location is based on previous background for nigerseed cultivation by small holder farmers. The other major criterion for selection was based on the availability of facilities for irrigation and simplicity to secure the land for experiment. Additionally the geographical proximity and convenience of follow up was also considered. This selection fulfills the criteria set (Weyesa et al., 2011) for agronomic requirements of nigerseed. Both locations are already research stations under Adet Agricultural Research Center of Amhara Regional Agricultural Research Institute (ARARI), Ethiopia. Koga station is just a newly constructed research station with traditional irrigation system during the commencement of this research work**.** The land at both locations was secured freely from the Amhara Regional Agricultural Research Institute (ARARI) with permission of the Amhara National Regional State.

Figure 4.3: Map of Amhara National Regional State (Ethiopia) where the study was conducted

Location-1 (Koga): This location was found to be appropriate to compare irrigation and rain fed cultivation because of its irrigation facility. The station is constructed in the command area of Koga Irrigation and Watershed Management project. Koga Irrigation and Watershed Management project site is an agriculturally potential area within the Blue Nile Basin and the Lake Tana watershed. This project was supported by the African Development Bank and the Ethiopian government. It has a 7000 hectare command area intended for cultivation of different crops. The catchment area, defined by its hydrological boundaries, is located at $11^0$10' N to 11^o25' N latitude and 37^o 02' E to 37^o 17' E longitude and ranges from 1800 to 3200 meters above sea level and has a mean annual rainfall of 1560 mm and a mean daily temperature between 16 and 20^oC. The dominant soil type in the watershed is nitisol which is the most productive soils to produce many common crops including Nigerseed *(Guizotia abyssinica* Cass***)*** (Alemie, 2009).

Location 2 (Adet): Adet (Figure 4.4.) is an additional location for comparison against Location 1 (Koga). Data on fatty acid and vitamin E profile was taken only from this location. This location is found at the head quarter office of Adet Research Center. It is one of the famous research centers in Ethiopia established in March 1986 and about 445 km form Addis Ababa and 47 km from Bahir Dar. It is located at 11º17'N and 37º43'E. Temperature (^{0}C) Max: 25.74 and Min: 9.27 (Figure 4.6). Rainfall (mm): Max. 1770.5 Min: 860.2 (Figure 4.5). Agro-ecology: Tepid moist cool mountains and plateau. The major soil type in this location is Nitosol and Cambisol (Ethiopian Institute of Agricultural Research, 2008).

Figure 4.4: Research locations in reference to Bahir Dar City, Lake Tana, and River Nile.

4.1.3. Climate of the locations of the Study

Meteorological data of the two locations shows similar rainfall and temperature pattern (Figures 4.5-4.7) and therefore factors such as soil fertility and precursor crops may play the major role for the difference rather than temperature and rainfall.

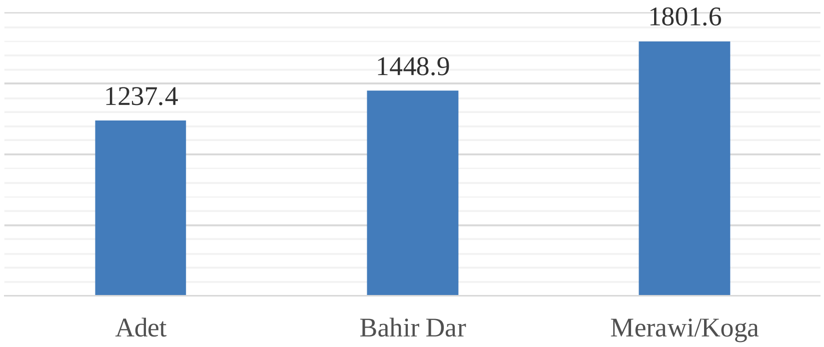


Figure 4.5: Annual rain fall of the two experimental stations and Bahir Dar city (Yassin, 2009).

The annual rainfall of both locations was above the range recommended by Weyesa *et al.*, 2011 (Figure 4.5).

In Koga station the main rainfall is concentrate between May and October (Figure 4.6). This rainfall has following effect on the cultivation of nigerseed:

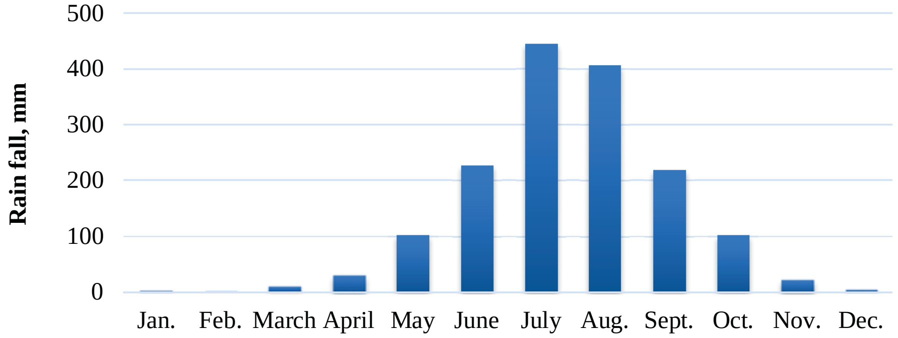


Figure 4.6: Monthly rainfall of Koga station Source: (Yassin, 2009)

Generally when rain fall is not enough for other crops nigerseed shows relatively better performance when rainfall is prolonged it will result in shattering of the seed and the seed starts to germinate while on the plant which could be reason for decrease of yield. Therefore increased rain fall is less likely to be contributing factor for yield.

The monthly temperature, maximum and minimum in Adet and Koga (Figure 4.7) is more or less balanced. The cultivation of nigerseed can be affected by the temperature level. It is generally known that nigerseed crop is classified as highland crop though it can perform to ranges of lowland. As these two locations are generally in the same range of highland and more or less similar temperature pattern the other contributing factor may be the soil nature and fertility or even precursor crops.

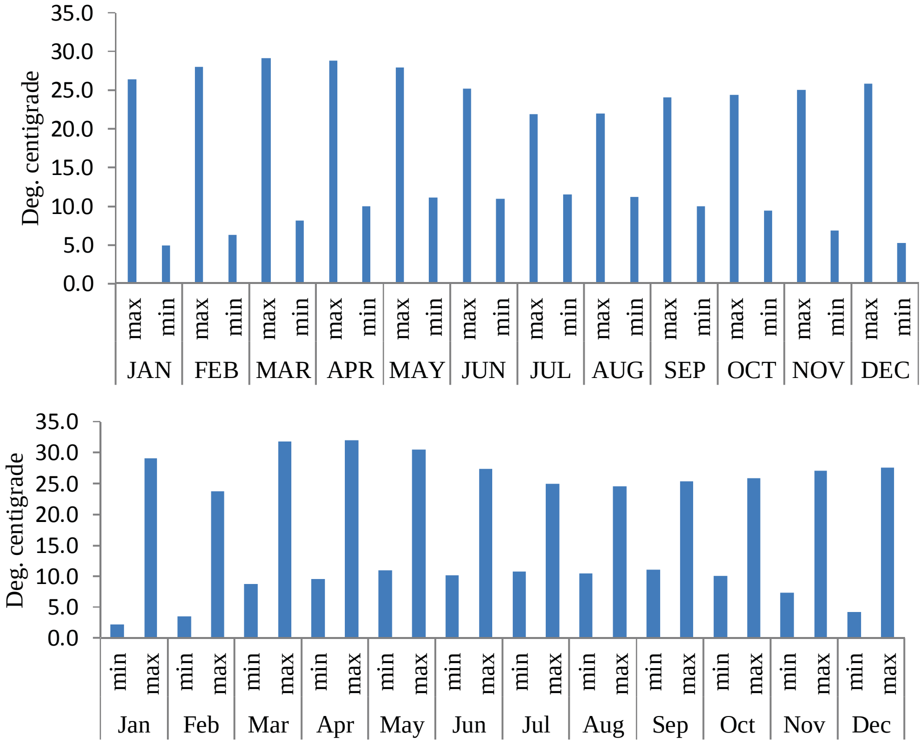


Figure 4.7. Monthly temperature pattern Adet (top) and Koga (bottom)

4.1.4. Levels of the Treatment Variables

The Seed Varieties and Seed Rates: Since the inherent potential for improved seed and/oil yield is from the plant itself the seed variety was the first factor of choice for this experiment. The Ethiopian nigerseed approved varieties are available only at the research centers mainly Holeta Agricultural Research Center which is specialized on highland oil crops. Among agricultural research centers in Ethiopia, Holeta is known to be the only center where the varieties are available at their purity. The varieties of nigerseed (*Guizotia abbysinica* Cass.), Fogera and Kuyu used for this study were provided by Holeta Agricultural Research Center near Addis Ababa.

For both seasons of cultivation the varieties were obtained from this center because after every cultivation and harvest the purity of the varieties is always in question due to non-self-pollinating nature of nigerseed plant. The two varieties were selected among the then released four varieties (EARO, 2004). Additionally, these two varieties had been recommended for these areas based on their previous performances (Alem, 2011). The variety selection was also based on discussion and recommendation from experts before the research work is started. The seed rates were each at three levels at low, medium, and high i.e. 5, 10, and 15 kg ha^{-1} respectively. The seeds were manually cleaned and made free from chaffs and other unwanted seed or foreign matters. The seeds at the planned rates for sowing were carefully weighed using analytical balance with precision of 0.0001g, packed and labeled. Similar preparations were made for the three field experiments (Koga irrigated, Koga rain fed, and Adet rain fed) during the respective sowing times.

The Fertilizer Type and Rate: The two types of fertilizers commonly used in Ethiopia, the nitrogen based fertilizer called urea and the phosphate based fertilizer called DAP (Diammonium Phosphate) (NPK/18-46-0) were used for this experiment. While the phosphate fertilizer (P_2O_5) was applied at 23 kg ha^{-1} for all plots and experiments alike, the nitrogen fertilizer (urea) (NPK/46-0-0) was applied at three levels of low, medium and high which are respectively 13, 23, 33 kg ha^{-1}. After calculating the equivalent of total nitrogen and P_2O_5 from each type, the fertilizers were weighed using analytical balance with precision of 0.0001g, labeled and packed. Similar preparations were made for the three cultivations (Koga irrigated, Koga rain fed, and Adet rain fed) during the respective sowing times.

Experimental Plot Design and Land Preparation: The land was already cleared, ploughed and prepared by the research center ready for experiment. Initially, a more uniform piece of land was selected from the prepared land and well ploughed so that the soil mixes well and uniformity is attained.

The experimental plot design was prepared which is the 54 plots according to the experimental design for the two varieties, three levels of seed rates, and three levels of nitrogen fertilizer rates in triplicate which becomes 2x3x3x3 = 54 (Figure 4.8). The 18 plots for the single experimental run were folded as hair pin turn to make the plots compact and maintain uniformity as 2x9 plots.

The measurement was made according to the experimental plot design prepared and further divided into three hair pin turn blocks (triplicate) with 18 plots each. Plot size was 1.8mx3m i.e. 5.4m^2. Six rows were prepared per plot and the spacing between rows was 0.3m. Spacing both between plots and between blocks was 1m. Spacing between replicates was 1.5 m. Additionally for the irrigation cultivation traditional canal for irrigation water was well prepared in such a way that controlled and more uniform water supply/irrigation can be supplied every third day using manual diversion. The plots were numbered 1-18 in a standard order and 19 to 54 in a completely randomized block and were well watered before sowing.

Preparing and Sowing of the Seed and the Fertilizers: The seeds prepared for the three levels (5, 10, and 15 kg ha^{-1}) and the nitrogen fertilizer prepared for the three levels (13, 23, and 33 kg ha^{-1}) were sown according to the treatment plan on the 54 plots by drilling on the six rows per plot. The Diammonium Phosphate (DAP) fertilized has 46% phosphate and 18% nitrogen and the urea fertilizer has 46% nitrogen. For one and uniform level of phosphate as well as different levels of nitrogen fertilizer the amount to be applied to each plot was calculated out. The irrigation cultivation was sown on 14th of January 2011 and the rain fed cultivation was sown 2nd of July 2011. For the low level, both the seeds and the nitrogen fertilizers were mixed with approximately equal amount of fine soil to increase bulk and sow uniformly on the six rows prepared for the treatments. The phosphate fertilizer which is uniform for all the treatments (23 kg ha^{-1}) was uniformly sown for all treatments. After sowing, the drills were dressed thinly with soil to protect the seeds from birds. For the irrigation experiment, water was supplied by releasing the water from the canal carefully every third day as much uniformly as possible (Figure 4.9). One hand weeding was done immediately after four weeks for both irrigation and rain fed.

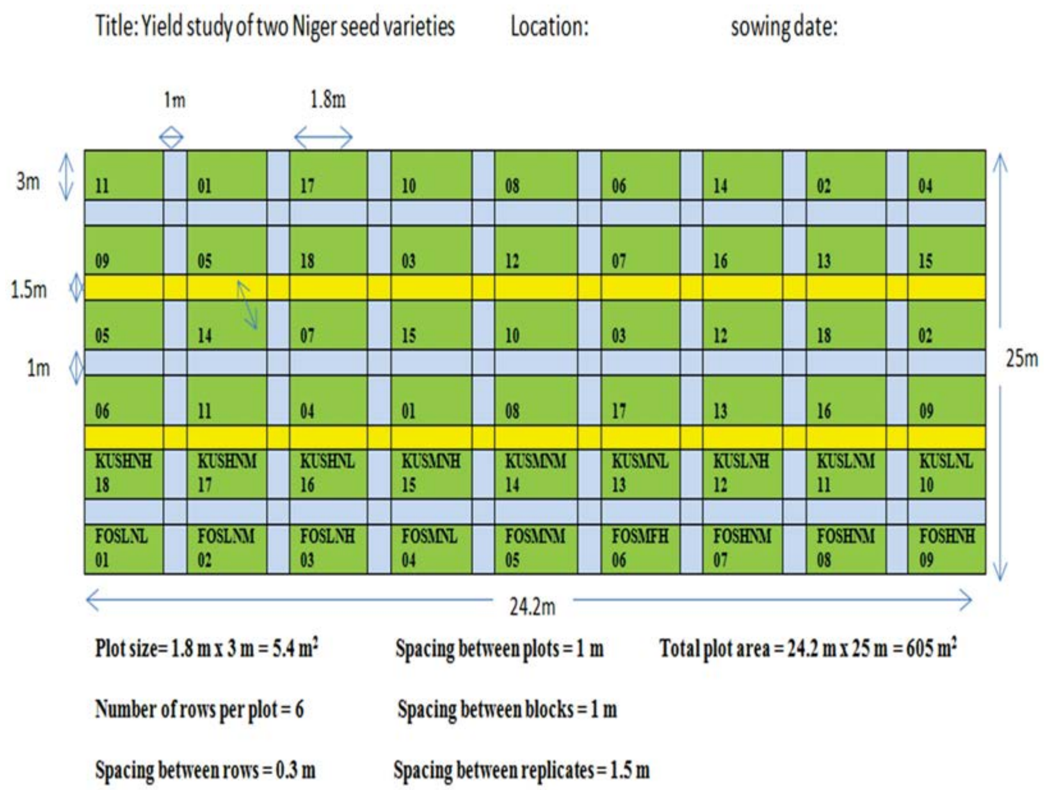


Figure 4.8: Plot design (FO, Fogera; Ku, Kuyu; SL, low seed level; SM, medium seed level; SH, high seed level; NL, low fertilizer nitrogen; NM, medium fertilizer nitrogen; NH, high fertilizer nitrogen).

4.1.5. Collection of Field Experimental Data

a. Phenotypic Data

In this study fundamental phenotypic data on nigerseed (*Guizotia abbysinica* Cass) were taken from the field experiment at Koga location by irrigation to compare the relationship between the treatments, the phenotypic characters and other responses. Plant height (centimeters), number of primary branches per plant, number of heads per branch, number of heads per plant, days for flowering (50%flowering), and days for maturity (50% petals fall) were phenotypic characters for which data was taken.

Harvesting: The seed was harvested after 140 days for all experiments. Only four of the six rows sown per plot were harvested for analysis leaving two rows, one row on each side as border effect. The plant was cut manually using sickle in the same way as local farmer harvest. All the 54 plots were harvested in separate bags and sun dried for ten days after which it was carefully threshed by hand after which it was cleaned and taken to laboratory in tagged bags (Figure 4.10). The label includes the plots, the treatments and the replications.

Figure 4.9: Plots Prepared with rows and traditional water canal (plants emerging)

Figure 4.10: Harvested seeds in tagged bags ready for laboratory analysis

Nigerseed is actually called fruit botanically together with small wing at its tip and has characteristic color and shape (Figure 4.11).

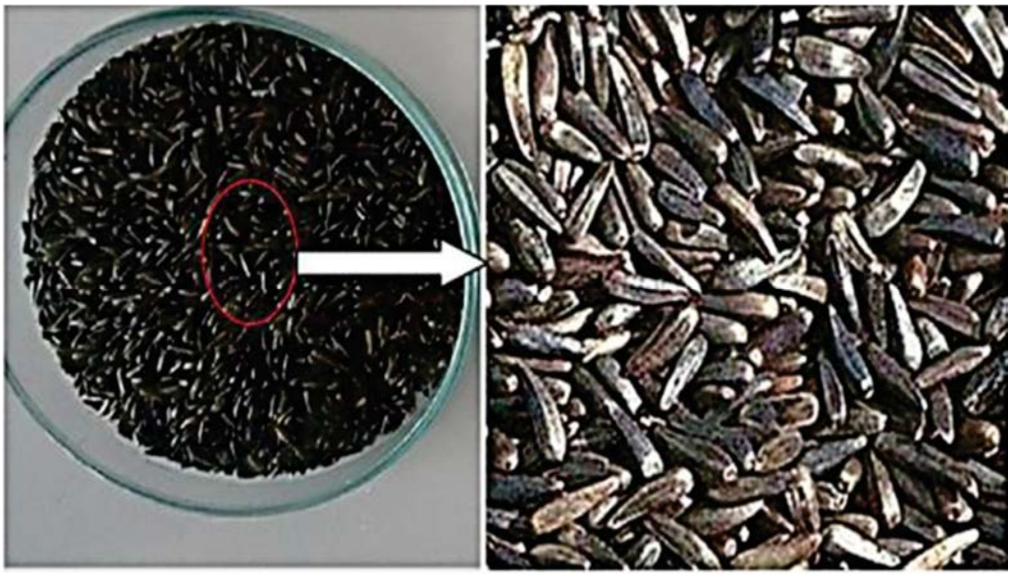


Figure 4.11: Nigerseed (black, small, angular, and elongated/tapered)

The seed was kept in the laboratory for four weeks before proceeding for analysis. Before any other laboratory analysis was conducted for seed yield (kg ha^{-1}), moisture content (%) (Dry basis), thousand seed mass (tsm) (gram), and total ash content (%). Oil content determination was done for all the three cultivations for comparison i.e. Adet (rain fed), Koga (rain fed), and Koga (irrigation). Fatty acid and vitamin E determination was done for the Adet experimental station (rain fed) only.

b. Determination of Moisture Content

Moisture content was determined according to the Ethiopian Standard (Agricultural Products (ES) 69:2001, 2001-06-27) (QSAE, 2001). The seed moisture determination was done for all samples from all plots by drying at a temperature of 103ºC in a temperature controlled oven at atmospheric pressure until the change in successive mass is constant. The drying sample is frequently taken out to desiccator with silica gel to cool before weighing. In this experiment the determination is done for the whole seed and not by grinding the sample (which is modification to the referred standard). Since the seed is small sized, size reduction is considered to be unnecessary. The result had been expressed as percentage by mass.

$$\boldsymbol{M} = \frac{(\mathbf{m1-m2})}{(\mathbf{m1-mo})} * \mathbf{100} \qquad (6)$$

Where M is moisture and volatile matter

m_1 is the mass, in grams, of the petri dish and the test portion before drying

m_2 is the mass, in grams, of the petri dish and the test portion after drying

m_o is the mass, in grams, of the petri dish

c. Determination of Total Ash Content

Determination of total ash was done according to Ethiopian Standard (modified), (Agricultural Products (ES) 72:2001 2001-06-27) (QSAE, 2001). According to this standard total ash refers to the residue obtained after incineration at 550±15ºC in an electrically heated muffle furnace until the change in mass is nil. In this experiment, however, the intact seed was incinerated overnight instead of milling which is a modification to the referred standard. Milling was found unnecessary due to small size of the seed. The result of every analysis was expressed as percent by mass and data was taken in triplicate.

$$Total\ ash = \frac{((m2-m0)}{(m1-mo)} * 100 \qquad (7)$$

Where m_2 is the mass, in grams, of the ash and the dish; m_1 is the mass, in grams, of the dish and the sample; m_o is the mass, in grams, of the dish

d. Determination of Oil Content

The oil content was determined according to (Agricultural Products (ES) ISO 659:2005, 2005-03-12) (QSAE, 2005). This Ethiopian Standard is identical with ISO 659:1998 and hence ES ISO.

For the determination of oil content, 30 g cleaned seed samples were prepared to represent each plot and carefully ground using coffee grinder with repeated shaking and grinding to make it as uniform size as possible and good size reduction without clumping or forming paste. Grinding was done by frequent interruption to minimize heating of the sample. The flour was passed through a 1 mm aperture sieve to ensure uniformity of particle size to determine the frequency of grinding by the grinder as a pre-run. The flour was then extracted with hexane (analytical grade) using soxhlet extractor and the hexane was recovered by distillation and using chiller. The last trace of solvent was dried by at 103°C for 60 minutes at atmospheric pressure (Figure 4.12). The extracted oil was weighed using analytical balance of precision of 0.0001. Finally, the oil content was determined by oil/seed (m/m %). The mean of the triplicate was taken as an oil content of the samples.

The oil content was calculated on dry basis.

$$Oil\ content\ (\%) = \frac{m1}{m2-(m2*w)} * 100 \qquad (8)$$

Where:
-m_1 is mass of dried extracted substance in gram
-m_2 is mass of test portion in gram
-w is per cent of moisture

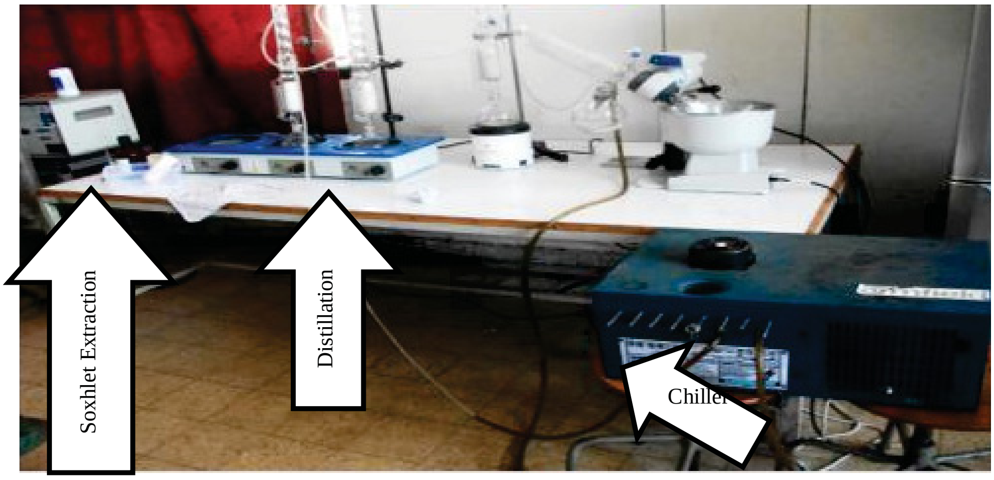


Figure 4.12: Soxhlet Extraction system and distillation with chiller.

e. Oil Sample Preparation (for fatty acid and vitamin E determination)

The seeds from the experimental plots of Adet location were cleaned and pressed (without any raw material pretreatment). The pressed oil was then allowed to settle for 96 hours after which it was carefully decanted and filled into cleaned, dried and labeled vials for determination of fatty acid and α-tocopherol contents (Figure 4.13). The samples were kept in refrigerator (4-5^{o}C) until it is packed for analysis. The samples were then analyzed at food chemistry laboratory of Beuth University of Applied Sciences, Berlin, Germany for fatty acid and vitamin E profiles.

f. Determination of the fatty acid profile

The fatty acid composition was determined by gas chromatography (GC) analysis on a capillary column after methylation according to the official method (AOAC Official Method 969.33). Analysis of fatty acid methyl esters (FAMEs) was performed on an Agilent 5890 Series gas chromatograph (Agilent) equipped with a flame ionization detector (FID) and a split-splitless injector (15:1) and fitted with a 100 m × 0.25 mm internal diameter (i.d.) (0.20 µm film thickness) SP-2560 fused silica capillary column (*Supelco* Inc., Bellefonte, PA, USA). The temperature program was 50°C for 2 min and then 4°C/min up to 240°C, held at 240°C for 10 min. Injector and FID temperatures were set at 260°C and 280°C respectively. The carrier gas was Helium at a flow rate of 4.4 ml min^{-1}.

g. Determination of alpha-tocopherol Content

Tocopherol were detected after normal-phase high-performance liquid chromatography (HPLC) separation after direct injection of the oil on an Agilent 1050 Series chromatograph (Agilent) equipped with a 250 mm x 4 mm i.d. (5 µm particle size) LiChrosphere 60 SE silica column (Knauer, Berlin, Germany). An Agilent Series 1050 fluorescence detector (Agilent) was used, setting 295 nm as the excitation and 330 nm as the emission wavelength. Elution was conducted using hexane / methyl tert-butyl ether (96/4 v/v) as the mobile phase at a flow rate of 2 ml/min; the column was thermostated at 30 °C.

Agilent ChemStation software was used for calculating peak areas and standard tocopherol samples (Sigma-Aldrich) have been eluted to identify the individual peaks: the total tocopherol content was quantitated as the sum of all the individual peaks identified.

Figure 4.13: Oil expressed, settled and decanted to vials from the respective experimental field plot and packed (ready for laboratory examination).

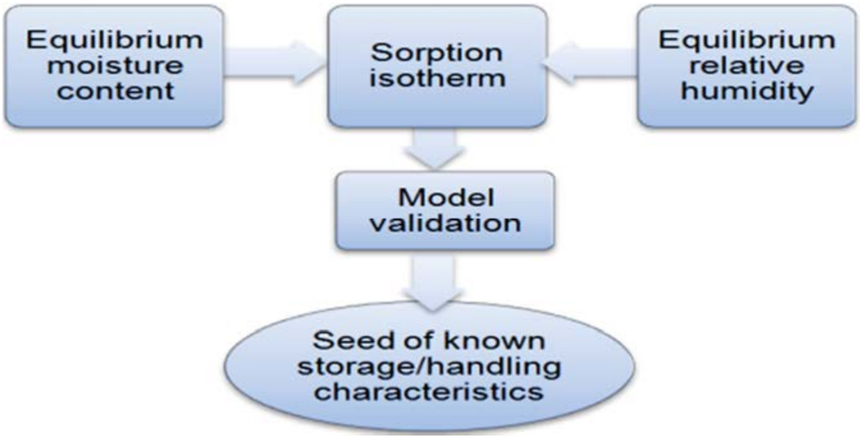


Figure 4.14: Major elements of Nigerseed storage characterization.

Data generated from the field and laboratory experiment were analyzed using statgraphics software version 16.0. For the phenotypic responses, seed yield, oil content, fatty acid and vitamin E to show the significance of differences between various treatments for the responses at 95.0% confidence level. Multifactor ANOVA was applied to show the effect of each variable and combinations at the various levels and multiple stage comparison were made to show which mean is significantly different from which other. To test the hypothesis on improvements of seed yield and oil content, hypothesis test had been applied based on the previously known values as mean null hypothesis against the alternative hypothesis greater than this mean null hypothesis value. This hypothesis test was done at different stages to see the contribution of each factor. Fisher's least significant difference (LSD) procedure is used to discriminate among the means. Multivariable analysis was also done to see the correlation between the variables. Row wise statistical analysis was also performed to compare plots with the same agronomic treatments but different cultivation conditions (locations and water supply/irrigation). The statistical significance is p-value > 0.05 unless otherwise stated and confidence limit is 95%.

4.2. Storage Characterization for Nigerseed

Characterization was made on physical parameters important for seed storage. The characterizations that had been done for major elements equilibrium moisture content and equilibrium relative humidity relationship at known temperatures after which the data were taken for model validation and estimation of parameters for monolayer (Figure 4.14). The equilibrium moisture content at the selected temperature and equilibrium relative humidity was determined in triplicates for varieties, Fogera and Kuyu, two temperatures and seven equilibrium relative humidity. Curve of the equilibrium moisture content (emc) versus equilibrium relative humidity (erh) at the two selected temperatures was developed. Fitness of selected monolayer models was also evaluated.

4.2.1. Experimental design and Procedure

The experiment of adsorption isotherm characterization was designed as full factorial. The seed variety, temperature, and equilibrium relative humidity are the experimental/treatment variables. The two varieties of nigerseed (Fogera and Kuyu) were obtained from Holeta Agricultural Research Center (Ethiopia). The fresh seeds were left in the laboratory to dry under ambient temperature to the lower possible moisture content (equilibrate). The moisture content of 4% was finally attained and taken for determination of adsorption isotherms of both varieties.

Two temperatures, 20 and 40ºC and seven equilibrium relative humidities (20, 30, 40, 50, 60, 70, and 80%) were selected. Anaerobic chamber with screw clamp to be tightened against rubber gasket lid was used as relative humidity chamber (Figure 4.15). Salt solutions were prepared for the seven relative humidity at both temperatures. Lithium Chloride was used for salt solutions of the seven relative humidity at 20ºC. Concentrated lithium chloride solutions were prepared and left overnight to equilibrate in the sealed chamber at 20ºC. Various salts were used for preparation of the seven relative humidity at 40ºC (Table 4.2).

Table 4.2. Saturated salt solutions of lithium chloride (LiCl) for 20ºC (Gold and Hay, 2008) and different salt solutions for 40ºC (Raji and Ojediran, 2011 and Padfield, 2013).

Weight of LiCl (g/200ml)	RH (%) at 20C	Salts	RH (%) at 40ºC
128	20	Potassium acetate	20.8
104	30	Magnesium chloride	32.0
88	40	Potassium carbonate	43.3
74	50	Manganese chloride	51.0
60	60	Sodium nitrite	61.4
50	70	Sodium nitrate	71.0
34	80	Ammonium sulfate	79.9

The seeds were prepared in about 10 g lots in triplicate and then uniformly spread on petri dishes. The petri dishes with weighed samples were then stacked in petri dish holder using spacer between each so that flow of air will not be blocked. The petri dish holders were then placed in the prepared humidity chambers with appropriate salt solution in a beaker to create the desired equilibrium relative humidity.

All the seven chambers each containing the samples in triplicate were incubated in big controlled atmosphere cabinet maintained at 20ºC for the first set of adsorption isotherm experiment and at 40ºC for the second set of adsorption isotherm experiment. The mass of the petri dish with seed is recorded every ca. 48 to 72 h using digital balance with precision of 0.0001g taking it out of the chamber with utmost care. The mass was taken until the mass of a given sample is about within ±0.001g range between two successive readings. The moisture content at this point is taken to be equilibrium moisture content (emc). The weight is carefully taken by immediately capping the sample as soon as it is taken out of the chamber before weighing and the chamber is also closed immediately after withdrawing the petri dishes to minimize the effect of the atmosphere outside the chamber. The moisture content of the initial and final stage was determined using oven drying method (105 ºC for 24 h). Adsorption isotherm data at 20 and 40ºC were obtained and the result was tabulated taking the average of the triplicates.

Figure 4.15. The equilibrium relative humidity chamber with screw clump rubber seal (the salt solutions in beaker and the two varieties of nigerseed in triplicate inside the chamber).

4.2.2. Model Evaluation/Comparison

After the adsorption isotherm data had been obtained, model fitting/ evaluation was done against selected models which are most advocated for food materials. Accordingly the models selected for this study were Guggenheim-Andersen-de Boer (GAB), Brunauer-Emmet-Teller (BET), and modified Chung & Pfost).

4.2.3. Data Analysis

Nonlinear regression analysis was done by SPSS software version 16.0. Evaluation was made on the outcome of model fitting analysis based on the coefficient of determination, ranges of monolayer capacity, and parameter estimate. The outcome of analysis for the three models was tabulated for comparison of the models' potential to fit the data of adsorption isotherm from the two varieties of nigerseed. Similarities and differences between the two varieties were also compared based on the outcome of the analysis. After the isotherm data, the respective equations of each model and initial values of the parameters were entered into the non-linear regression. The data is analyzed to generate the parameter estimates as well as how much the three models explain the generated data.

4.3. Screw Press Oil Expression

Virgin oil was expressed from clean and fresh seed of good quality using small screw press. The cleaned seed was conditioned at various preset temperatures and times. Next the expeller machine was set according to the experimental plan on efficiency of oil expression. These were feed rate and selected nozzle diameter (Figure 4.16). The feed rates were determined based on pre-run experimentation by varying the rotational speed. After expression, the oil was settled for 72 hours and decanted for hydratable degumming. Degumming was done at 70ºC with 2% of water for 15 minutes.

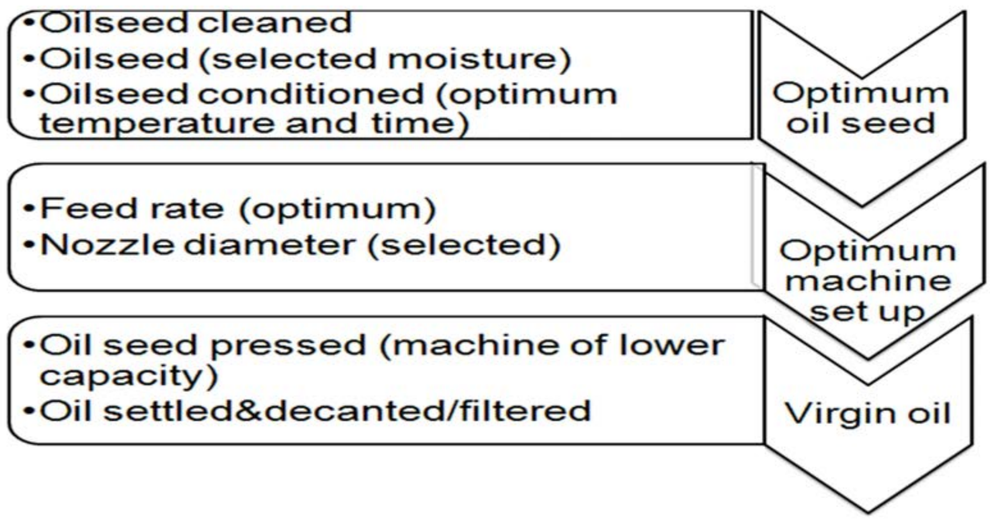


Figure 4.16: Major steps of evaluation for virgin oil production by small scale oil mills

4.3.1. Experimental Design and procedures for Oil Pressing

Full factorial experimental design with three levels of conditioning temperature, three levels of conditioning time, and two levels of feed rate in triplicate was used for this experiment. The experimental run order was not randomized because of the difficulty to randomize each and every experimental seed sample and complication that may result from frequent set up of the machine. As a result split plot type design was used.

4.3.2. Conditioning of the Seed

Unlike other experiments in this study, this experiment was not conducted using approved variety seeds instead freshly harvested local variety seed was purchased from Adet Agricultural Research Center (Ethiopia). The seeds were thoroughly cleaned manually to remove dusts, chaffs, broken seeds, and other foreign materials. The oil and moisture contents were determined immediately before the experiment proceeds.

The seed with its natural moisture content of 4% dry basis. was used as such for the experiment. Seed oil content was also 36.5% dry basis. The weighed seeds were conditioned in kilning jars with rubber seal and tightened screw cap to avoid moisture escape and pickup during conditioning (Figure 4.19). The heating was done in a time-temperature programmed water bath with precision of 0.5ºC.

4.3.3. The Oil Expeller Machine

Small expeller machine with capacity of 3 to 5 kg hr^{-1} manufactured by IBG Monforts Oekotec GmbH & Co.KG, Germany was used for the experiment (Fig. 4.17).

The machine has heating ring which can be fitted to or adjacent to the barrel/cylinder mainly for initial heating up or during blockage. The problem with the heating ring is that the heat it provides is unregulated and may even burn the seed unless due care is taken. In the absence of such a heating ring some sort of pre-run is necessary until the machine attains its steady state temperature and steady state oil expression.

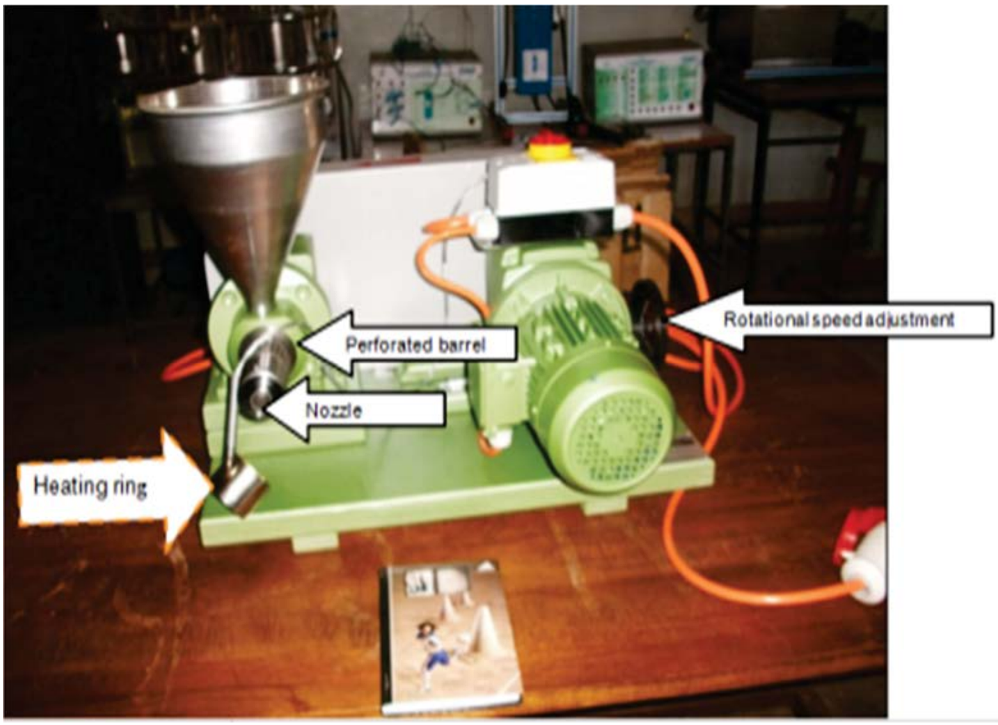


Figure 4.17: Oil press machine which is used for the experiment

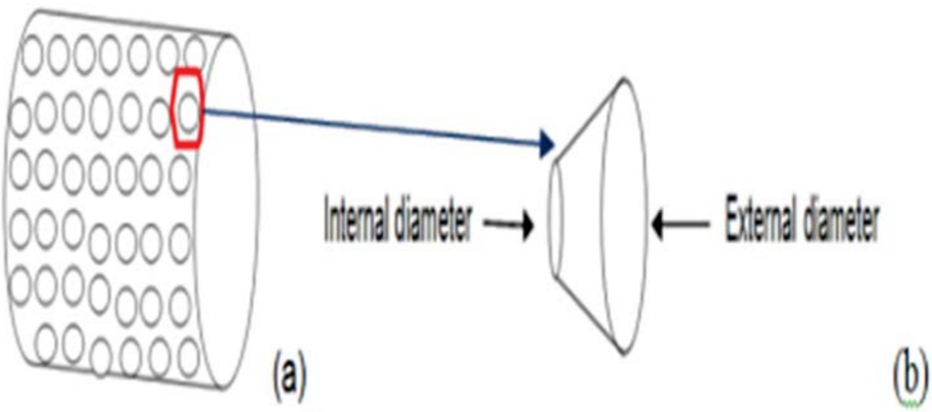


Figure 4.18: Perforated Barrel (a) and geometry of the perforation (cut cone) (b).

The cylinder wall of this machine is perforated type (hole-cylinder type) where the internal diameter of the holes is very small as compared to its external diameter. Therefore these holes have the geometry of cut cones which facilitates oil expression as well as filtration (Figure 4.18).

In addition to expression of the oil, the barrel wall is used for filtration of the oil during expression. The machine is provided with nozzles of varying diameters (4, 6, 8, and 10 mm) which can be fitted depending on the pressure desired for expression of oil. The diameter of nozzle to be used for an efficient oil expression depends on the raw material type, feed rate/screw speed. In this experiment, however, a nozzle of six millimeter diameter was selected and set as constant throughout based on pre-run and experience for the nigerseed.

Before expression of the oil was started, the machine was set at the right feed rate which was determined by switching the machine rotational speed which in this experiment was selected to be 3 and 4.25 kg h^{-1}. The machine was preheated to a temperature of 70ºC which is equal to the steady state temperature produced by friction from repeated experimentation with nigerseed. Since the machine does not have temperature reading, optical pyrometer was used to observe the temperature profile across the barrel during initial preheating and pressing process. The selected nozzle of 6 mm diameter was fitted. Finally, it was run using 200 gram of seed mass for pre-run before the experimental sample was fed to the hopper. After the steady state run is attained by the pre-run sample, the experimental samples were fed into the hopper. The samples were fed to the hoper with care and then continuous monitoring and follow up was made to prevent blockage and ensure continuous flow according to the feed rate set for each experimental run. The oil samples expressed from each experimental runs were collected and allowed to settle for about 48 hours after which it was carefully decanted and weighed. *Determination of Oil Expression Efficiency* The efficiency of oil expression is defined as the percentage of the ratio of the percent of oil expressed to the percent of oil naturally available in the seed sample. Since the percentage of oil in the seed sample is already known, given the percentage of oil expressed from the experiment, the efficiency of the expression was calculated from carefully weighed seed sample and expressed oil (Figure 4.19 and 4.20).

Figure 4.19: The clean seed is weighed and transferred to the kilning/conditioning bottle for heat treatment (conditioning)

Figure 4.20: The oil expressed from the conditioned seed is settled, decanted and weighed to determine the efficiency of expression.

$$\text{Efficiency (\%)} = \left(\frac{\text{\% of oil expressed}}{\text{\% of oil in the seed}}\right) \text{x } 100 \qquad (9)$$

For evaluation of the expressed oil, quality reference was made to the Ethiopian Standard, Food Products ES 50:2001, 27/06/2001. The acid values and the peroxide values were determined for every experimental run as quality indicators according to the Ethiopian Standards, Agricultural products ES 26:2001, 27/06/2001 and Food Products ES ISO 3960:2001, 27/06/2001 respectively. Acid value refers to the number of milligrams of potassium hydroxide necessary to neutralize the free fatty acid in 1 g of a given oil sample. After the neutralization was made using the appropriate solution, the result was calculated based on the volume used for neutralization, and mass of the sample used for the analysis as follows.

$$\text{Acid value} = \frac{(V*N*56.1)}{m} \qquad (10)$$

Where -V, the volume in milliliters of N, normality of ethanolic potassium hydroxide solution (0.1); the number 56.1, molecular weight of Potassium Hydroxide; m, mass, in grams of the test portion.

The arithmetic mean of two determinations was taken as a test result. Peroxide value refers to those substances in the sample, expressed in terms of active oxygen, which oxidize potassium iodide under the conditions specified in a given standard, divided by the mass of the test portion. Peroxide value was expressed in miliequivalent per kilogram. Then the results of both the expression efficiency and the quality indicators (acid value and peroxide value) were tabulated.

4.3.4. **Data Analysis**

Statistical analysis was done using statgraphics version XVI software. Multifactor ANOVA to show interaction of the factors, one way ANOVA to show the effect of each factor are mainly used. General linear model was analyzed mainly to show the contour plot for extrapolation and 95% significance level was considered throughout.

5. Results and Discussion

5.1. Field Experiment

Phenotypic responses, seed yield, seed oil content, oil fatty acid and vitamin E profile, and seed ash content were the data taken from the field experiment. Some of these responses were taken from both experimental locations one of which (Koga location) has two water supply modes (rain fed and irrigation) and the other one (Adet location) has one water supply mode (rain fed) (Table 4.1).

5.1.1. Phenotypic Response

From the field experiment the phenotypic responses of the two selected nigerseed varieties (Fogera and Kuyu) were measured in addition to other responses. This phenotypic data was taken only from Koga location with irrigation cultivation. Except number heads per plant the phenotypic variation due to the treatments at various levels was found to be non-significant for both varieties (Figure 5.1). Number of heads per plant would be of meaningful importance if and only if it has significant contribution to seed yield. It can be seen that the significant difference in number of heads per plan appears to be cumulative of slight and non-significant difference in number of branches per plant and number of heads per branches which made Fogera variety significantly higher number of heads per plant. It is also clearly seen that flowering day, maturity period as well as thousand seed mass for the two varieties is almost same.

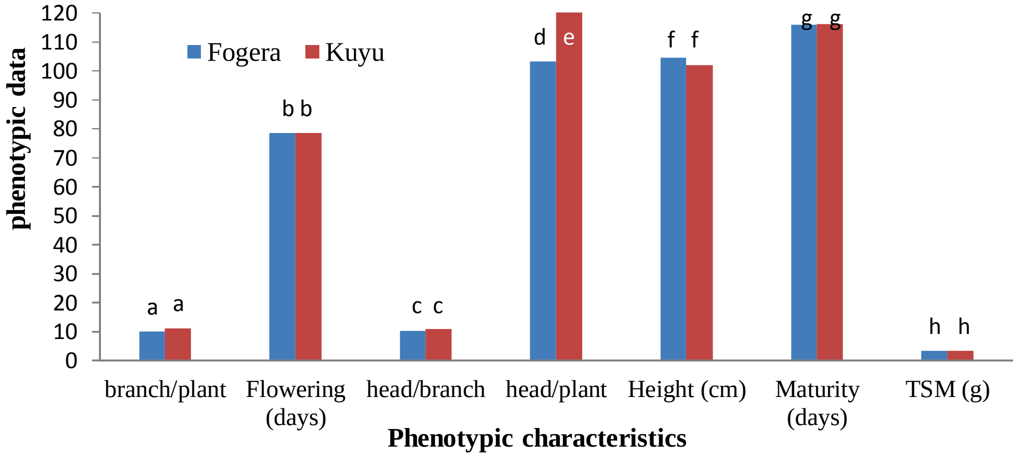


Figure 5.1: Mean values of various phenotypic characteristics of Fogera and Kuyu varieties during cultivation (Tukey test, P<0.05)

Analysis of the phenotypic response correlation among each other and with treatment variables (seed rate and nitrogen fertilizer rate) shows different results for the two varieties (Table 5.1.).

Table 5.1: Correlation between of some phenotypic responses to seed rate and nitrogen rate.

Factor	Variety	Seed Rate	N rate	Branch/ plant	Flower days	Head/ branch	Heads/ plant	Height	Maturity days
Branch / plant	F	-.476	-.680*						
	K	.725*	.104						
Flower Days	F	-.674*	-.622	.783*					
	K	-.357	-.713*	-.288					
Head/ branch	F	-.598	-.276	.676*	.591				
	K	.144	.289	.239	.074				
Head/ plant	F	-.531	-.478	.890**	.686*	.928**			
	K	.641	.356	.874**	-.338	.575			
Maturity Days	F	-.569	-.569	.581	.827**	.537	.575	.301	
	K	-.662	.000	-.686*	-.013	-.115	-.547	.218	
Seed Yield	F	.168	.361	-.175	-.455	.310	.150	-.602	-.452
	K	.045	.903**	.109	-.773*	.078	.340	-.335	-.046
tsm	F	.000	.818**	-.735*	-.441	-.336	-.557	-.305	-.280
	K	-.217	.217	.075	-.272	-.063	.072	.331	-.143

Pearson correlation * P>0.05 confidence level **P>0.01 confidence level (K-Kuyu; F-Fogera)

Seed rate showed positive correlation with number of branches per plant for Kuyu variety but did not show significant correlation for Fogera variety. On the other hand seed rate showed negative correlation with flowering day for Fogera variety but with no significant correlation with Kuyu variety. Nitrogen rate showed negative correlation with branches per plant for Fogera but no significant correlation for Kuyu. Nitrogen rate has positive correlation with thousand seed mass for Fogera variety whereas did not show significant correlation with that of Kuyu variety. Nitrogen rate showed positive significant correlation only with seed yield for Kuyu variety. Plant height, however, did not show significant correlation with both seed rate and nitrogen fertilizer rate for both varieties.

Branches per plant with heads per branch and heads per branch with heads per plant showed positive correlation for Fogera variety whereas no significant correlation for Kuyu variety. Similarly flowering day with branches per plant and flowering day with head per plant showed positive correlation for Fogera variety whereas without significant correlation for Kuyu variety. On the other hand head per plant with branch per plant showed positive correlation for both varieties. Thousand seed mass with branches per plant showed negative correlation with Fogera variety but with no significant correlation with Kuyu variety. The inverse relationship between the seed rate and number of heads per plant can be clearly seen as natural compensation but at low seed rate (5 kg ha^{-1}) there appears to be certain degree of departure from this trend. Even for the number of heads also the change from the medium (10 kg ha^{-1}) to high (15 kg ha^{-1}) is noticeable as compared to from low to medium for seed rate. Clustering pattern can also show the relationship among the phenotypic responses (Figure 5.2). As can be seen from the Dendrogram heads/branch and heads/plant have closer relation with branch/plant. Similarly maturity date

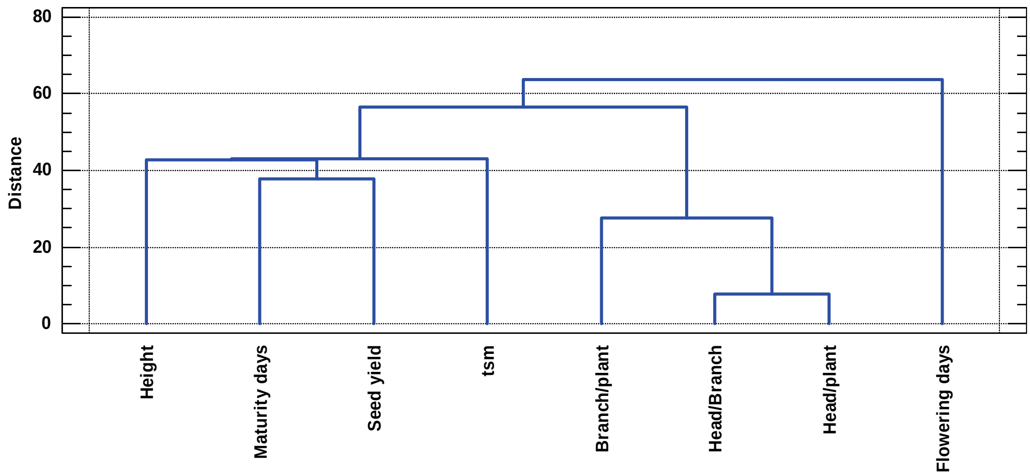


Figure 5.2: Dendrogram by group average method (Squared Euclidean) for clustering pattern of phenotypic responses of the Nigerseed.

In addition to these varieties, three other types of Ethiopian nigerseed were reported based on maturity. These are the early maturing nigerseed called ‘Bunign’, the late maturing nigerseed called ‘Abat’ and the frost resistant nigerseed called ‘Mesno’ (Getnet and Sharma, 1996; Alemaw and Wold, 1995). Unlike these types, however, significant distinctiveness of maturity was not observed between the varieties Fogera and Kuyu (Figure 5.2). In addition to other lack of similarities between the varieties this makes them under question of whether the two are really distinct varieties or not.

Since the role of full vegetative development on seed yield cannot be underestimated comparison of phenotypic responses with seed yield and with each other appear to be important. It is already reported that fertilizer in excess of 30 kg ha^{-1} will result in only luxurious growth rather than further improvement of seed yield of nigerseed. Also it is also reported that nigerseed compensates for the yield level through decreasing/increasing the number of heads for decreased/increased seed rate (Getnet and Sharma, 1996).

5.1.2. Seed Yield

After harvesting the seed from each plot in separate and tagged bags it was taken to laboratory for analysis. The seed was cleaned manually before the seed yield data was taken in kilogram of seed per hectare (kg ha^{-1}). The analysis of variance to show the effect of all factors at every level and their combination using the least square mean and other statistical results (Table 5.2) shows the nature of interaction between factors and the results of the field observation.

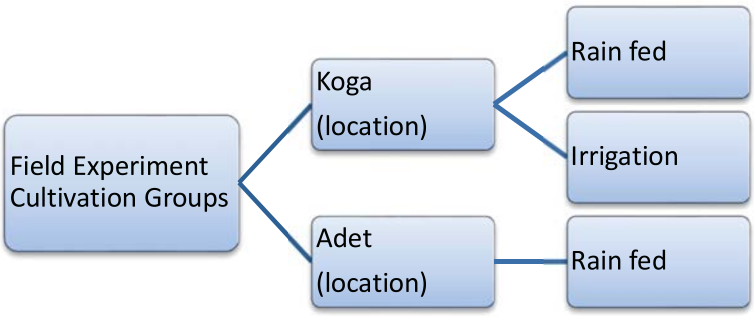


Figure 5.3: The three field experiment groups to be compared based on location and water supply mode.

Comparison of the three groups (Figure 5.3) formed by location and water supply mode for analysis of variance the overall contribution to variance of the main effects and their interactions in the three groups is shown based on p-value. These three groups are cultivated based on three seed rates in triplicate and three nitrogen fertilizer rates in triplicates. This is done for both varieties, Fogera and Kuyu. Therefore the total number of cultivated rows would be 54, 27 for each variety. The overall seed yield for each cultivated row shows high variability (Fig. 5.4) and need to be analyzed separately.

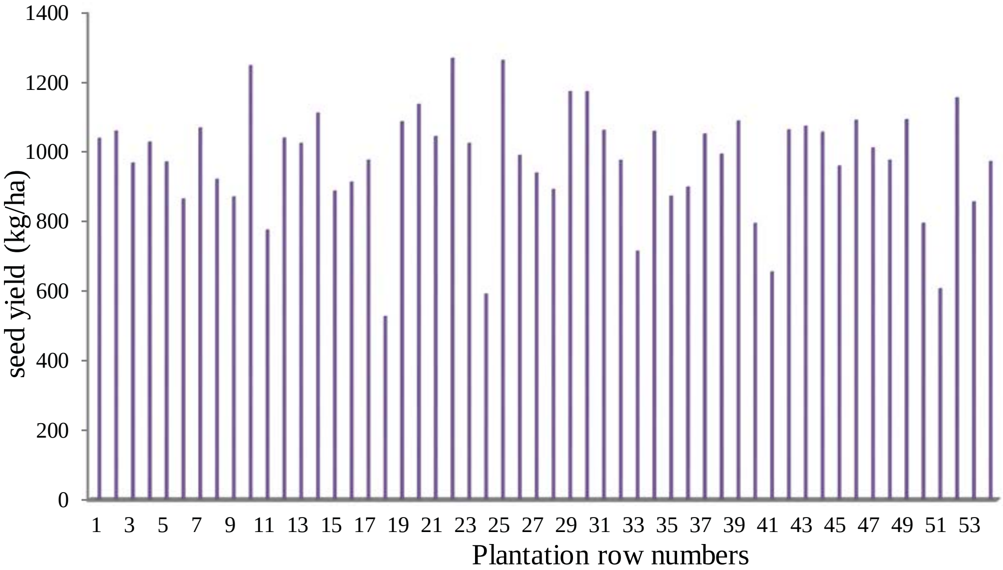


Figure 5.4: Mean per plot yield of two varieties (Fogera, rows 1-27 and Kuyu, rows 28-54) cultivated under different treatments

However ANOVA to compare between and within group variation after decomposing into within and between group shows that there is an overall significant difference between seed yields of the three categories of cultivation (Koga by Irrigation, Koga by Rain fed, and Adet by Rain fed) (Table 5.2). But there is no significant difference within group (seed rate, nitrogen rate, and variety) except nitrogen rate at Adet by rain.

The significance of seed rate and nitrogen rates on seed yield is clearly seen (Fig.5.5). In this regard the contrast between the high and low nitrogen rate for cultivation at Koga under irrigation and the contrast between high and low seed rate for cultivation at Adet under rain fed show the positive impact of nitrogen fertilizer and seed rate respectively at higher levels. Significant difference and contrast was lacking for seed rate at Koga irrigation and nitrogen rate for Adet rain fed and also no significant difference was observed for both seed and nitrogen rates at Koga rain fed cultivation (Appendix II).

Table 5.2 Influence of Seed rate, Nitrogen rate, Variety and their interaction on the Seed yield (kg ha^{-1}) at the two locations (Koga and Adet).

EFFECTS	Koga by irrigation	Koga by rain	Adet by rain
MAIN EFFECTS			
A:Seed rate	0.5970	0.1912	0.0662
B:Nitrogen rate	0.0470	0.1728	**0.9724**
C:Variety	0.1783	0.5926	0.0918
INTERACTIONS			
A x B	0.4586	**0.9889**	0.6219
A x C	0.3012	**0.8985**	0.7273
B x C	0.4183	0.6721	0.8807
A x B x C	0.9143	0.7466	0.3588

Significant difference between nitrogen rates of 13 and 33 Kg ha^{-1} at Koga by irrigation and seed rates 5 and 15 kg ha^{-1} for Adet location by rain fed is observed (Fig. 5.5).

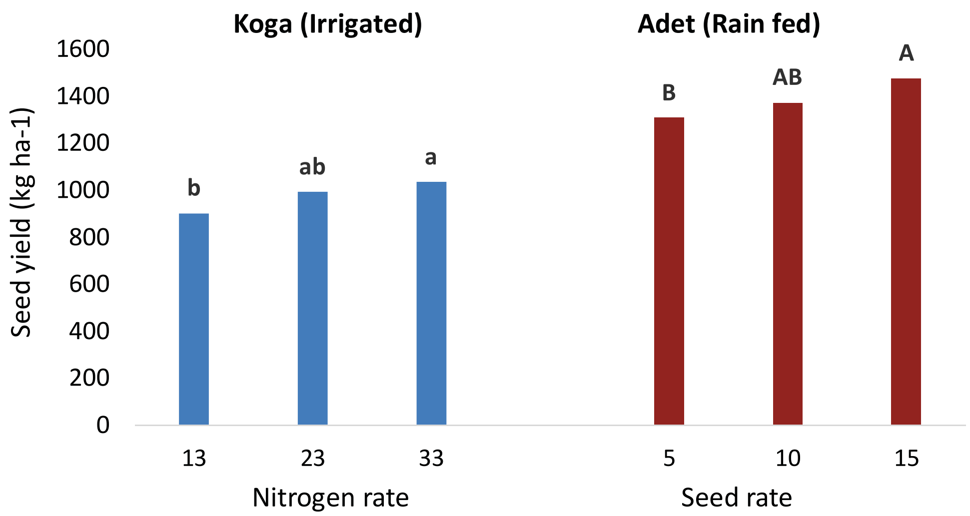


Figure 5.5: Influence of N-rate in Koga (irrigated) and of Seed rate in Adet (rain fed) on the Seed yield (Kg ha^{-1}). Different letters represent significant differences (Tukey test $P<0.05$).

It was also similarly possible to see that seed rate and nitrogen rate and also seed rate and variety have significant interaction at Koga by rain fed. Not only the three categories of cultivation differ from each other significantly but also all the three contrasts made from these groups show significant difference (Table 5.3).

Table 5.3: Multiple Range Tests to compare and contrast of the three categories of cultivation (based on location and rain)

Contrast	*Sig.*
Koga Irrigation - Koga Rain fed	*
Koga Irrigation - Adet Rain fed	*
Koga Rain fed - Adet Rain fed	*

* denotes a statistically significant difference (Tukey test P< 0.05).

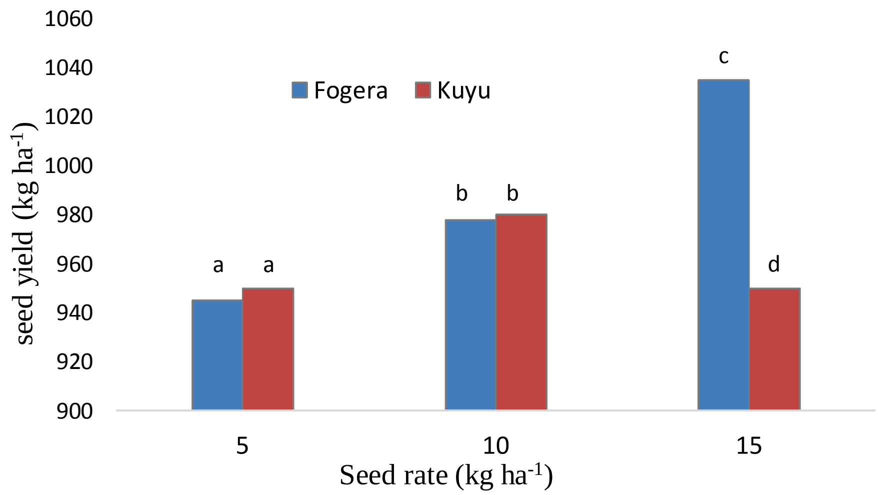


Figure 5.6: Mean seed yield (kg ha^{-1}) for Fogera and Kuyu varieties at three different seed rate (kg ha^{-1}) and different letters indicate statistically significant difference (Tukey test, P<0.05).

Irrespective of whether it is rain fed/irrigated and location the overall significance of seed yield for different rate was found to be very important (Fig. 5.6). In this situation it was found that the seed yield was linearly related with seed yield for Fogera variety and this was not the case for Kuyu variety. For Fogera variety significant yield difference was observed between 5 and 15 kg/ha implying that the highest rate for this experiment is recommended. Although it is already known that variety (two varieties) has no significant contribution to variability, it was included to expand the group from three to six (three by each variety) (Figure 5.7). The six contrasts can be still further expanded to fifteen by applying both intra- and inter-variety contrast. Again although the contrast is expanded to fifteen the significant contrasts are limited to nine due still combined effect of the two varieties. In all cases of contrast multiple comparison procedure to determine which means are significantly different from which others is used to show pairs with significant differences. The two varieties did not show clear yield performance difference and the differences observed may be due to location which in turn could be due to difference in soil and/ or precursor crop or even the weather (Fig.5.8).

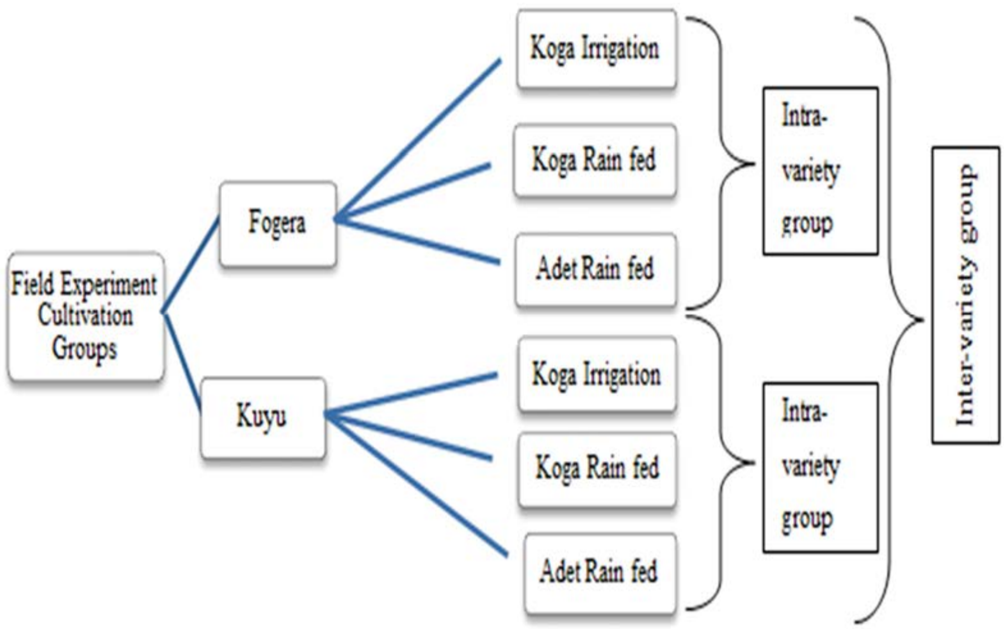


Figure 5.7: Expansion of the groups from three to six by including the contribution of the two varieties

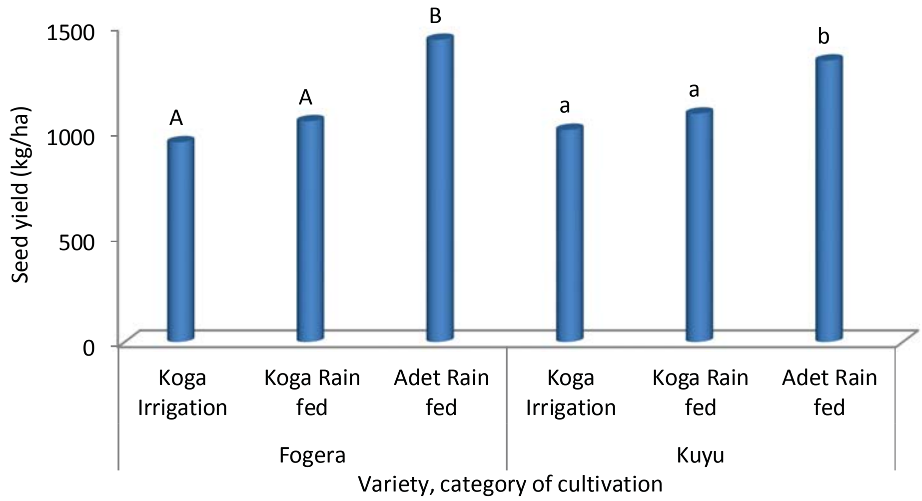


Figure 5.8: Comparison of the six modes of cultivation (location by varieties) the different letters indication significantly contrasting seed yields (Tukey test, P<0.05)

To evaluate the yield in comparison with the previous research results and to test the hypothesis that the seed yield can be improved, hypothesis test was conducted at various levels. The hypothesis test was conducted stepwise using one variable analysis method taking seed yield of 1000 kg ha^{-1} as mean of null hypothesis and alternative hypothesis as greater than 1000 kg ha^{-1}. The mean null hypothesis of 1000 kg ha^{-1} was based on yield performance of the varieties of 911 kg ha^{-1} (Fogera) and 1100-1300 kg ha^{-1} (Kuyu) (EARO, 2004; Bulcha, 2007). Additionally since there is no significant difference between the two varieties in this study an approximation of 1000 kg ha^{-1} was taken for null hypothesis for both varieties.

The hypothesis test was first conducted for the three cultivation conditions (Table 5.4) and the null hypothesis was rejected in favor of the alternative hypothesis for cultivations at Koga by rain fed and Adet by rain fed with alpha values of 0.05 and 0.01 respectively.

Table 5.4: Results of hypothesis test for seed yield from different location/water supply condition (mean null hypothesis of 1000 kg ha^{-1})

Location /water supply	Mean seed yield	Alpha value	t-test P-value	Conclusion, null hypothesis
Koga/ Irrigation	976.00	0.05	0.860	Not rejected
Koga/ Rain fed	1064.72	0.05	0.023	Rejected
Adet/ Rain fed	1384.60	0.01	0.000	Rejected

The second step is where the hypothesis test is repeated by the two varieties, seed rate and nitrogen rate. The test with seed rate and nitrogen rates is done separately where one is nested in the other (Table 5.9 and Table 5.10).

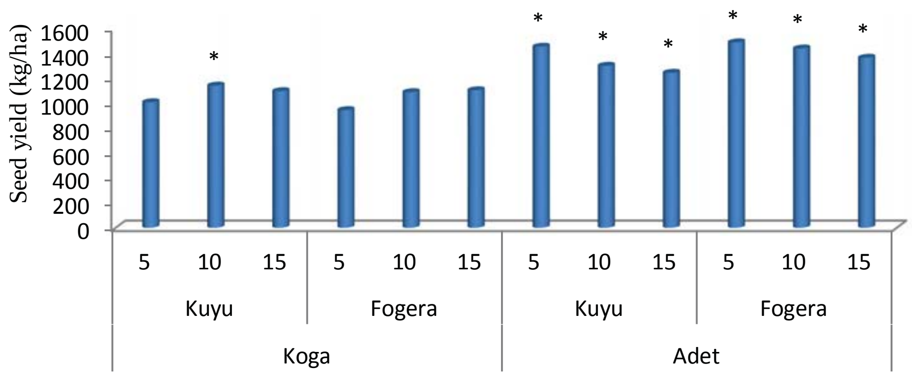


Figure 5.9: Seed yield in Koga and Adet under rain fed conditions for the varieties Kuyu and Fogera and three seed rates (5, 10, 15 kg/ha).

(* significant differences, Tukey test with P<0.05).

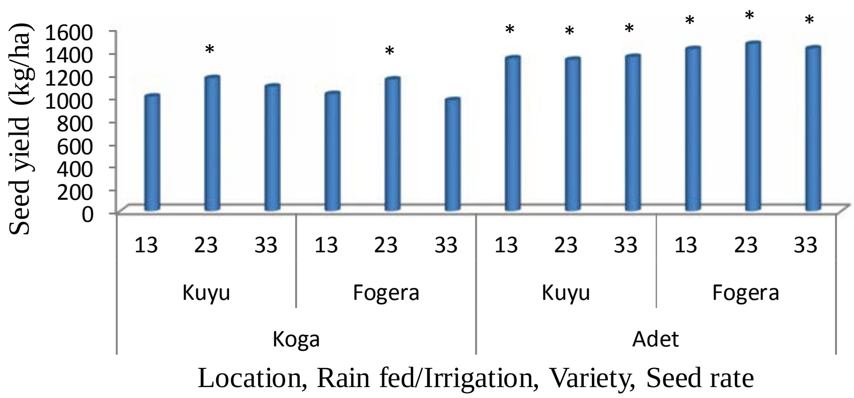


Figure 5.10: Seed yield in Koga and Adet under rain fed conditions for the varieties Kuyu and Fogera and three nitrogen fertilizer rate (13, 23 33 kg/ha) (*significant differences, Tukey test with P<0.05).

The seed yield from Adet by rain fed was the highest whereas in Koga by rain fed the yield was for two dosages of Nitrogen fertilizer significantly lower it seems further tests are necessary. Analyzing the contribution of each factor at different levels and in this case the influence of nitrogen rate of 23 kg ha^{-1} (Kuyu at Koga by Rain fed) and seed rate of 10 kg ha^{-1} (both Kuyu and Fogera at Koga by Rain fed) it can be stated this treatments are to be in favor in comparison to the other treatments. Therefore in general the rain fed was superior to irrigation water supply mode and Adet location was superior to Koga and in favor of the alternative hypothesis. Difference between the two varieties was seen more clearly from cultivation at Adet location (rain fed) where Fogera generally appears to be better than Kuyu. Adet location is again observed to be better than Koga location (Fig. 5.9 and Fig. 5.10).

In the report during the variety release seed yield for varieties range from 911 kg ha^{-1} (Fogera variety) and 1100-1300 kg ha^{-1} (Kuyu variety) (EARO, 2004). Yield of the Indian nigerseed which is about 308 kg ha^{-1} (Getnet and Sharma, 1996) was the least compared to many other oilseeds and also much less than the Ethiopian nigerseed. According to studies conducted in Indiana, Illinois, and Missouri (USA) yielded only 480 kg ha^{-1} which is again much lower than the results documented in Ethiopia (Kandel et al., 2004). The existing nigerseed market, coupled with the high cost of nigerseed

(\$1.10 kg^{-1} for nigerseed compared to \$0.26 kg^{-1} for sunflowers), indicated that the market potential was great. Given yields of 900–1,120 kg ha^{-1}, 28,000–35,000 ha would be required for nigerseed production in the US to supply the then demand (Quinn and Myer, 2002). Attainment of the mentioned yield and even more should be targeted for any research targeting to improve nigerseed yield.

The overall mean yield and particularly the result from Kuyu variety in this study meet this analysis of market competitiveness except that the market and special (cultivation) differences between Ethiopia and USA should be considered. The cause of the yield difference may be more complicated by adequacy of rainfall. Then this shows that weather and climate alone has such a big impact on yield instability (CSA, 2011). Even in this case differences in yield could be further complicated by other factors than weather. Other factors such as local farmer's variety seed, the nature of land allocated for cultivation, local/traditional agronomic practices, and seed vigor must be taken into account. Although the average variation from state to state is not as such significant, the variation with in a state is sometimes obvious.

In Amhara state (center of the Ethiopian highland) the yield ranges from 329 kg ha^{-1} (Awi) to 783 kg ha-1 (North Gondar). In Oromiya State (central Ethiopia) which is next to Amhara State in nigerseed production the yield ranges from 307 kg ha-1 in Jimma zone to 658 kg ha-1 in West Welega zone (Table 5.5). Further exploration can show an even more variability in yield of both higher and lower from place to place. This shows that further location comparison may be important for the best possible yield. In addition to high variation in agro-climatic in Ethiopia and even in Regional States, it is also common that the small holder farmer have their own local varieties which make general comparison difficult. The agronomic practice from land preparation/sowing to seed harvest method also varies from place to place. Some farmers, for instance, may still continue to allot marginal land, less land preparation, apply little or no fertilizer, no weeding, minimum care during harvest (to minimize shattering and loss on threshing ground). The high variability of yield observed in Ethiopia to the zonal (structure below regional state) level and even district/local areas can depict the situation.

The results from this study is in agreement with Choferie et al. (2011) where the experimental results indicate highly significant differences among environments (location-year interaction) and planting dates and on the contrary, environments versus planting dates and environments versus varieties interactions were not significantly different. As a result it was found that there is no significant difference in varieties performance in nigerseed. In other studies mean yield data among varieties of nigerseed showed no significant variability and rather location showed significant variability can also be one of the research results comparable to this particular study Temesgen, et al. (2011). Similar study on other oilseed of the same family, safflower (*Carthamus tinctorius* L.) which is relative of nigerseed showed similar response towards environment and other treatments (Elfadl et al., 2009).

Table 5.5: Comparison of nigerseed yields from three nigerseed producing zones in the Regional States of Ethiopia

Amhara		Oromiya		Benishangul-Gumuz	
Zone	Yield (kg ha^{-1})	Zone	Yield (kg/ha)	Zone	Yield (kg ha^{-1})
North Gondar	783	West Welega	658	Asosa	469
South Gondar	705	East Welega	603	Kammashi	603
North Wollo	600	Illubabor	484	Maokomo	682
South Wollo	592	Jimma	307		
East Gojjam	547	West Shewa	556		
West Gojjam*	578	North Shewa	507		
Waghimra	536	Horoguduru	635		
Awi	329				
Average	583	Average	536	Average	585

Source: Extracted from (CSA, 2011) *Zone where this study was conducted

Regarding seed rate (plant density), compensating plants such as wheat, for example, have the ability to respond to density, and other plants such as maize compensate very poorly and need to be planted at much more precise spacing (Winch, 2006). Nigerseed is also known to be compensating plant through increasing number of branches and heads per plant for low seed rate (Getnet and Sharma, 1996) and this is demonstrated by ANOVA which shows contribution of each factor and combination. Therefore from previous studies it was clearly observed that nigerseed did not show significant variability to seed rates. Some crop's response to the same application of fertilizer as well depends on interaction of other factors. The following year's yield of wheat grown in rotation with a fallow, for instance, may be limited by the amount of available phosphate; so it will respond to a phosphate fertilizer rather than nitrogen (Winch, 2006). The role of precursor crop and its effect on soil fertility is also important.

Several reports released on nigerseed are not far from each other. Agegnehu (2011) also reported that 10 kg ha^{-1} seed rate to be appropriate for the highest seed yield which agrees with this result but the locations differ. Nigerseed response to nitrogen and phosphate fertilizer is poor except that it is required for plant establishment (Getnet and Sharma, 1996). In this study although the variability is not statistically significant but the seed yield observed was encouraging compared to the previous reports of research result and Ethiopian Statistics Agency. The other factor which is responsible for decrease in yield is harvesting date which if late shattering will reduce the yield by as much as 25% and recommended about 150 days but varying depending on many factors (Weyessa, 2011). Another report still shows wide variation for harvesting date. Agegnehu (2011), for instance reported 145 to 175 days. This is a wide range when the shattering nature of the seed is considered. This still shows that there is lack of uniformity in maturation.

5.1.3. Oil Content

Oil content was analyzed for both locations/ the three cultivations (Koga irrigation, Koga rain fed, and Adet rain fed) with 54 plots each. Result of the analysis is presented by mean oil content (wt. /wt. %) which is 39.59% (Koga location by irrigation), 41.54% (Koga location by rain fed), and 38.67% (Adet location by rain fed). The overall pattern of the mean oil content with the rows 1-27 being Fogera variety, the rest 28-54 Kuyu variety (Fig. 5.11).

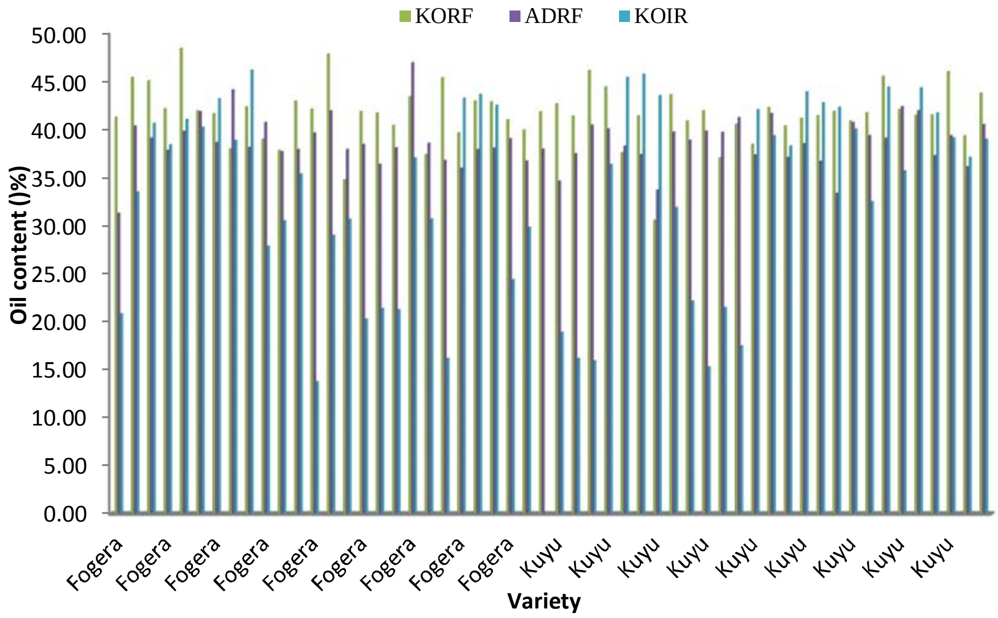


Figure 5.11: Oil content of Nigerseed cultivated completely randomized treatments in triplicate (KORF- koga rain fed, ADRF- Adet rain fed, and KOIR-koga irrigation).

From the ANOVA for all the three cultivations and the three factors and their interactions it could be observed that there is no main or interaction effect which has p-value less than 0.05 i.e. none of the main or interaction contribute significantly to the difference in oil content (Appendix IV). The comparison by only location/water supply mode shows that there is significant difference between locations Adet and Koga by rain fed as well as between Koga locations by rain fed and irrigation. On the other hand there is no significant difference between Koga location by irrigation and Adet location by rain fed (Fig.5.12).

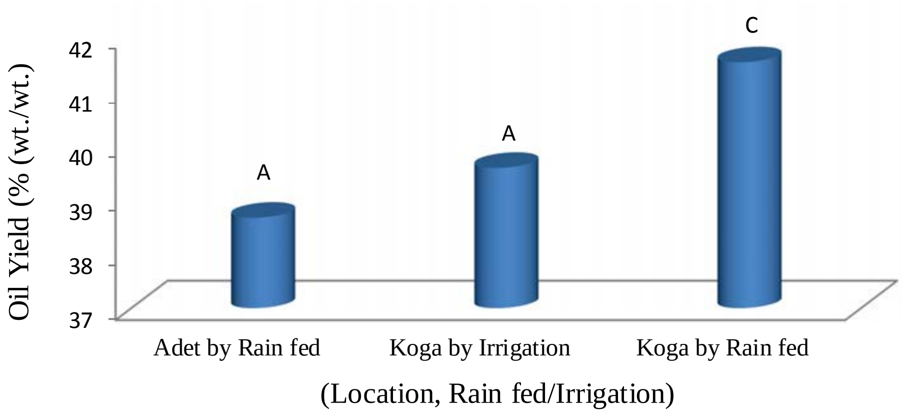


Figure 5.12: Comparison of oil yield from three categories of cultivation, the different letters indicate significant contrast between the respective categories of cultivation (Tukey test, $P<0.05$).

However when this same analysis is repeated by variety the group will increase to six and more detailed comparisons can be observed (Fig.5.13). From the result of this study multiple stage comparison of group variables for oil content using Fisher's least significant difference (LSD) to see which factor contributed to significant difference between groups it was found that location and mode of water supply are more important (Fig. 5.13). Location Koga specially the rain fed appears to be generally better than location Adet in this regard. From the location Koga with rain fed itself Kuyu variety showed better performance than Fogera variety (Fig.5.13). That means homogeneity among variables of the groups was mainly due to location. The contribution of nitrogen fertilizer and seed rates appears to be less important to homogeneity/variability as could already be seen from multiple factor ANOVA (Appendix IV). Therefore one very interesting observation from this study is that the Adet location which showed better seed yield than Koga location became lower in its oil yield than Koga location specially by comparison based on rain fed (Fig. 5.13 and Fig.5.14).

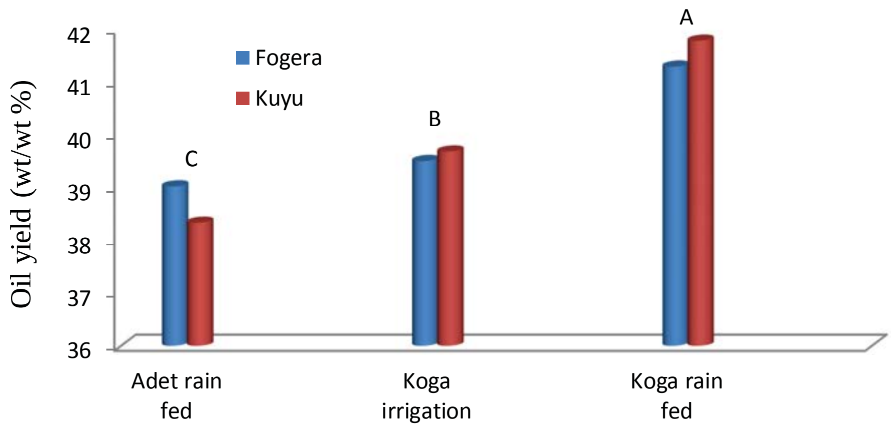


Figure 5.13: Oil yield from the cultivation categories including varieties (different letters indicate significant yield difference, Tukey test, P<0.05;)

Although significance of variability and significance of difference between groups is important it is also worth considering the real effect or the actual oil content of these groups whether or not they have significant or non-significant difference. In this regard an approach is made to set a mean null hypothesis and an alternative hypothesis.

In this case reference mean null hypothesis was made for the value of both varieties i.e. Fogera and Kuyu with oil content of 37.41 and 38.39% respectively from the previous report. However taking into account the observation from this study of non-significant difference between the two varieties and considering some reports which appear to be over stated (although varietal status is not indicated in many) the mean null hypothesis was set higher and taken to be 39% oil content for both Fogera and Kuyu varieties alike. The alternative hypothesis is therefore set to be greater than 39% (Fig.5.14).

Therefore it possible to generalize that it could be possible to improve the oil content as proven to be in favor of the alternative hypothesis of greater than 39% at least for 50% of the treatments. This result also shows that location/water supply is more important than the other treatments (seed rate, nitrogen rate, and variety). Comparison of location/water supply shows that Koga location by rain fed to be the best performer and Adet location by rain fed to be the least performer (Fig.5.14).

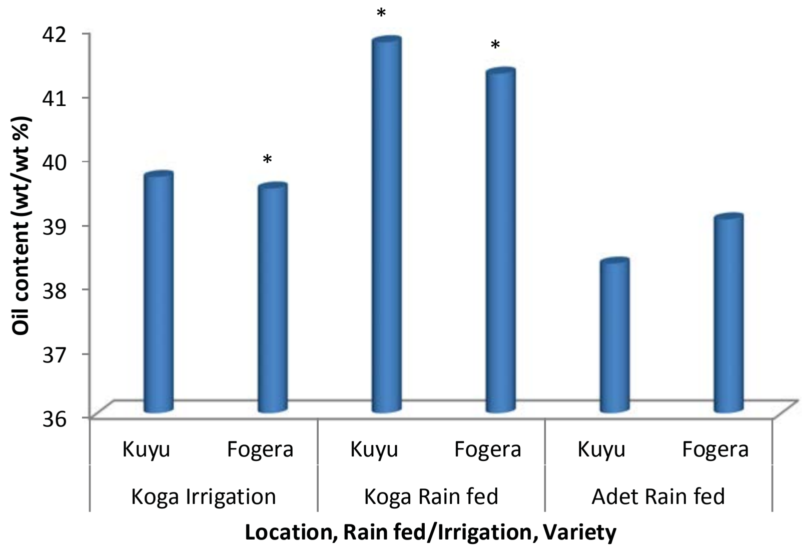


Figure 5.14: Results of hypothesis test for oil content of nigerseed cultivated under the three conditions taking 38.39% and 37.41% for Kuyu and Fogera respectively (EARO, 2004) (Tukey test P< 0.01 for Koga rain fed and P< 0.05 for the rest).

The other important aspect is comparison of the oil yield which is kilogram of oil per hectare (kg ha^{-1}) for all cultivations and treatments (Figure 5.15).

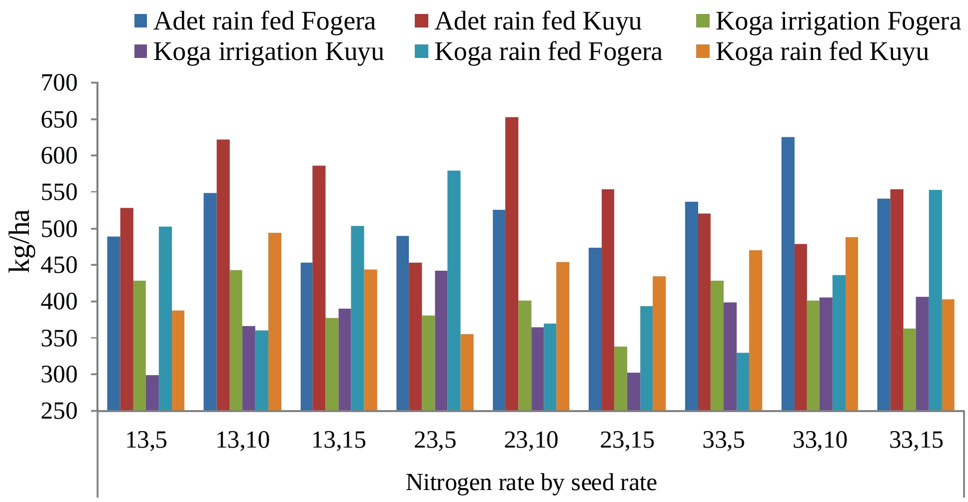


Figure 5.15: Mean oil yield (kg ha^{-1}) from the six categories of cultivation condition by variety, water (rain fed/irrigation) (N-rates: 13, 23 and 33kg/ha and Seed rates: 5, 10 and 15).

Whether it is the seed yield or the oil content their relative importance depends on the net values of the oil and/ or the meal. Therefore in this case the oil yield gives a good picture of how much oil is obtained from a hectare of land rather than simply seed yield or oil content. In this study also it is observed that oil content and seed yield showed negative correlation (Figure 5.16 and 5.17). Koga site has significant lower seed yield as compared to Adet site (both rain fed) however the oil yield in reverse was found to be lower for Adet site than that of Koga site. In this case the additional value of the meal may play important role in making decision as, for instance, high seed yield production would have a high meal output as compared to the low seed yield according to this result. Regarding oil content of nigerseed from some previous works as high as 42–44% reported (Dagne and Jonsson, 1997) is sometimes said to be overstated however this could be possible since the diversity within Ethiopia itself is very high. A range of 29–39% was also reported (Dutta et al., 1994). Therefore this study generally appears to be in agreement with the previous reports but showing the influence of location, and water supply (rain fed/irrigation) as well as seed and nitrogen rates.

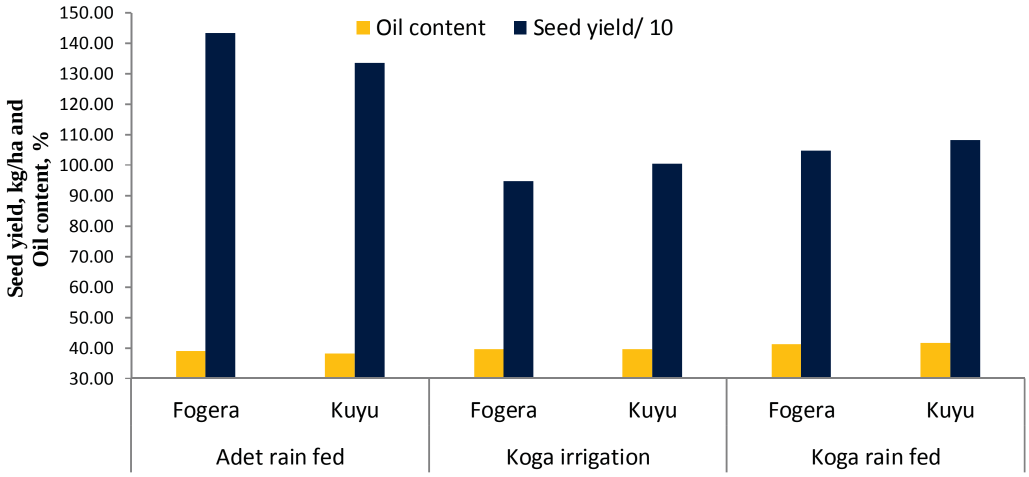


Figure 5.16: Comparison of seed yield and oil content from different locations, varieties, and watering (rain fed/irrigation) (Negative correlation, -0.53).

However, when overall oil yield (kg ha^{-1}) (calculated from seed yield and oil content) is considered irrespective of the meal, the outcome still appears to be better at Adet location with rain fed for both varieties with Fogera and Kuyu variety(550.0 kg ha^{-1}) showing similar performance.

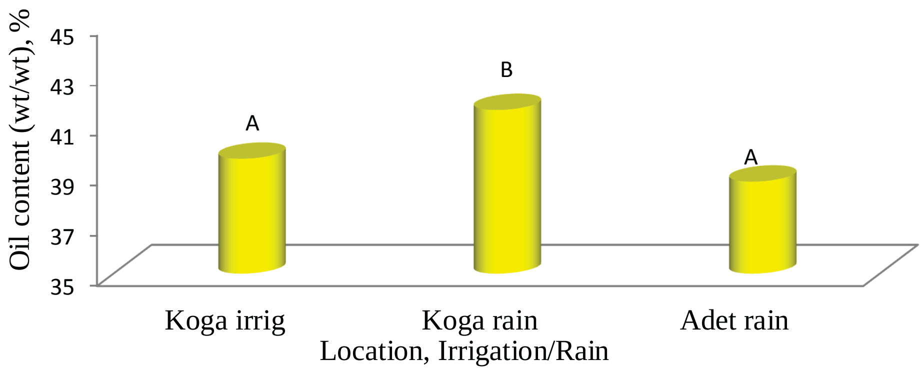


Figure 5.17: Comparison of oil content of nigerseed harvested from different locations/cultivation (Different letters indicate significant difference, Tukey's test with P<0.05)

5.1.4. Ash Content

It is very interesting observation that the Adet rain fed cultivation showed high seed yield but low oil yield but the ash content is found to be significantly higher than the other cultivation conditions, Koga rain fed and Koga irrigation (Fig. 5.18). This shows that the seed yield of Adet rain fed was mainly due to its ash content rather than its oil content. It was clearly seen that the ash content of nigerseed from Koga was significantly lower than that of Adet irrespective of whether irrigated or rain fed. This is in line with traditional knowledge of the small scale oil millers who, from their own experience, tell that the nigerseed from one area is different from the other in its oil content and this is the basis for their preference for purchase of raw material.

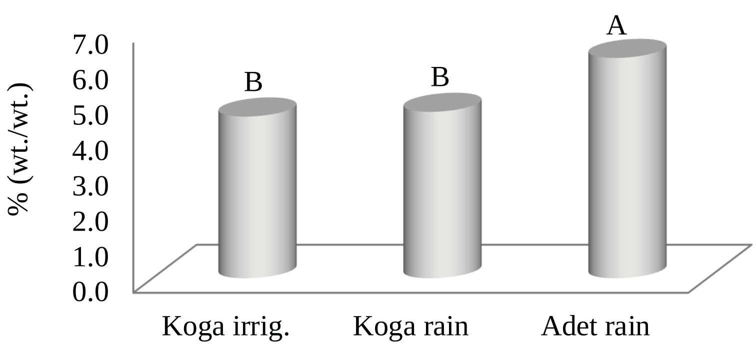


Figure 5.18: Ash content of nigerseed from different cultivation condition

5.1.5. Fatty Acid Profile

Fatty acid profile was analyzed for nigerseed from Adet location cultivated by rain fed. As could be anticipated from previous studies and crops of the same family, linoleic (C18:2) (omega-6) was the predominant fatty acid in nigerseed oil.

Table 5.6: Fatty acid composition (%) of the two varieties from Adet location (Rain fed)

Fatty acid	Fogera				Kuyu			
	Average	St. dev.	Mini.	Max.	Average	St. dev.	Mini.	Max.
Palmitic (16:0)	8.42	0.03	8.36	8.46	8.42	0.25	8.04	8.77
Stearic (18:0)	6.92	0.10	6.78	7.09	6.89	0.17	6.63	7.18
Oleic (18:1)	5.04	0.05	4.95	5.10	5.02	0.13	4.83	5.20
Linoleic(18:2)	78.20	0.17	77.93	78.47	78.46	2.11	74.95	81.42
α-linolenic (18:3)	0.11	0.03	0.10	0.15	0.11	0.02	0.10	0.14
γ-linolenic (18:3)	0.40	0.01	0.39	0.41	0.39	0.01	0.38	0.41
Behenic (22:0)	0.63	0.02	0.60	0.65	0.63	0.02	0.60	0.66
Lignoceric (24:0)	0.37	0.01	0.35	0.39	0.37	0.01	0.36	0.39

On the other hand α-linolenic acid (omega-3) is of trace level and was even not detectable from most of the samples/plots i.e. only 17 of the 54 were above detectable limit. Other fatty acids were found to be in between these two in relative abundance (Table 5.6). The difference in composition between linoleic acid (omega-6) and linolenic acid (omega-3) is very high for both varieties. Total saturated fatty acid content is generally low which is 15.32% from this study and 13 and 16.9% from other studies referred. Comparison can also be made with oil from other sources than nigerseed (Table 5.7).

The mean alpha-linolenic acid (omega-3) which is 0.11% for both Fogera and Kuyu is not only the least among the fatty acids found in the oil but also showing extreme discrepancy from linoleic acid (omega-6) with which it is expected to be in a certain recommended ratio according to the current trend related to health. It seems less likely to narrow this difference by agronomic management, breeding or genetic manipulation and therefore it seems better to take this oil as a major source of omega-6. Regarding fatty acid composition, highly radical change was reported by breeding where 80% oleic acid is attained in nigerseed (Petros et al., 2009).

Table 5.7: Fatty acid composition and oil content of nigerseed compared to the other oilseeds (Source: (Francis and Campbell, 2003) (modified))

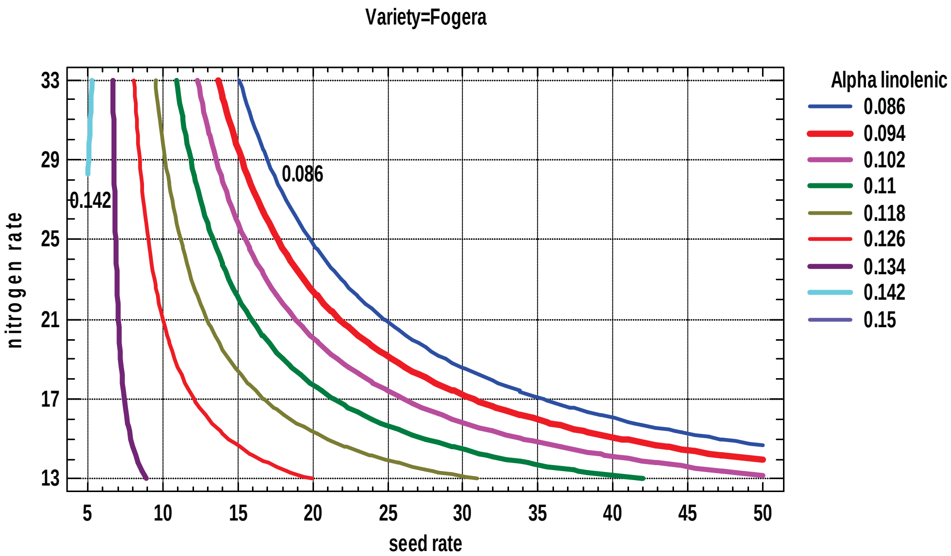
	Canola	Borage	Evening primrose	Camelina	Crambe	Niger-seed[1]	Niger-Seed[2]	Niger-seed[3]	Mtthiola	Linseed
Saturated	7	17	10	8	5	13	16.98	15.32	11	9
Oleic	60	19	10.5	16.5	14.5	6	7.52	5.03	14	18
Linoleic	21	36	65	16.5	8	80	70.7	78.32	13	18.5
G-linolenic	-	22	9	0.1	-	-	-	0.40	-	-
A-linolenic	10	-	-	36	-	0.5	0.40	0.12	60	54
Eicosenoic	-	-	-	16	-	-	-	-	-	0
Erusic	1	3	-	3	62	0.5	-	-	-	0.5
Behenic							0.35	0.63		
Lignoceric							-	0.37		
Oil content	40	35	22	38	32	38	-	40	22	38

1-Francis and Campbell, 2003; 2-Marini et al., 2003; 3-Result from this study

In this case the required ratio of omega-6 to omega-3 may also be attained by proportional blending with other oils like linseed oil with higher omega-3 content.

Although there is no significant difference in composition of fatty acid of the two varieties, the contour plot of estimate shows that there is difference in trend with varying seed and nitrogen rates for the most important fatty acids (omega-6 and omega-3 respectively as indicated on the Figures 5.19 and 5.20).

For the decrease in seed rate, for instance, there is generally an increase in nitrogen rate for a contour line except some lines showing critical limit. A more or less somewhat reverse trend is observed for the two varieties trend of contour plots.



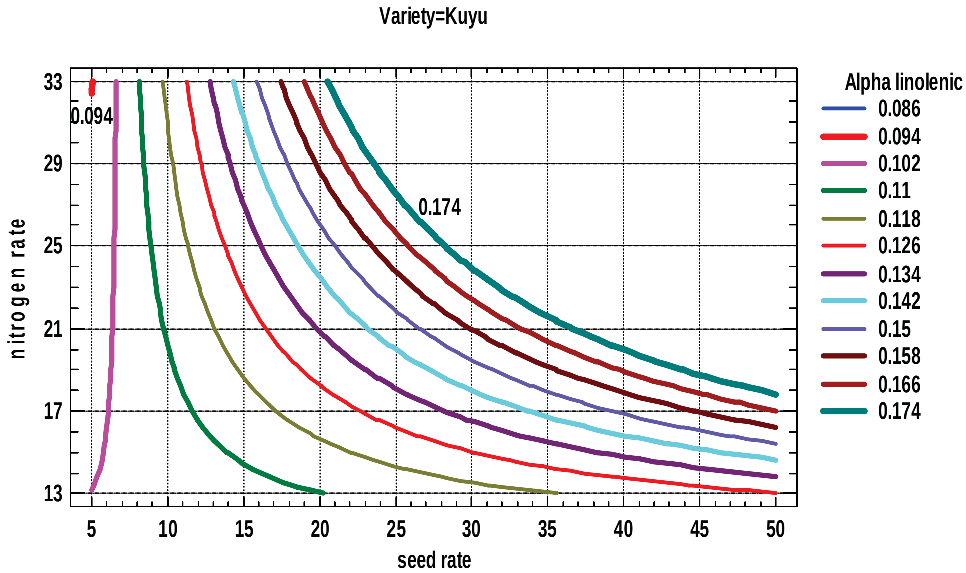


Figure 5.19: Contour plot of estimate for alpha-linolenic acid oil of the two varieties of nigerseed (nitrogen and seed rates (kg ha^{-1})).

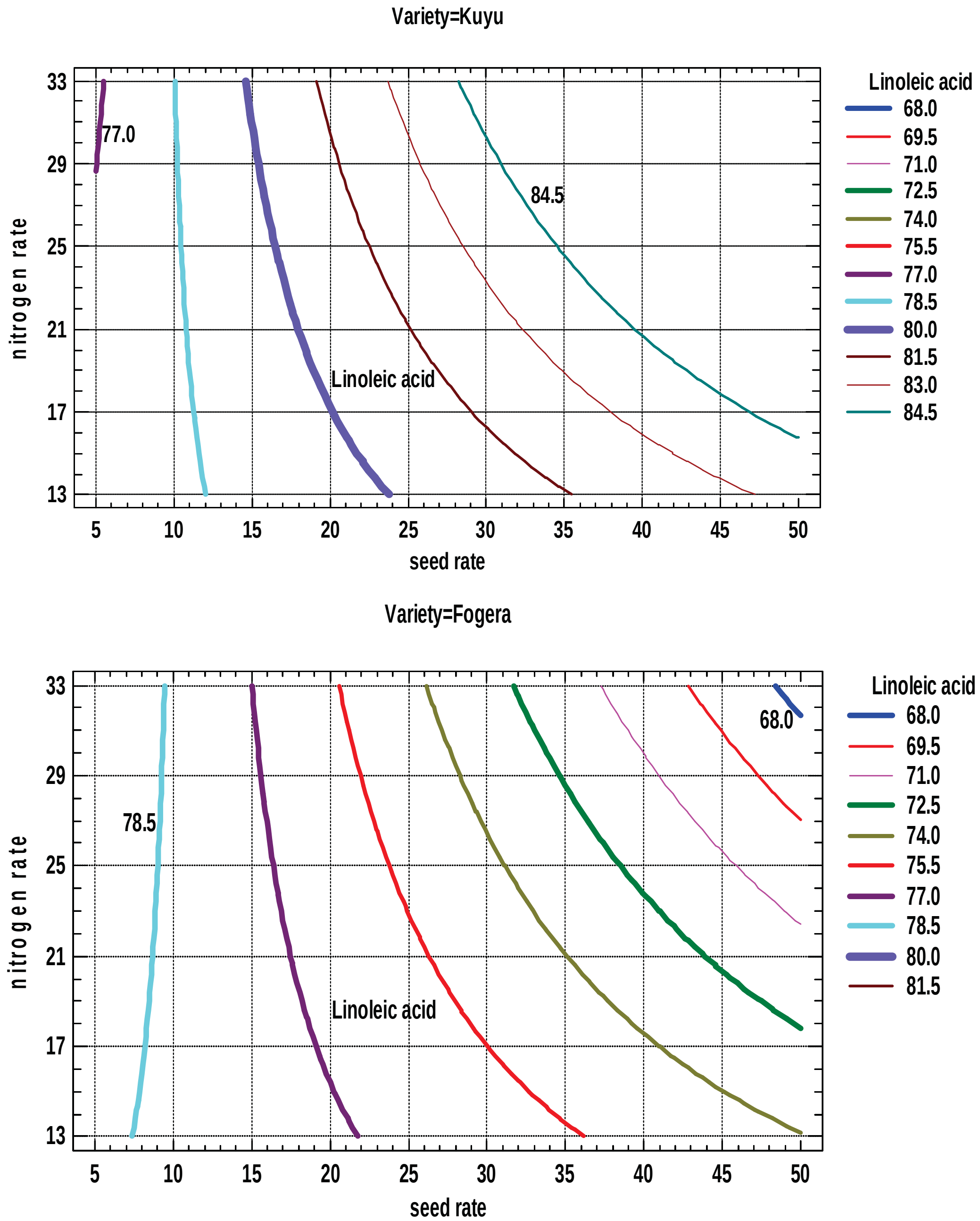


Figure 5.20: Contour plot of estimate for Linoleic acid of oil of the two (Kuyu, upper and Fogera, lower) varieties of nigerseed against nitrogen and seed rates (kg ha^{-1})).

Dutta et al. (1994) reported that the Ethiopian nigerseed oil contains linoleic acid more than 70%, whereas, (Dagne and Jonsson, 1997) reported 66–69% and similarly (Alemaw and Wold, 1995) reported 74.8-79.1%. One of the main questions in considering fatty acid profile of a given oil/oilseed is the content of essential fatty acids (omega-3 and omega-6) and the ratio/balance with which these essential fatty acids exist.

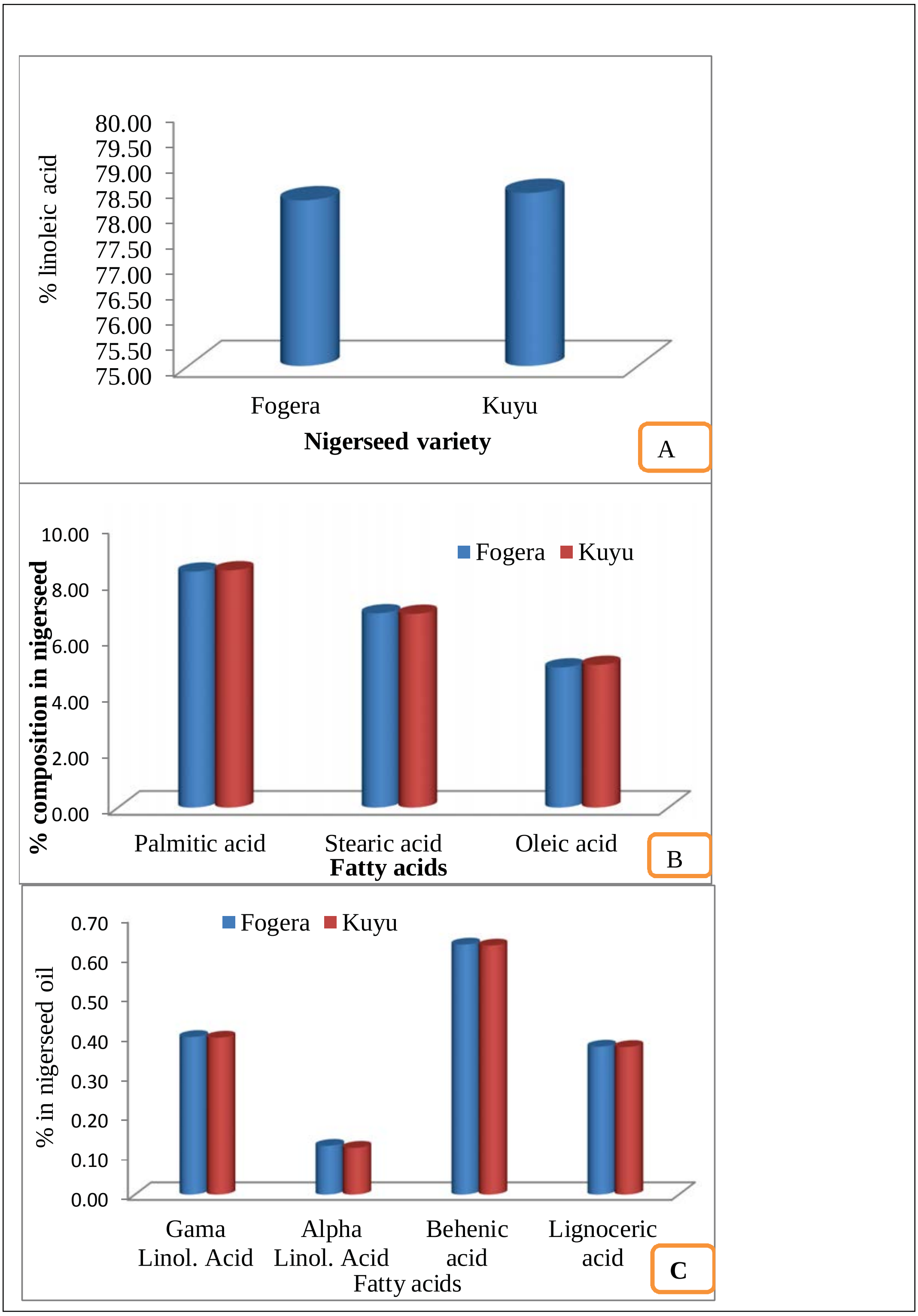


Figure 5.21: Composition (A) Major (B) Medium (C) Minor fatty acids in nigerseed oil.

Although unsaturated fatty acid is generally known to be advantageous to health, later on the importance of omega-6 got a great deal of attention. More recently, however, the ratio of omega-6 to omega-3 (rather than omega-6 alone) was found to be very important. Kapoor and Patil (2011) thoroughly revised the importance of the omega-3 fatty acid and its ratio with omega-6.

In this study the analysis of individual fatty acid shows that mean linoleic acid content was 78.2 and 78.5 % for Fogera and Kuyu varieties respectively irrespective of the agronomic treatments with an overall mean of 78.32% and range of 68.56-87.31% (Fig. 5.21-a, b, and c). This result appears to be not far from those reported in the literature for Ethiopian nigerseed oils. The reported percentages of the other fatty acids also are in good agreement with the results of previous investigations. In the works so far done on the fatty acid composition linoleic acid is by far the dominant fatty acid present in the nigerseed oil followed by Palmitic, oleic, and stearic acids (Dutta et al., 1994; Dagne and Jonsson, 1997; Ramadan and Moersel, 2003; Alemaw and Wold, 1995) which is also more or less in agreement with this observation. In this study there is some deviation from the mentioned order of abundance. The composition from the highest to the least is: Linoleic, Palmitic, stearic, oleic, Behenic, γ-linolenic, Lignoceric, and α-linolenic acid. In this study result stearic acid content is higher than oleic acid. Behenic acid which is less commonly stated is higher than γ-linolenic acid and similarly Lignoceric acid higher than α-linolenic acid in this study. Additionally there is no significant difference between varieties Fogera and Kuyu.

5.1.6. Vitamin E /α-Tocopherol/

In a similar way to fatty acid, the data for α-tocopherol was taken only for Adet location by rain fed (54 plots). The analysis of variance shows that only seed rate contributes statistically significantly to difference (Appendix V). Of particular interest here also is the significance of the difference between the two varieties. In this regards the varieties do not contribute significantly to the difference in vitamin E content (Figure 5.22).

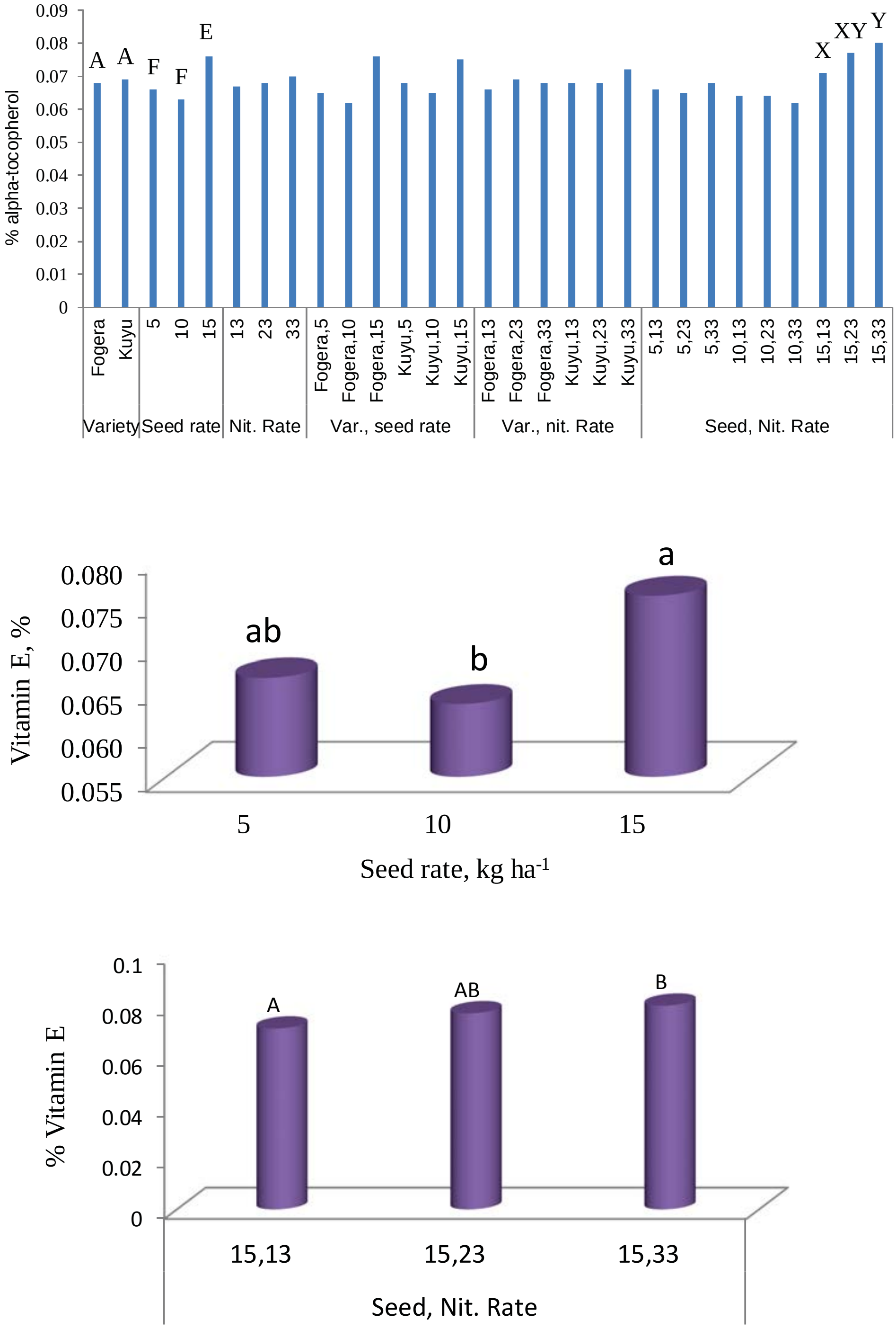


Figure 5.22: Variety, seed rate, nitrogen rate, and their interactions effect on vitamin E (alpha tocopherol) content of nigerseed oil (letters indicate significant difference, Tukey test P<0.05).

Although significant difference is lacking between vitamin E for most of the factors involved and the interactions, it is possible to observe the effect of the factors and their interactions. As was already seen from ANOVA seed rate has significant effect for differences observed. It could be noticed that the interaction of seed rate and nitrogen rate depicted significant effect compared to the other interactions. The maximum mean vitamin E content of 0.08 ranging 0.0698 - 0.0892 mg/100 g was recorded from the interaction of maximum seed rate (15 kg ha^{-1}) and maximum nitrogen rate (33 kg ha^{-1}) (Figure 5.22). This interesting observation of positive correlation between seed density and vitamin E content need further investigation as especially the interaction with nitrogen fertilizer is also encouraging. Although there are extreme values which tend to be outliers these values need attention and further investigation rather than generally considering them to be outliers to be discarded from the data. The vitamin E values 0.106, 0.101 (outliers), and 0.091 mg/100 g all come from nitrogen rates 23, 33, and 13 kg ha^{-1} respectively and are from one variety (Fogera) with one seed rate (15 kg ha^{-1}). Therefore the distribution needs close scrutiny.

The observation of vitamin E from high seed and high nitrogen rates is encouraging (Appendix V) has similar trend with some of the fatty acids. Comparison of the result of this study and previous studies on vitamin E content of nigerseed shows interesting agreement. (Dutta et al., 1994) showed tocopherol analysis of nigerseed samples collected from different regions of Ethiopia to be 0.068-0.085 % (wt. /wt.). α-tocopherol is 90% of the total tocopherol and γ-tocopherol is 3-5%, β-tocopherol was found to be minor in composition of ca. 1%. The cumulative, Ethiopian and Indian nigerseed were reported to contain 0.072, 0.071, and 0.072% α-tocopherol (90% of total tocopherol being α-tocopherol) respectively (Dutta et al., 1994). This is more or less in agreement with the result from this study. The amount of vitamin E needed to protect PUFAs against oxidative damage is at least 0.4-0.8 mg vitamin E per gram PUFAs and may be in excess of 1.5 mg/g when diets contain higher-than-average levels of long-chain PUFAs (Weber, 1997). Therefore this extra high vitamin E content can make this oil candidate for use as antioxidant. Compared to any other vitamin E source nigerseed is could also be worth specialty status or nutraceutical level (Table 5.8).

The analysis result of this study is from virgin oil which is directly pressed in laboratory (unrefined) and therefore this high vitamin E may not be maintained if the oil is to be subjected to refining procedure.

Table 5.8: Vitamin E content of some oilseeds and non-oilseeds (mg/100 g) (McKevith 2005; Belitz et al., 2009)

Food Product	Content	Food product	Content
Oilseeds		Non-oilseeds	
Peanut	10.1	Fish (cod liver oil)	3.26
Linseed	0.3	Human milk	0.28
Rapeseed	-	Butter	2.2
Sesame seed	2.53	Egg (Chicken egg yolk)	5.7
Soya (boiled in unsalted water)	1.13	Beef muscle	0.41
Sunflower	37.77	Fish (herring)	1.5
Olives (in brine)	1.99	Wheat, whole kernel	1.4
Nigerseed oil	70	Wheat, germ	27.6

The other fact is the virgin oils are generally lower in percentage of expressed oil (lower efficiency) as compared to medium and large scale production with hot pressing/extraction which is refined and as a result their price is generally higher. Therefore in addition to all other efforts, improvement of the oil expression efficiency could be one way to reduce the price for the customers without compromising the profit of the producers.

5.2. Seed Storage Characterization

5.2.1. Sorption isotherm/Equilibrium Moisture Content

In the determination of equilibrium moisture content and sorption isotherm, selection of temperature and equilibrium relative humidity for the experiment was the first task.

Primarily, temperature of 20ºC was selected because the common ambient room temperature in Ethiopia is about 20ºC. This is important because the storage facilities in Ethiopia are less likely to be temperature controlled both from economic and technical points of view. The 40ºC temperature is selected to represent areas and some short seasons of the year where the temperature becomes high. Additionally the two temperatures are considered due to its importance for the model validation of non-linear regression as well.

The seven equilibrium relative humidities were selected to address as more relative humidities as possible from lower to the higher ranges. The graph of mean equilibrium moisture content at the two temperatures (20 and 30ºC) and the seven relative humidities can depict the situation (Figure 5.24 and 5.25). The isotherm determined was net adsorption isotherm since the seed was made to start from lower moisture content of 4% which was the most common and natural moisture content of nigerseed. In this experiment the two varieties of the nigerseed (Fogera and Kuyu) were considered for comparison between them. The samples were prepared in triplicate for every temperature and relative humidity combinations (full factorial) for which equilibrium moisture content was determined. Then the mean equilibrium moisture content versus temperature and equilibrium relative humidity was plotted for both varieties. Graphs comparing the equilibrium moisture contents at various relative humidity for the two temperatures are plotted together from which one can compare the difference between the two varieties. From this graph it is possible to trace the equilibrium relative humidity-temperature combinations for desired level equilibrium moisture content. The moisture content of nigerseed, for instance, should not exceed 6% according to quality and standards authority of Ethiopia (Table 5.9) (QSAE, 2005) and then at which temperature and which relative humidity this can be maintained can be traced on the graph (Figure 5.24). Different materials have their own typical sorption isotherm curve and similarly food materials have the typical curve by which they are known and classified accordingly.

In this case, the adsorption isotherm of both Nigerseed varieties is an S-type (sigmoid curve) particularly Type II (showing asymptotic approach to saturation pressure) (Brunauer et al. (1940) in Lewicki (2009). The SPSS 16.0 non-linear regression analysis also shows the result of parameter estimate to be asymptotic. The inflections appear to be smooth at 20ºC especially for Kuyu variety. Major inflection of divergence was observed above 60% equilibrium relative humidity (the point where convergence was seen for both varieties and for both temperatures). At less than 60% equilibrium relative humidity it was clearly seen that the inflection points were almost at the same equilibrium relative humidity except that of 20ºC was at higher moisture content for the same temperature and equilibrium relative humidity. For both varieties, at a given temperature, equilibrium moisture content increased with increasing equilibrium relative humidity. As can be seen from the isotherm curves of the two varieties, the change in equilibrium moisture content with equilibrium relative humidity is not constant. This relationship can be classified as the behavior of equilibrium moisture content below 60% and above 60%.

Table 5.9: Physical and Chemical requirements for grading of nigerseed for oil milling

Characteristics	Requirements			Method of testing
	Grade 1	Grade 2	Grade 3	
Moisture and volatile matter content, % by mass, max.	6	6	6	ES ISO 665
Oil content (dry basis) as received, % by mass, max.	38	33	32	ES ISO 659
Impurity, % by mass, max.	3.0	8.0	10.0	ES ISO 629
Acidity of extracted oil (as oleic acid), % by mass, max.	1.5	2.5	4.0	ES 26:2001

Source: Agricultural Products ES 1079:2005, 12/03/2005. (QSAE, 2005).

Regarding the difference between the two varieties, major and clear difference is lacking at both temperatures.

The oil in the oil body of the cell breaks down to free fatty acid when the condition is suitable for the lipase enzyme naturally present in the seed, stopping this natural even is what good storage has to achieve (Figure 5.23).

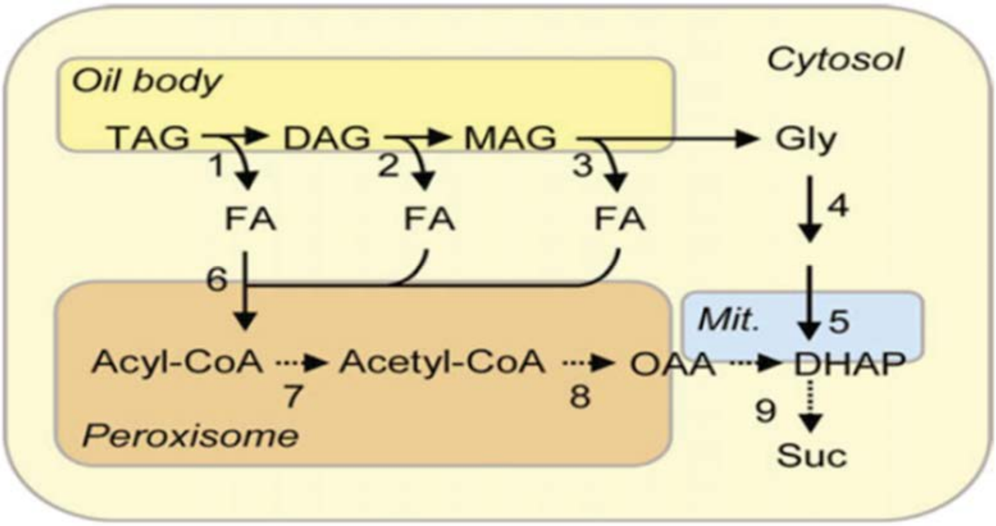


Figure 5.23: Breakdown of fatty acid by different enzymes in cell organelles and cytosol (Quettier and Peter, 2009)

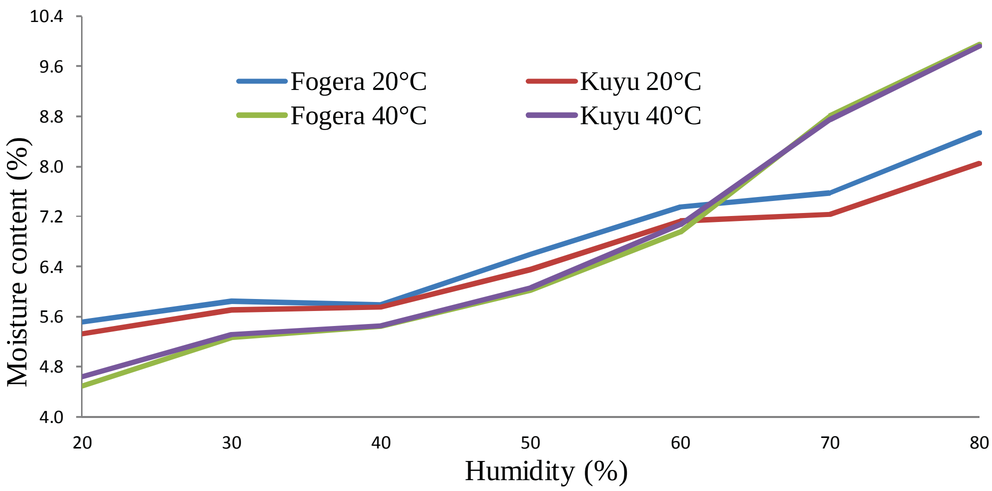


Figure 5.24: Isotherm curves of nigerseed varieties (Fogera and Kuyu), typical sigmoid curve.

Comparison of isotherm curves of the two nigerseed varieties with rapeseed shows interesting similarity between the oil seeds, nigerseed and rape. The oil content and seed size appears to be not much different between them. Similarly departure of the non-oilseed (wheat and barley) from both nigerseed and rapeseed can be clearly seen (Figure 5.25). This difference can be seen in terms of physicochemical composition of the seed, seed size, nature and thickness of seed coat.

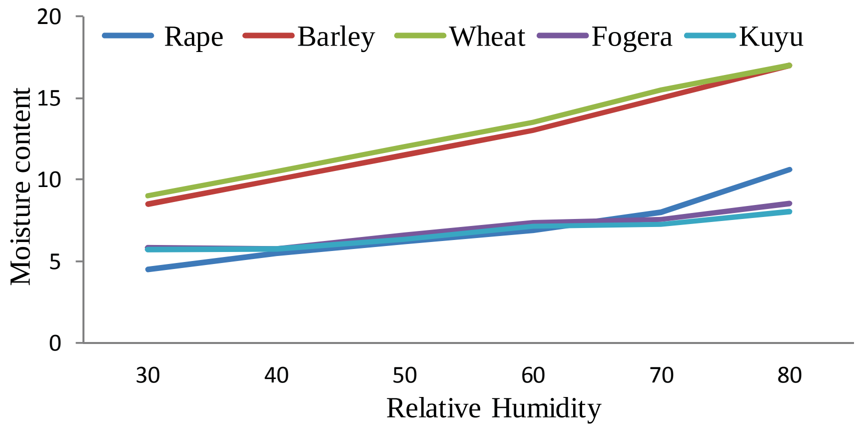


Figure 5.25: Isotherm curve comparison of the nigerseed varieties with rapeseed* and non-oilseeds, wheat* and barley* (*Data from United oilseeds, 2009).

The fact that observed and predicted value show very interesting relationship makes the result promising for practical application (Figure 5.26).

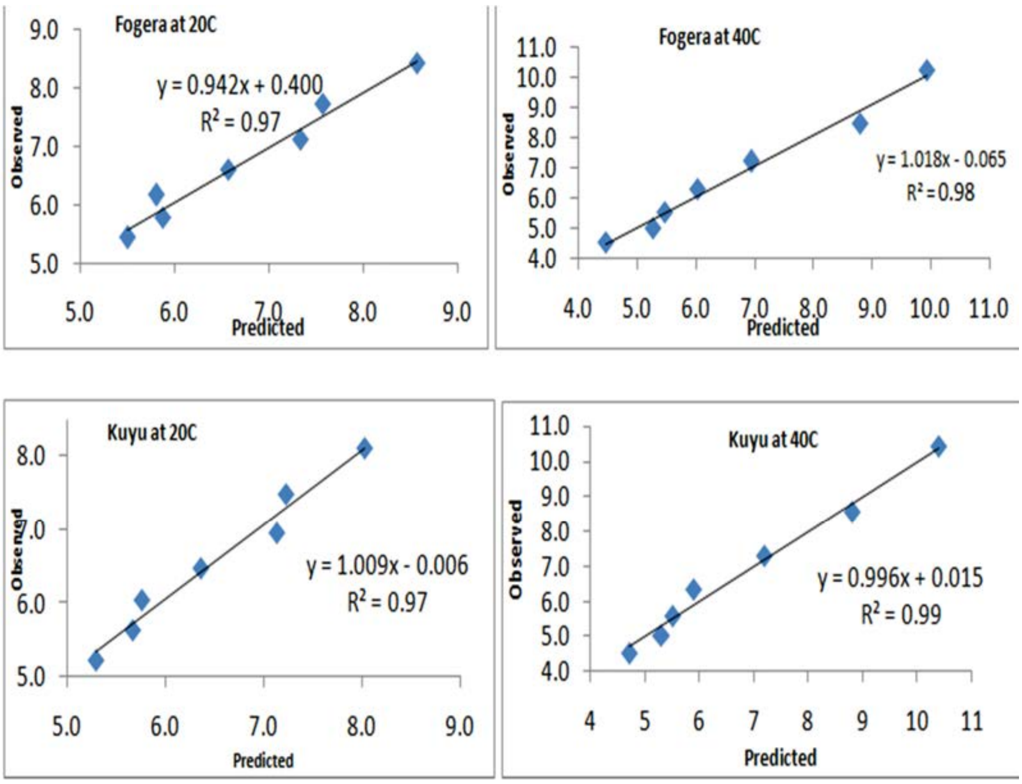


Figure 5.26: Relationship between observed and predicted values of equilibrium moisture content.

5.2.2. Evaluation/Comparison of Models

While the determination of equilibrium moisture content and equilibrium relative humidity for multilayer sorption isotherm is important on its own as discussed in the previous section its interpretation is still another important question (Timmermann, 2003). This multilayer sorption isotherm data can be used as an input for validation of different theoretical equations/models developed to interpret the multilayer sorption isotherm curves. In this study SPSS 16.0 software was used for nonlinear regression analysis of the adsorption isotherm data from the two nigerseed varieties. Parameters were taken to be unconstrained. For the analysis option of Levenberg-Marquardt was used. The models to be validated were chosen based on the criteria indicated (Table 5.10).

Table 5.10: Evaluation different model for fitting to adsorption isotherm of two nigerseed varieties at two temperatures

Model	Equation	Variety	Temp. (°C)	Coef. of det. (R^2)
GAB	$u = \frac{u_m cka_w}{(1-a_w)[1+(c-1)ka_w]}$	Fogera	20	0.972
			40	0.970
		Kuyu	20	0.978
			40	0.986
BET	$u = \frac{u_m ca_w}{(1-a_w)[1+(c-1)a_w]}$	Fogera	20	< 0
			40	0.441
		Kuyu	20	< 0
			40	0.485
Modified Chung & Pfost	$u = E - (F * \ln(-(t+C) * \ln(aw)))$	Fogera	20	0.880
			40	0.880
		Kuyu	20	0.854
			40	0.854

Accordingly the models Brunauer-Emmet-Teller (BET), Guggenheim-Anderson-de Boer (GAB), and Modified Chung-Pfost were evaluated for their suitability in estimating monolayer capacity and parameters in the model for both varieties at the two temperatures on the basis of the coefficient of determination (R^2). Starting value for the parameters to be estimated is critically important to proceed in the model evaluation. The values the starting parameters u_m (monolayer moisture value), k (model parameter), c (net heat of adsorption), were 3.5, 0.46, and 10.5 respectively for all models to be validated.

To predict these initial values an approach was made by referring to the values of these parameters from other oilseeds of similar size and in this case rapeseed was used as a reference. Rapeseed has u_m (3.6), k (0.876), and c (10.63) values at 25°C for GAB model (Rahman, 1995 in Lewicki, 2009)). With these values as a reference continuous trial was made until reasonable starting value was obtained. The initial values were applied to all the three equations for both temperatures. To have relatively good description of the sigmoid type isotherm and to *fulfill the requirement of BET* the parameters of GAB model should be kept in the range: $0.24<k\leq 1$ and $5.67 \leq c \leq \infty$.

The ranges from this study for nigerseed are well in agreement with this precondition except that the parameter *c* goes below this range and hence high error load (Table 5.11). Of course the physical meaning of parameter c in BET may not be valid in many cases due to limited validity of the relation of *c* with heat of sorption owing to a number of assumptions involved in BET theory (Iglesias and Chirife, 1976a in Lewicki, 2009).

Among the three models validated GAB model was found to be fit and was also used to estimate the monolayer moisture content and other parameters with their standard error of estimates and ranges (Table 5.11). GAB model has coefficient of determination above 97% to explain the relationship between water activity (a_w) and equilibrium moisture content (emc) at both 20 and 40ºC for both varieties (Table 5.10). The estimated monolayer is 4.863 and 3.828 kg /100 kg for Fogera at 20 and 40ºC respectively and 4.976 and 3.824 kg/100 kg for Kuyu at 20 and 40ºC respectively. As compared to BET equation, modified Chung & Pfost has shown more potential to explain the data although not significantly. Of course as can be seen from the curve of multilayer (Figure 5.24), up to about 65% equilibrium relative humidity (where upward inflection is seen), the curve of equilibrium moisture content of 40ºC is below that of 20ºC. This is what the estimated monolayer also shows except that the range the monolayer equilibrium moisture content is limited to about 6.1% maximum (Kuyu at 20ºC). Plotting of experimental versus predicted value (from the nonlinear regression) for both varieties at 20 and 40ºC to further prove the correlation is shown.

Table 5.11: Parameter estimates by GAB model for the two varieties of nigerseed at two temperatures

Variety	Temp. (°C)	Parameters	Estimate	Standard error	Range (95% C.*I.)*
Fogera	20	Monolayer	4.86	0.200	4.308 to 5.418
		C	3.933E8	1.476E15	-4.908E15 to 4.908E15
		K	0.529	0.40	0.419 to 0.640
	40	Monolayer	3.83	0.503	2.431 to 5.225
		C	1.031E3	3.628E4	-99697.851 to 101760.103
		K	0.784	0.064	0.607 to 0.961
Kuyu	20	Monolayer	4.98	0.421	3.809 to 6.144
		C	168.849	287.527	-629.456 to 967.153
		K	0.489	0.062	0.318 to 0.661
	40	Monolayer	3.82	0.216	3.223 to 4.424
		C	7.288E8	1.848E15	-5.130E15 to 5.130E15
		K	0.791	0.028	0.714 to 0.869
Rapeseed	25	Monolayer	3.6	-	-
		C	10.63	-	-
		K	0.876	-	-

The Quality and Standards Authority of Ethiopia grades nigerseed for oil milling into three (Agricultural Products ES 1079:2005, 12/03/2005) (QSAE, 2005) and moisture requirement is 6% for all grades. This moisture requirement can be attained at equilibrium relative humidity of about 42-44% and 50% for 20 ºC and 40ºC temperatures respectively. The difference between the two varieties is minimal at 20 ºC as compared to that of. The influence of higher temperature appears more or less clearly starting from about 60% equilibrium relative humidity. In conclusion, the multilayer adsorption isotherm of the two varieties did not differ significantly and the curve is Type II/typical of food (according to Brunauer's classification). The curve of nigerseed is typical of type 3 according to another classification proposed by Heiss and Eichner

(1971) in Lewicki (2009). The equilibrium moisture content was higher for the lower temperature (20 ºC) up to the major inflection point of about 61 - 63% equilibrium relative humidity where the trend was reversed i.e. high equilibrium moisture content for the 40ºC as opposed to the situation below 61 - 63%. The GAB model as seen after analysis using SPSS 16.0 was found to be the best as compared to others evaluated for model fitting and parameter estimation. The correlation between observed and predicted moisture content from GAB model was also found to be significant with coefficient of determination 97 to 99% strengthening significance of the observation.

5.3. Oil Pressing

5.3.1. Initial Diagnosis of Local Edible Oil Millers

The technical problems of oil pressing which the small scale millers were facing were more clearly identified during the field visits to the oil mills and detailed discussion and additionally during the technical training workshop held with oil mill operators and owners. The importance of controlling of moisture content of the seed, heating of the seed before pressing, and controlling of the seed feed/flow rate are some of the process techniques raised and discussed. Therefore identification of where improvements are necessary/ possible was made through the discussions, observations of their production process, and taking oilseed and cake samples and making laboratory evaluation for oil content to see how effective their pressing method was. Their oil samples were also taken and evaluated for free fatty acid and peroxide value. Based on this initial assessment on the problem this study was planned in a more focused way to deal with the problem of improving oil expression efficiency. The pressing of this experiment is typical of cold pressing (Figure 5.27) and it is a type of edible oil product.

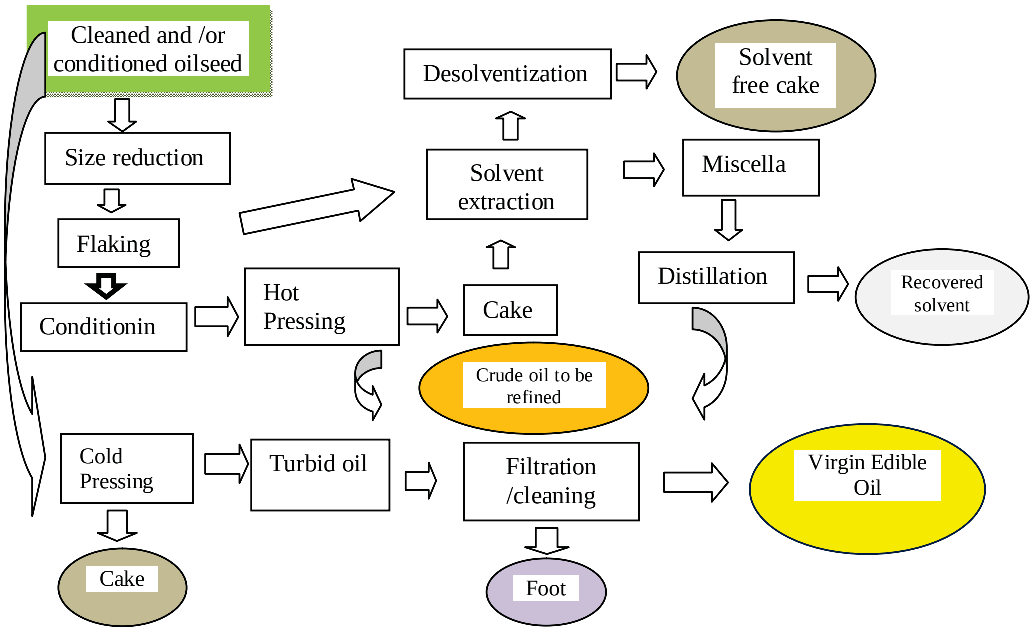


Figure 5.27: Typical Flow diagram of oil milling and refining (cold and hot pressing)

5.3.2. Screw Press and Selection of Experimental Factors

The history of development of oil expression shows that the contribution of trial and error and artistic creation of individuals, in addition to scientific research, played significant role (Kemper, 2005). Many factors complicate oil expression and of these some factors are difficult to control and therefore nosiness may dominate. These factors can generally be classified into three.

a. Pressing Machine, Types and Screw element

The function of a screw press is generally to separate liquids including oil from solids by expelling the liquids through a screen that surrounds the compression screw. It takes pressure to make the fluid flow through the holes or slots in the screen. As screw presses evolved, a number of mechanisms have been found useful for this separation process. Firstly the compression can be achieved by gradually increasing the inner shaft diameter of the screw. This forces the material out against the screen so that liquid is expelled through the screen as the clearance between the wall and the shaft progressively decreases along the length towards the discharge Secondly, compression can be achieved by tightening the pitch of the flighting. As the number of the screw turns per unit length decreases towards the discharge there is more material being forced into the press than is being removed. This results in increase in pressure with decrease of pitch. The third way to achieve compression is to install a cone at the discharge. This cone is also referred to as a choke, stopper or door. In many screw press designs it is bolted into a fixed position, creating a fixed discharge orifice or changeable cone with varying orifice diameter. The forth method is Supercharger screw or a positive displacement pump. This creates a pressure differential that pushes liquid through the screen. The technique has limited applications because in many conditions the pressure simply plasters solids against the screen of the press, forming an impenetrable mat layer. Similarly, differential pressure across the screen can be achieved by operating with a vacuum around the outside of the screen. This vacuum can draw high volumes of liquid through the screen. While successful in certain applications, the same problem of screen blinding due to a mat layer of fiber on the screen is possible (vincent corporation, 2004). Both feed rate and screw speed force the raw material forward. The effect of both must be seen in relation with the rate at with the cake is being discharged which depends on the screw element such as pitch.

b. **Nature of the Raw Material**

Nature of the raw material include /seed/nut/fruit or hard/soft or oil/moisture content/ or small or large size. This nature of the raw material can be modified such as by drying or moistening, size reduction, flaking, expanding, extruding. Whether this oleaginous material is modified or unmodified, for instance, by heating or moistening or both or enzymatically treated is critically important.

Based on the first factor oil pressing machine from Monfort Company, CA59G model (Germany) was selected and the rest two factors are taken as bases of experimental factors. This pressing machine is screw press which is perforated barrel type. The machine has heating ring although there is no inbuilt temperature control mechanism. The following major conceptual background summary made from the previous works and reviews (Khan and Hanna, 1983; Bredesen, 1983; Jacobsen and Backer, 1986; Vadke et al., 1998; Singh and Bargale, 2000; Oyinlola et al., 2004; Kemper, 2005) and observation of the selected perforated wall screw pressing machine are found to be important before starting the experimental work (Figure 5.28)

- The progressive increase of the shaft diameter, decrease of pitch length along the length of the barrel towards the exit of the cake, and the cone diameter are responsible for major buildup of axial and radial pressure.

- As the fibrous matrix (meal) continues to be pushed forward by the axial pressure until it exits through the nozzle but the oil sets back because of its low viscosity compared to the matrix.

- The oil is expressed through the barrel wall perforation pushed by net radial pressure. It ceases to set back due to choke pressure from the feed end and the expressed oil starts to ooze from the first set of perforation rings towards the feed end since net radial pressure is the highest at this point.

- The radial pressure for pressing the seed against the barrel wall increases as the diameters of the wall perforations decrease. Therefore the inner surface diameter of the wall perforation is set at critical minimum and maximum at the outer surface of the wall resulting in cut cone geometry.

- Similarly the progressive increase of the wall hole diameter outwards will cause progressive decrease in radial pressure along the cut cone until the pressure is null at the outer most diameters. This progressive decrease of radial pressure along these holes will facilitate the outward flow of the expressed oil/ purging of the oil.

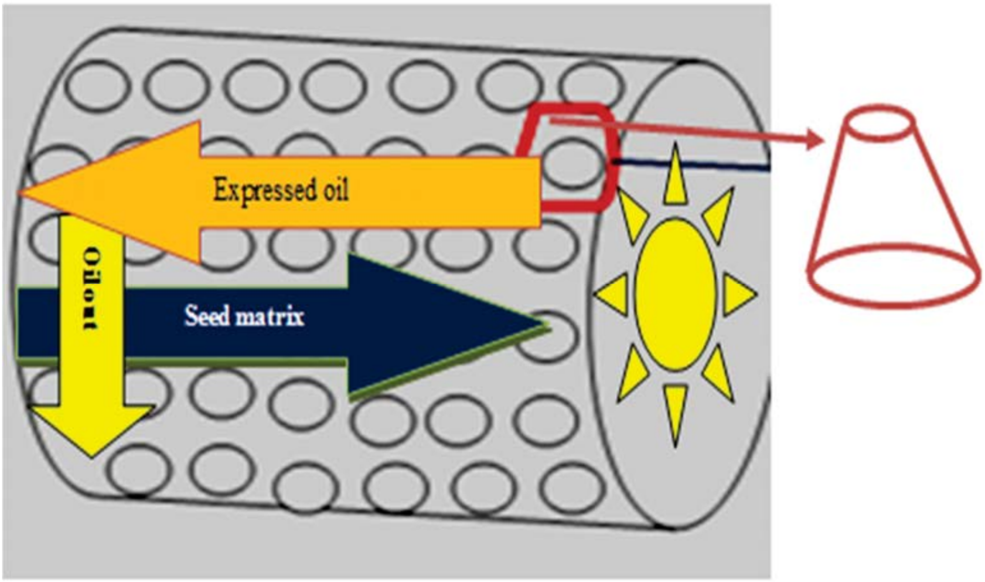


Figure 5.28: Expression of oil from 'perforated barrel' of screw press and the cut-cone geometry of the barrel wall hole (smaller inner surface and larger outer surface diameters)

For small screw presses like the one used for this study the processes of size reduction, heating, flaking, and oil expression all take place along the length of the screw shaft.

The pressing machine used for this experiment has a heating ring but the temperature cannot be controlled. Additionally the machine has a screw rotation speed control from which feed rate is determined by experimentation using the scale on the screw speed control. The temperature at which it was operating is observed at remote using optical pyrometer. In selecting parameters for the process technique optimization, the approach was made simpler by further dividing the problems affecting efficiency as raw material based and process technique based. The problem related to raw material was planned to be modified by conditioning/pre-treatment (heating at certain temperature for a given period of time). The second problem (process technique based) was related to controlling operation which in this case is feed rate i.e. the rate at which the raw material is fed in to the screw press. The experimental treatment variables were limited to three by taking these most important ones and leaving the others as constant after careful pre-run experiments. Nozzle diameter, for instance, was set at 6 mm throughout the experimental runs. Repeated pre-run experiments showed that the meal will be flaky (loss of oil with meal) for larger diameter and too hard (causing blockage) for smaller diameter. Sesame and black cumin, for instance, were expressed with better efficiency when the diameter is smaller (4 mm) without blockage. Similarly, moisture content was taken as it is (the most common natural moisture of 4%) of the seed. Therefore the three parameters selected for optimization of the efficiency of oil pressing from nigerseed were temperature and time of seed conditioning and seed feed rate.

Figure 5.29: Kilning jar filled with nigerseed, for conditioning in temperature-time programmable water bath (with precision of 0.05°C).

5.3.3. Conditioning of the Seed

In the expeller machine itself although the main purpose is expression of oil from the raw material, the seed is subjected to different prepress processes such as size reduction, heating, change in pressure along the length of the screw shaft (Vadke et al., 1988). Further changes include change in moisture content, denaturation of protein including oil bodies and enzymes, softening of the seed coat, decrease in the viscosity of the oil itself, matrix bulk density and more physicochemical changes of the oilseed matrix. Even while pressing these parameters are dynamic along the length of the shaft in the barrel. This change of raw material property can be represented by version of Koo's reduced equation below. The change in property of raw material is, however, complicated although the time temperature and moisture could be set precisely (Figure 5.29). Regarding choice of the levels, for instance, of temperature, exceeding 90ºC may be high enough to harm the oil and the meal quality. Therefore these temperatures are unnecessary for virgin oil millers since they do not refine their oil. However the result of quality analysis shows that the seed heated to 90ºC was within the range of acceptable quality. It does not either make sense to condition it below 70ºC since the friction in the screw itself rises the temperature to about 70ºC (steady state temperature) for nigerseed. The optimum expressing temperature of course depends on the type of oilseed, but is generally above 70ºC (Oyinlola et al., 2004).

Time at three levels is selected approximately so that enough heat is transferred to the oil body to melt the storage oils and facilitate its flowability during pressing. Time-temperate has also complex interaction impact on the proteins which mainly form the wall of the oil bodies. Softening of the seed hull is also another effect where time-temperature is important.

5.3.4. Oil Expression

Among the variables, seed feed rate based on controlling option on the screw press. The levels of feed rate, for this experiment, are limited to only two due to limited range of feed rate of the expeller machine being used (3 to 5.5 kg hr^{-1}). The capacity of the machine is given to be 3 to 5 kg hr^{-1} but for nigerseed it reaches up to 5.5 kg hr^{-1}. The machine has variable rotational speed which is indirectly used for controlling feed rate. The importance of rotational speed has been recommended and found to be desirable to obviate the limitation of the experimental press by using an expeller fitted with a variable motor speed (Omobuwajo et al., 1999). For this experiment, the 5 and 5.5 kg hr^{-1} feed rates were excluded as the meal was flaky and obviously less yielding at these maximum rates. Therefore the feed rates 3 and 4.25 kg hr^{-1} was considered.

Since heat is already applied to the seed during conditioning it was not necessary to heat before pressing except up to near steady state. It is also known that heat will be generated during pressing. Therefore application of temperature is somewhat difficult to control and mainly when the time-temperature combined effect is considered. Although, heat is generated by the shearing action of the worm shaft against the seed/barrel wall, the steel press barrel is expected to act as a temperature moderator towards attainment of steady state temperature. Then the temperature profile along the barrel length will be nearly isothermal (Omobuwajo et al., 1999; Vadke et al., 1988).

The efficiency of oil expression was recorded for every experimental runs in triplicate and the average was taken. Additionally for every experimental press quality of the oil is checked by testing the acid and per oxide values which are selected as indicators of quality (Table 5.12). The acid value and peroxide value of the oil expressed was found to be within the range of requirement and even lower than the required value for virgin oil according to the Ethiopian Standard (ES) (Table 5.13). Here it is worth noting that not only the acid and peroxide value but also the values of insoluble impurity, iron and copper are also lower for unrefined/virgin oil.

Table 5.12**:** Efficiency of oil expression from nigerseed under different experimental treatments and the related quality parameters

S. No.	Temperature	Time	Feed rate	Efficiency (mean)	Standard deviation	Acid value	Peroxide value
	ºC	Min.	$kghr^{-1}$	%		$mg(KOH)g^{-1}$	millieq. O_2kg^{-1}
1	70	20	3	93.32	0.71	1.62	6.6
2	70	20	4.25	92.85	0.71	1.62	6.9
3	70	30	3	93.08	0.31	1.62	6.3
4	70	30	4.25	94.04	0.45	1.62	6.6
5	70	40	3	93.18	1.30	1.62	7.9
6	70	40	4.25	93.57	1.12	1.62	6.3
7	80	20	3	94.57	1.08	1.62	7.1
8	80	20	4.25	94.66	0.60	1.62	6.1
9	80	30	3	94.13	0.60	1.62	6.4
10	80	30	4.25	93.66	0.60	1.62	5.6
11	80	40	3	93.90	0.28	1.42	5.3
12	80	40	4.25	91.46	3.10	1.42	4.8
13	90	20	3	94.71	0.67	1.62	5.0
14	90	20	4.25	94.37	0.87	1.62	6.5
15	90	30	3	94.87	0.97	1.42	6.0
16	90	30	4.25	95.32	1.03	1.42	8.1
17	90	40	3	94.98	0.67	1.42	7.5
18	90	40	4.25	95.31	0.26	1.42	6.7

Table 5.13. Physical and Chemical Characteristic Specification of Nigerseed Oil

Characteristics	Requirements			Test Method
	Unrefined	Semi-refined	Refined	
Acid value mg KOH/g oil Max.	4	0.6	0.6	ES ISO 660
Peroxide value (miliequivalent peroxide oxygen /Kg oil, max)	15	10	10	ES ISO 3960
Unsaponifiable matter, % (m/m) max.	1.0	1.0	0.8	ES ISO 3596
Insoluble impurities, % (m/m), max	1.0	0.05	0.05	ES ISO 663
Iron (Fe), mg/Kg, max	5	1.5	1.0	ES ISO 66
Copper (Cu), mg/Kg, max.	0.4	0.1	0.1	ES ISO 67

Source: (QSAE, 2001) (nigerseed oil specification)

The multifactor ANOVA shows that only one of the three factors (temperature) contribute statistically significantly to efficiency of oil expression (Figure 5.28). In addition, multiple range tests for efficiency by temperature, feed rate, and time were tested using one way ANOVA (multiple stage comparison) to show the significance of level from one to the other and this case, the two feed rates and the three time levels did not differ statistically significantly. However the multiple stage comparison of the conditioning temperature shows that 70 and 90°C and also 80 and 90°C have statistically significant differences on efficiency. Although not statistically significant, both time and feed rate are directly related to efficiency of expression and this is in agreement with mathematical simulation by Vadke (1988) where the residual oil content of the cake is lowered at slower speed of shaft rotation from model prediction as well as experimental results. Contour plot from general linear model was used to extrapolate the parameters for different possible efficiencies. Comparisons with other oils and nigerseed from previous results show high difference although the method used could differ (Table 5.14).

Table 5.14: Oil extracted (ml) from 1kg of seed and extraction efficiency (%) by first press of some oilseeds

Species	Oil extracted (ml)	Percent extracted
Canola	350	83.3
Nigerseed	310	86.0 and 94*
Camelina	300	81.1
Linseed	275	88.0
Crambe (in hull)	225	72.5

Source: Francis and Campbell (2003)   * from this study

Pearson correlations between each pair of variable shows the highest correlation between temperature and efficiency and negative weak correlations between feed rate and efficiency and time of conditioning and efficiency. There is high correlation between temperature and expression efficiency (Table 5.15). The correlation between feed rate and expression efficiency is negative but the significance is in question. The correlation of time with expression efficiency which is expected to be positive came out to be negative although the significance is very low. From the result it can be seen that the efficiency improves from 20 to 30 minute conditioning time but the efficiency drops at 40 minute. It may be important to further explore the times 30 minutes and below. The reason for decrease in efficiency at 40 minutes may be due to more softening of the seed than melting of the oil.

Result of the experiment shows that the efficiency remains high when the feed rate is increased from 3 kg hr^{-1} to 4.25 kg hr^{-1} for 90°C implying that this shift in temperature overrides the effect of feed rate that was more significant at the lower temperature (Figure 5.30). This is also seen by extrapolation of the contour surface response. The contour plot extrapolation shows arrays of possibilities of parameters giving various efficiencies (Figure 5.31). Different combinations of the three parameters on the contour surface plot have another important dimension when the energy cost and product quality is considered. For a matter of a small change in efficiency, for instance, either the energy cost or product quality or both may be compromised. This could be taken in to consideration for further study.

Table 5.15: Correlation for raw material pretreatment variables and efficiency of oil expression

Variables	Expression efficiency
Temperature	0.67**
Time	-0.15
Feed rate	-0.09

** Correlation is significant at the 0.01 level. Pearson correlation

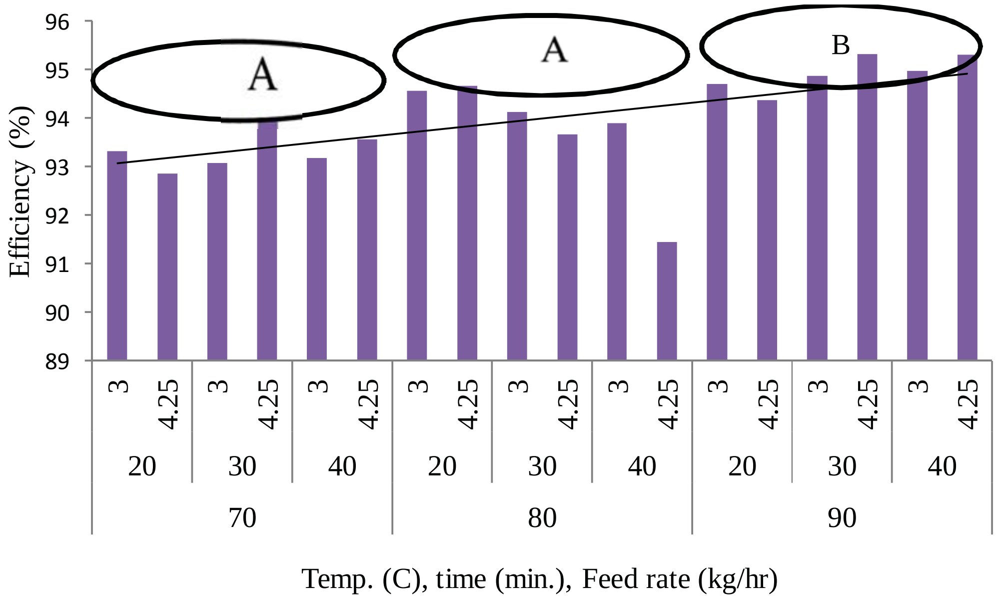


Figure 5.30: Effect of temperature, time, and feed rate and their interaction on oil expression efficiency (different letter indicate significant difference, Tukey test, P<0.05)

At the beginning of this study the samples collected from small scale oil millers around Bahir Dar city showed that they have the efficiency close to 90% and this was much more than expected. Based on that observation this study targeted efficiency above 90%. The optimum condition is not only to obtain maximum oil yield, but also uncompromised quality products, both oil and cake (Oyinlola et al., 2004). Therefore it could be seen from the result of this study that conditioning and flow rate could further improve the efficiency of nigerseed oil expression to above 94% without compromising quality of the expressed oil. Study conducted (Akinoso et al., 2009) on efficiency of oil expression using compressive stress, feeding rate, and speed of rotation, shows the maximum expression efficiency of 94.4% when all the variables are at their maximum levels at a time and the minimum expression efficiency when the mentioned variables are more or less at their minimum.

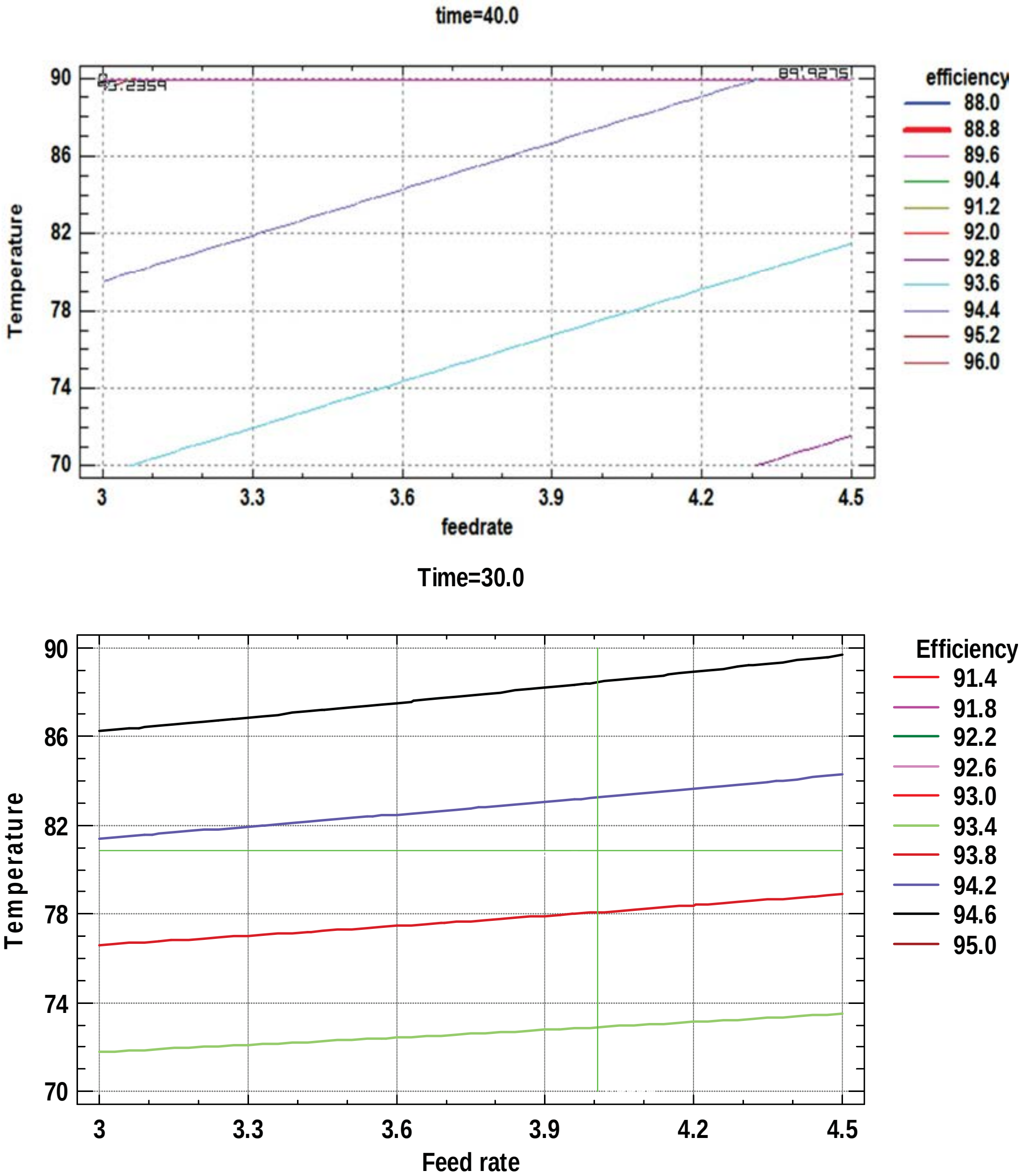


Figure 5.31: Contour of estimated response surface to locate various efficiencies at 40 minute (top) 30 minutes (bottom) conditioning at various temperatures and feed rates.

Compared to other variables in this study, the impact of feed rate was found to be very important in improving efficiency of expression next to temperature. It could be that feed rate is the major source of compressive pressure which is ultimately important in the oil expression. The reduced form of Koo's equation (equation 11), for instance, magnifies the role of compressive pressure and reduces all other terms to a constant (equation 12).

$$Y = C_o(\alpha)P^{1/2}h^{1/6}V^{-z} \quad (11)$$

(Koo; 1942 cited in Akinoso et al., 2009)

Where Y, oil yield in % wt.; C, constant for a seed type; α, initial oil content of the seed in % wt.; P, applied pressure in MPa; h, time of pressing in hours; v, kinematic viscosity in m^2/s; z, exponent of kinematic viscosity (1/6-1/2=-1/3).

This equation reduces to equation 12 since all terms other than P (applied pressure) were collected together as a constant *K* to account for the nature of raw material.

$$Y = (K)P^{\frac{1}{2}} \quad (12)$$

This implies that yield depends directly or indirectly solely on pressure and factors contributing to pressure. Since *K* is a constant accounting for the nature of raw material, it can vary for one and the same material depending on whether it is subjected to conditioning (time temperature treatment) or intact /undergone size reduction. Therefore the reduce Koo's equation may be rewritten as

$$Y = K_cP^{1/2} \quad (13)$$

K_c (equation 13) as distinguished from K (equation 12) is simply to emphasize the changed nature of raw material particularly by conditioning.

$$Y = 11.5 + (9.5 * 10^{-1}P) + (4.6 * 10^{-3}F) + (4.8 * 10^{2})S \qquad (14)$$

(Omobuwajo, 2009)

Where Y, yield; P, compressive pressure; F, feed rate; S, rotational speed of the screw

Omobuwajo's model (equation 14) can be more or less reduced to that of Koo (equation 12) as both feed rate (F) and rotational screw speed (S) are contributors to compressive pressure and therefore can be reduced to one term responsible for oil expression. In this study also it is possible to see that the conclusion is similar since feed rate is the major source of compressive pressure and the other two variables (temperature and time) are important in changing the nature of the raw material i.e. equivalent to the constant, *K* of Koo's reduced equation.

The oil expressed in this study was clarified by hot water degumming (Figure 5.32) and efficiency measurement was based on this clean oil.

Figure 5.32: The oil samples expelled from nigerseed clarification by hot water degumming.

6. General Discussions

While many regions of the World have shown significant change over about 30 years interval, the fat supply (g per capita per day) of Africa has shown an astonishing stagnation. The situation in some African countries including Ethiopia is even worse. The current domestic edible oil supply of Ethiopia, for instance, is not more than 20% of the total demand. This acute shortage of edible oil is mainly due to raw material (oilseed) shortage although multifaceted problems are contributing to this. In addition to this the problem is exacerbated by export of nigerseed and other oilseeds from which Ethiopia obtain significant foreign exchange. Due to shortage of nigerseed Ethiopia is likely to face serious challenge and tough competition when the US America farmers, who produce nigerseed as bird feed, continue to produce nigerseed in the desired quantity and could manage better and more competitive yield. The second challenge is from the traditional competitors of the Indian subcontinent including newly emerging nigerseed users which implies that the seed export competition itself is likely to be more and more intensive.

Therefore seed yield of nigerseed is one dimension of this study. It is known that higher yielding varieties must be available for high yield of seed and/ or oil. In addition to variety, environment is known to play vital role in attaining better yield and this includes seed rate/density, the fertilizer rate, mode of water availability (rain fed/irrigation) and weather/climate/soil. Although there are already approved nigerseed varieties there is a need for investigation about these seed and/or oil yield and quality before recommending them for cultivation by farmers and oil pressing by millers. The second dimension on nigerseed was the seed handling and storage aspect which is fundamental to both seed and oil quality. The seed characterization and storage was found necessary because of two major problems observed. The first one is hoarding of the seed, generally poor storage and handling, is partly responsible for the acute oilseed shortage in Ethiopia. This is mainly due to speculation of rise of price from the farmers to the oil millers themselves including intermediaries. The second reason is to show how seed storage and handling affects virgin oil quality as the nigerseed oil is consumed in its virgin oil form. The very importance of virgin oil is a point of controversy in Ethiopia rather that how virgin oil should be produced. But it is known that virgin oil from nigerseed is consumed from time immemorial at least in Ethiopian tradition and is not either new to the other World. However the virgin oil is known to be produced from different raw material which may differ from country to country. The refined and unrefined virgin oil had been subjected to investigations regarding their advantages and disadvantages. Cordain et al. (2005) has shown the impact of modern industrial processed food including refined oil. However the virgin/cold pressed/refined oils must be judged based on valid standard and analytical method (Choo et al., 2007). The three mains sources of challenge the quality of virgin oil may be classified as seed handling / storage (quality of raw material), mode of oil pressing, and the oil packaging and storage. For any oilseed which is candidate as raw material for virgin/cold pressed these questions must be duly addressed. The question whether edible oil has to be refined or not is highly controversial in Ethiopia. The government regulation generally demands refining without considering the raw material nature, mode of pressing, and packaging. Therefore this study focuses on the seed yield/quality, seed storage, and oil expression/quality.

The study on seed yield and/quality was conducted on the highland of Ethiopia which is origin of nigerseed. Therefore locational comparison includes varietal level and is based on the expectation that there could be yield performance difference from one part of the highland to the other. In this experimental field study on the two varieties of nigerseed (Fogera and Kuyu), the yield found was promising although the variability between treatments was not significant. The yield already observed from both varieties at both locations and both rain fed and irrigation was encouraging. When the comparative advantage of cultivating nigerseed is considered, it is even more encouraging. The comparative additional advantages of cultivating nigerseed as compared to other crops include usage of land which is not suitable for other crops, improvement of the soil fertility, checking weeds, relative simplicity of land preparation for cultivation, use as a fence to protect other crops from animals since animals do not eat the nigerseed plant.

The seed rate as one of the factors relevant to the yield performance, the question usually raised is the compensating nature of the nigerseed plant through changing the number of branches per plant, heads per branch or heads per plant. This was observed in this study that there is a trend to increase the number of heads and branches per plant for a reduced seed rate. Location comparison of this study which showed Adet location to be better than Koga location shows that more exploration on the location aspect may show even better yields. Rain fed was also found to be generally better than the irrigation.

Regarding fertilizer application, as has been stated in the relevant publications, addition of more fertilizer will contribute to luxurious growth of the vegetative part rather than improving the seed yield. This may be taken as natural limit to which the fertilizer can contribute in improving the seed yield. Therefore the yield observed from this study is encouraging particularly in the average yield per hectare. Moreover the current price for nigerseed, following the high price of edible oil, is very encouraging for the farmers and this may change the trend of nigerseed cultivation.

Both Kuyu and Fogera varieties at Adet location under rain fed condition showed comparatively higher yield. To the contrary both varieties showed lower seed yield at Koga location under irrigation condition. The oil content shows reverse performance on the two locations (higher at Koga and lower at Adet) as compared to seed yield. It was an interesting observation that the ash content was higher at Adet location the Koga location which is reverse of the oil content. Since water stress is known to increase the oil content for some plants where the fatty acid composition is also changed in favor of saturated fatty acids in water deficit (Laribi et al., 2009). Therefore further studies on nigerseed targeting oil yield need to be conducted comparing water stress and non-stress locations to compare both oil content and fatty acid profile. Although the fatty acid and vitamin E content was not different from the previous works (Ramadam, M.F. and Moersel, J.-T., 2002; Ramadan, M.F. and Moersel, J.-T., 2003; Ramadan, M.F. and Moersel, J.-T., 2006) it was confirmed that the omega-6 fatty acid and vitamin E contents are extra high in all cases. In this work it is very interesting relationship that is observed between seed density and vitamin E content. In this work it is also found that nitrogen fertilizer showed a positive interaction with seed density in contributing to increasing of vitamin E content of nigerseed. With regard to nitrogen rate or fertilizer in general more research should be conducted before reaching at conclusions from limited research works. The time of fertilizer application, for instance, can be varied to show the effective application time that has impact on seed/oil yield. The other approach regarding fertilizer may be studies on the possibility of other mineral fertilizers which are not common and may be required in smaller quantity. Methodologies and best practices applied to relatives of nigerseed such as sunflower or even of other oilseeds can be considered in this case. The location comparison appears to be very important in Ethiopia since the agro-ecological diversity is very high and this could be demonstrated from this limited work.

In addition to improved seed yield, ensuring a standardized and quality seed supply to both oil millers is of paramount importance. Handling and storage are the means to maintain seed quality. Setting standard moisture content alone is meaningless unless the method to maintain that moisture content for the duration of storage is known. In this regards the storage characterization from this study can be taken as an input for planning standardized seed handling and storage. The equilibrium moisture content/equilibrium relative humidity relationship, nature of the curve, estimation of parameters for monolayer, selection of which model best explains nigerseed are among the results of this study.

The other main problem was the method of quality oil expression from the seed. Before the experiment was started selection of variables was made based their anticipated contribution to the improvement of the efficiency of oil expression with emphasis on small scale millers. Even though it was initially seen that the efficiency of the small scale millers was about 90%, it was also observed that they were applying the maximum possible pressure using adjustment. Although this was not the main objective of this study it could be realized that this efficiency was achieved at the expense of the wear and tear on the machine parts. Therefore it was found wise to modify the nature of the raw material through treatment instead of depending only on the machine adjustment for maximum pressure. Parameters such as moisture content and nozzle diameter were selected by pre-run experimentations to simplify the approach. The result obtained from this study which is even higher efficiency than 95% is a good step forward.

Two trainings on proper oil pressing and processing were provided to the processors ; it resulted for some of them in an immediate increase in productivity (2-3% increased oil content); some processors indicated their willingness to buy cookers but the vast majority are unable (or unwilling) to invest in individual processing facilities, which is why the agencies switched to clustering the processors around a common facility (small scale refinery) instead of supporting the most willing or proactive processors (Lefebvre, 2012).

The aforementioned training was given to the millers based on results from this research work. This improvement in efficiency is achieved without compromising quality. The acid and peroxide values (used as indicators of quality) of the expressed oil are within the standard set by quality authority of Ethiopia. The outcome of this study was used and will also be used in training the small scale oil millers and was appreciated by the beneficiaries. The oils expressed from fresh seeds/nigerseed were analyzed for quality including by independent quality laboratory and the result was found very encouraging. The International standard for virgin oil and that of Ethiopia as well were compared with the result of quality analysis. The experience and the data were used as inputs for the workshop organized to introduce the concept of virgin oil. The need to increase efficiency of oil expression improves the cake/meal value as animal feed as high oil content reduces nitrogen solubility, decrease fiber digestibility, and increase methane production (Assefa, 2011).

Generally in addition to a short term target of import substitution, nigerseed oil has a big business potential for market of both domestic and outside Ethiopia especially if multinational companies who can promote the product are involved. The experimental seed yield the oil content of the nigerseed is quite encouraging. Particularly its high vitamin E and vitamin K content makes nigerseed oil quite attractive. If the seed handling which is bottleneck in virgin oil production is improved using the output of this study, small scale oil millers can be encouraged. Concerted effort across the value chain to bring this and other study result can improve the value addition as well as address nutritional problems. Even further research can be conducted specially on its nutraceutical aspect and this will make it even more attractive at this time where health concerns are growing.

7. Conclusions and Recommendations

Field study conducted for seed yield, oil content, fatty acid profile and vitamin E content of the two nigerseed varieties shows that the seed yield is encouraging mainly for comparison based on location as compared to any other factor like watering, seed rate and nitrogen rate. The seed yield observed was above the recommended profitable margin proposed by some studies (of course different location). The results of seed yield are compared for varieties by rain fed/irrigation, location, seed and nitrogen fertilizer. Similarly, the oil content of the seed is also interesting in that the oil content of the two locations (Adet and Koga) are reverse where seed yield is significantly higher in Adet and the oil content is significantly higher in Koga. This difference is supported by the fact that the ash content of Adet location is higher than that of Koga Further improvement of nigerseed/oil yield demands more attention on location comparison for the existing varieties until the best variety – location – rain fed/irrigation matching for even better seed and/oil is obtained. Since irrigation potential of nigerseed is nearly not attempted, irrigation cultivation should be given attention at least from the pilot scale in areas where irrigation facilities are available. Further irrigation experiments could include different levels of water stress since water stress is known to influence oil content and fatty acid profile from studies conducted on other oilseeds. In this study it was found that overall rain fed cultivation was found to be better yielding than the irrigation in this study for both seed yield and oil content. Over and above mitigation of the general shortage, irrigation can be a remedy to acute shortage during off season where the price will also be higher. One of the factors contributing to decreased yield of nigerseed is obviously shattering of the seed in times of close to harvesting. Therefore harvesting of nigerseed before shattering will clearly give better result as recommended by many researchers. However since the farmers exclusively depend on natural sun drying (leaving the cut plant on the open field) shattering is generally accepted as natural and inevitable by farmers. But if the facility for post-harvest drying of at least the whole plant on the sun is available and the threshing is done on a well prepared ground, the loss could decrease and the quality could improve.

The fatty acid analysis shows that nigerseed can be the best source of omega-6 and in agreement with previous works. Similarly vitamin E content is the best in comparison with up-to-date information available. Comparison of treatments shows that both fatty acid and vitamin E content are similar. The positive correlation between seed density and vitamin E was found to be very interesting and additionally the interaction of seed density and nitrogen fertilizer was also found to have positive correlation and this is worth further investigation. One of the major stages for loss of quality of both seed and oil is storage/handling of the seed. Accordingly control over storage facility/condition and storage period should be given more emphasis as this determines not only quality but also yield of the oil expressed from the seed.

The standardization and control can solve the problem of competing for an even low quality seed. Unnecessary hoarding of seed may also be discouraged. Consumption of nigerseed in different forms including the oil is a long tradition which is still persisting specially among the highlanders. Related to the tradition of consuming nigerseed oil aroma, flavor, and color of the oil is of paramount importance to the population consuming it for generations. In this regard virgin nigerseed oil pressed from quality seed will have better oil content, better quality and generally improves competitiveness of the value chain.

The efficiency of nigerseed oil expression by using screw press which is observed from this study was compared for feed rate, conditioning time and conditioning temperature. Particularly heating of the seed which serves both as raw material pretreatment and reduction of moisture appear to be promising for small scale pressers because the powerful sun/solar heating in Ethiopia is very convenient. Generally the heating temperature was found to be more yielding the time and feed rate.

From the literature, results of this study, practical experiences on nigerseed and other oilseeds the following recommendations are of value for further enhancement of the edible oil value chain with emphasis on virgin oil from nigerseed. Further improvement of seed yield appear to be possible if further locational comparisons are done for varieties, input supply is improved and the current knowledge and achievements are communicated to the farmers especially on harvest/post-harvest management of nigerseed the seed supply will improve. It seems reasonable to assume the supply of edible oil in Ethiopia will improve by the mushrooming small scale millers when the seed supply by a fair price is possible. The fact that nigerseed is the major preference in Ethiopian tradition can be taken as an opportunity for nigerseed and its oil producers' market. The oil millers in Ethiopia can play their role if institutionalized technology support is provided in addition to oilseed supply. It is known that either fresh type seed or properly stored seed must be used for virgin oil production. Therefore seed storage and handling must be given due attention. In this regard further studies are needed where different storage materials and conditions are included. Therefore deterioration kinetics of the seed is necessary in this regard. Concerning virgin oil special attention must be given to maintain it in an improved way of production while ensuring the quality. But there is a need to have a guideline for production of virgin oil and related control mechanism on the production system and final product packaging and handling. Studies on utilization of solar power for raw material pretreatment can simplify the process and reduce energy cost. Particularly for oil pressing and cleaning aspect technology support system must be in place so that this industry can play its role. Regarding the virgin oil sensory analysis of the oil is also important since the product quality includes the flavor, color and aroma. Thermal kinetics study on the oil is also necessary to understand its suitability for different temperature cooking.

Results of the nutritional composition of nigerseed oil so far is quite encouraging but the results should be more publicized and communicated in addition to further studies on this area. The high omega-6, α-tocopherol, and vitamin K (not included in this study), for instance, makes the oil more attractive including the possibility to blend with other oils. For example linseed oil can be one such oil for blending with nigerseed oil since it is very rich in omega-3 which is very low in nigerseed oil. The blend may even include the third or more diversified types of oil for better nutritional quality and consumer suitability. Therefore blending technology should be introduced with the view of curbing nutritional problem. Further health related researches should also be conducted by comparing regions consuming nigerseed oil with those consuming different oil. Therefore the shortage/quality of oilseed, edible oil can be solved by involvement of interdisciplinary researches from agriculture, food science/technology, nutrition/health and more in a well-planned way so that the present situation in Ethiopia changes.

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Appendices

Appendix I: Nutritional goals for age-gender groups, based on dietary reference intakes (Source: UDA and USDHHS, Dietary Guideline)

Nutrient (units)	1-3	4-8		9-13		14-18		19-30		31-50		51+	
	Child	F	M	F	M	F	M	F	M	F	M	F	M
Protein (g)	13	19	19	34	34	46	52	46	56	46	56	46	56
(% calories)	5-20	10-30	10-30	10-30	10-30	10-30	10-30	10-35	10-35	10-35	10-35	10-35	10-35
Carbohydrate (g)	130	130	130	130	130	130	130	130	130	130	130	130	130
(% calories)	45-65	45-65	45-65	45-65	45-65	45-65	45-65	45-65	45-65	45-65	45-65	45-65	45-65
Total fiber (g)	14	17	20	22	25	25	31	28	34	25	31	22	28
Total fat (% calories)	30-40	25-35	25-35	25-35	25-35	25-35	25-35	20-35	20-35	20-35	20-35	20-35	20-35
Satur. fats (% cal)	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
LA (g)	7	10	10	10	12	11	16	12	17	12	17	11	14
LA (% cal)	5-10	5-10	5-10	5-10	5-10	5-10	5-10	5-10	5-10	5-10	5-10	5-10	5-10
ALA (g)	0.7	0.9	0.9	1.0	1.2	1.1	1.6	1.1	1.6	1.1	1.6	1.1	1.6
ALA(% cal)	0.6-1.2	0.6-1.2	0.6-1.2	0.6-1.2	0.6-1.2	0.6-1.2	0.6-1.2	0.6-1.2	0.6-1.2	0.6-1.2	0.6-1.2	0.6-1.2	0.6-1.2
Cholesterol (mg)	<300	<300	<300	<300	<300	<300	<300	<300	<300	<300	<300	<300	<300

Appendix II: Comparison of mean seed yield of two nigerseed varieties (V) with varying seed rate (SR) and nitrogen rate (NR) and cultivated at two locations and two water supply modes with 95.0% CI.

Factor		Koga by Irrigation				Koga by Rain fed				Adet by Rain fed			
Level and Interac	Count	Mean	Stnd. Error	Lower Limit	Upper Limit	Mean	Stnd. Error	Lower Limit	Upper Limit	Mean	Stnd Error	Lower Limit	Upper Limit
G. MEAN	54	976.0				1064.7				1384.6			
SR													
5	18	944.9	37.30	869.3	1020.6	976.6	58.23	858.50	1094.7	1474.4	49.3	1374.4	1574.3
10	18	993.6	37.30	917.9	1069.2	1116.0	58.23	997.89	1234.1	1372.6	49.3	1272.6	1472.5
15	18	989.5	37.30	913.9	1065.2	1101.6	58.23	983.46	1219.7	1306.9	49.3	1206.9	1406.9
NR													
13	18	901.1	37.30	825.5	976.78	1010.9	58.23	892.78	1129.0	1376.1	49.3	1276.1	1476.0
23	18	992.6	37.30	917.0	1068.3	1155.5	58.23	1037.4	1273.6	1392.5	49.3	1292.5	1492.5
33	18	1034.2	37.30	958.6	1109.9	1027.8	58.23	909.67	1145.9	1385.2	49.3	1285.3	1485.2
V													
Fogera	27	1005.6	30.45	943.8	1067.3	1082.9	47.55	986.44	1179.3	1335.3	40.3	1253.7	1416.9
Kuyu	27	946.4	30.45	884.7	1008.2	1046.6	47.55	950.14	1143.0	1433.9	40.3	1352.3	1515.5
SR x NR													
5,13	6	921.7	64.60	790.7	1052.7	906.8	100.9	702.20	1111.3	1516.2	85.4	1343.0	1689.3
5,23	6	916.8	64.60	785.8	1047.8	1064.0	100.9	859.48	1268.6	1498.9	85.4	1325.8	1672.1
5,33	6	996.3	64.60	865.3	1127.3	959.0	100.9	754.46	1163.6	1408.0	85.4	1234.8	1581.2
10,13	6	846.3	64.60	715.3	977.35	1095.9	100.9	891.36	1300.5	1368.4	85.4	1195.3	1541.6
10,23	6	1077.7	64.60	946.7	1208.7	1189.3	100.9	984.73	1393.8	1319.4	85.4	1146.2	1492.6
10,33	6	1056.6	64.60	925.6	1187.6	1062.8	100.9	858.21	1267.3	1429.8	85.4	1256.6	1603.0
15,13	6	935.4	64.60	804.4	1066.4	1029.9	100.9	825.40	1234.5	1243.6	85.4	1070.4	1416.7
15,23	6	983.4	64.60	852.4	1114.4	1213.2	100.9	1008.7	1417.8	1359.1	85.4	1186.0	1532.3
15,33	6	1049.8	64.60	918.8	1180.8	1061.5	100.9	857.0	1266.1	1317.9	85.4	1144.8	1491.1

Appendix II (Cont'd): Comparison of mean seed yield of two nigerseed varieties (V) with varying seed rate (SR) and nitrogen rate (NR) and cultivated at two locations and two water supply modes with 95.0% CI.

Factor		Koga by Irrigation				Koga by Rain fed				Adet by Rain fed			
Level and Interac	Count	Mean	Stnd. Error	Lower Limit	Upper Limit	Mean	Stnd. Error	Lower Limit	Upper Limit	Mean	StndError	Lower Limit	Upper Limit
SR x V													
5,Fogera	9	1015.3	52.74	908.3	1122.3	1008.4	82.35	841.40	1175.4	1456.9	69.7	1315.5	1598.3
5,Kuyu	9	874.6	52.74	767.6	981.54	944.78	82.35	777.76	1111.8	1491.8	69.7	1350.4	1633.2
10,Fogera	9	1024.6	52.74	917.6	1131.5	1142.3	82.35	975.26	1309.3	1302.9	69.7	1161.5	1444.3
10,Kuyu	9	962.6	52.74	855.6	1069.5	1089.7	82.35	922.68	1256.7	1442.2	69.7	1300.8	1583.6
15,Fogera	9	976.8	52.74	869.9	1083.8	1097.9	82.35	930.90	1264.9	1246.1	69.7	1104.7	1387.5
15,Kuyu	9	1002.2	52.74	895.2	1109.2	1105.2	82.35	938.19	1272.2	1367.7	69.7	1226.3	1509.1
NR x V													
13,Fogera	9	949.8	52.74	842.9	1056.8	999.73	82.35	832.72	1166.8	1335.0	69.7	1193.6	1476.4
13,Kuyu	9	852.4	52.74	745.5	959.41	1022.0	82.35	855.00	1189.0	1417.1	69.7	1275.7	1558.5
23,Fogera	9	1043.7	52.74	936.8	1150.7	1161.5	82.35	994.48	1328.5	1323.0	69.7	1181.6	1464.9
23,Kuyu	9	941.5	52.74	834.6	1048.5	1149.5	82.35	982.50	1316.5	1462.0	69.7	1320.6	1603.4
33,Fogera	9	1023.1	52.74	916.2	1130.1	1087.4	82.35	920.36	1254.4	1347.9	69.7	1206.5	1489.3
33,Kuyu	9	1045.3	52.74	938.4	1152.3	968.16	82.35	801.14	1135.2	1422.6	69.7	1281.2	1564.0

Appendix III: Contrast of variety, location and water supply mode

Contrasts ……with…….		Sig.
Fogera-Adet-Rain fed	Fogera-Koga-Irrigation	*
Fogera-Adet-Rain fed	Fogera-Koga-Rain fed	*
Fogera-Adet-Rain fed	Kuyu-Adet-Rain fed	NS
Fogera-Adet-Rain fed	Kuyu-Koga-Irrigation	*
Fogera-Adet-Rain fed	Kuyu Koga Rain fed	*
Fogera-Koga-Irrigation	Fogera-Koga-Rain fed	NS
Fogera-Koga-Irrigation	Kuyu-Adet-Rain fed	*
Fogera-Koga-Irrigation	Kuyu-Koga-Irrigation	NS
Fogera-Koga-Irrigation	Kuyu Koga Rain fed	NS
Fogera-Koga-Rain fed	Kuyu-Adet-Rain fed	*
Fogera-Koga-Rain fed	Kuyu-Koga-Irrigation	*
Fogera-Koga-Rain fed	Kuyu Koga Rain fed	NS
Kuyu-Adet-Rain fed	Kuyu-Koga-Irrigation	*
Kuyu-Adet-Rain fed	Kuyu Koga Rain fed	*
Kuyu-Adet-Rain fed	Kuyu Koga Rain fed	NS

Appendix IV: Oil content for each factor at various levels.

		Koga Irrigation				*Koga Rain fed*				*Adet Rain fed*			
Level	*Count*	*Mean*	*Stnd. Error*	*Lower Limit*	*Upper Limit*	*Mean*	*Stnd. Error*	*Lower Limit*	*Upper Limit*	*Mean*	*Stnd. Error*	*Lower Limit*	*Upper Limit*
GRAND MEAN	54	39.59				41.54				38.67			
SR													
5	18	38.24	1.12	35.97	40.51	40.88	0.68	39.51	42.26	38.44	0.60	37.22	39.66
10	18	40.17	1.12	37.90	42.44	42.00	0.68	40.62	43.38	39.11	0.60	37.89	40.33
15	18	40.35	1.12	38.08	42.62	41.72	0.68	40.35	43.10	38.47	0.60	37.25	39.69
NR													
13	18	39.74	1.12	37.47	42.01	41.79	0.68	40.42	43.17	39.23	0.60	38.02	40.45
23	18	41.12	1.12	38.85	43.39	40.71	0.68	39.33	42.08	37.92	0.60	36.70	39.14
33	18	37.90	1.12	35.63	40.17	42.10	0.68	40.73	43.48	38.87	0.60	37.65	40.09
V													
Fogera	27	39.50	0.91	37.64	41.35	41.29	0.55	40.16	42.41	39.02	0.49	38.02	40.01
Kuyu	27	39.68	0.91	37.82	41.53	41.78	0.55	40.66	42.91	38.33	0.49	37.34	39.33
SR by NR													
5,13	6	37.03	1.94	33.10	40.97	40.93	1.18	38.55	43.31	39.22	1.04	37.11	41.33
5,23	6	42.20	1.94	38.27	46.13	41.37	1.18	38.99	43.75	36.87	1.04	34.76	38.98
5,33	6	35.50	1.94	31.57	39.43	40.36	1.18	37.97	42.74	39.22	1.04	37.11	41.33
10,13	6	41.03	1.94	37.10	44.97	41.85	1.18	39.46	44.23	39.32	1.04	37.21	41.43
10,23	6	38.85	1.94	34.92	42.78	41.81	1.18	39.43	44.19	37.81	1.04	35.70	39.92
10,33	6	40.62	1.94	36.68	44.55	42.34	1.18	39.96	44.73	40.20	1.04	38.09	42.31
15,13	6	41.17	1.94	37.23	45.10	42.61	1.18	40.22	44.99	39.16	1.04	37.05	41.27
15,23	6	42.30	1.94	38.37	46.23	38.95	1.18	36.57	41.33	39.08	1.04	36.96	41.19
15,33	6	37.58	1.94	33.65	41.52	43.61	1.18	41.23	45.99	37.18	1.04	35.07	39.29
SR by V													
5,Fogera	9	38.94	1.58	35.73	42.15	41.89	0.96	39.95	43.84	39.16	0.85	37.44	40.88
5,Kuyu	9	37.54	1.58	34.33	40.75	39.88	0.96	37.93	41.82	37.72	0.85	35.99	39.44
10,Fogera	9	40.64	1.58	37.43	43.85	41.61	0.96	39.66	43.55	40.28	0.85	38.55	42.00
10,Kuyu	9	39.69	1.58	36.48	42.90	42.39	0.96	40.45	44.34	37.95	0.85	36.22	39.67
15,Fogera	9	38.90	1.58	35.69	42.11	40.36	0.96	38.42	42.31	37.62	0.85	35.89	39.34
15,Kuyu	9	41.80	1.58	38.59	45.01	43.08	0.96	41.14	45.03	39.33	0.85	37.61	41.05
NR by V													
13,Fogera	9	39.69	1.58	36.48	42.90	41.70	0.96	39.76	43.65	39.45	0.85	37.72	41.17
13,Kuyu	9	39.80	1.58	36.59	43.01	41.88	0.96	39.94	43.83	39.02	0.85	37.30	40.75
23,Fogera	9	41.99	1.58	38.78	45.20	40.47	0.96	38.52	42.41	38.45	0.85	36.72	40.17
23,Kuyu	9	40.24	1.58	37.03	43.45	40.95	0.96	39.00	42.89	37.39	0.85	35.67	39.11
33,Fogera	9	36.81	1.58	33.60	40.02	41.69	0.96	39.74	43.63	39.16	0.85	37.44	40.88
33,Kuyu	9	38.99	1.58	35.78	42.20	42.52	0.96	40.57	44.46	38.58	0.85	36.85	40.30

Appendix V: Least Squares for vitamin E for each level of the factors with 95.0% CI

Factors, Level	Count	Mean	Lower Limit	Upper Limit
GRAND MEAN	54	**0.069**		
Variety	(standard error = 0.0022)		p value = 0.58	
Fogera	27	**0.068**	0.0631	0.0722
Kuyu	27	**0.069**	0.0648	0.0740
S rate (standard error = 0.0028)			p value = **0.01**	
5	18	0.066	0.0608	0.0720
10	18	0.063	0.0578	0.0690
15	**18**	**0.076**	**0.0702**	**0.0814**
N rate	(standard error = 0.0028)		p value = 0.79	
13	18	0.067	0.0617	0.0728
23	18	0.068	0.0627	0.0739
33	18	0.070	0.0644	0.0755
Variety by S rate	(standard error = 0.0039)		p value = 0.85	
Fogera,5	9	0.065	0.0567	0.0725
Fogera,10	9	0.062	0.0543	0.0701
Fogera,15	9	0.076	0.0682	0.0840
Kuyu,5	9	0.068	0.0603	0.0761
Kuyu,10	9	0.065	0.0567	0.0726
Kuyu,15	9	0.075	0.0675	0.0834

*Variety x seed rate x nitrogen rate interaction has p value of 0.9385.

Appendix V (Cont'd): Least Squares for vitamin E for each level of the factors with 95.0% CI

Factors, Level	Count	Mean	Lower Limit	Upper Limit
GRAND MEAN	54	**0.069**		
Variety by N rate	(standard error = 0.0039)		p value = 0.84	
Fogera,13	9	0.066	0.0585	0.0744
Fogera,23	9	0.069	0.0607	0.0765
Fogera,33	9	0.068	0.0600	0.0758
Kuyu,13	9	0.068	0.0602	0.0760
Kuyu,23	9	0.068	0.0602	0.0760
Kuyu,33	9	0.072	0.0641	0.0799
S rate by N rate	(standard error = 0.0048)		p value = 0.86	
5,13	6	0.066	0.0565	0.0758
5,23	6	0.065	0.0553	0.0747
5,33	6	0.068	0.0583	0.0777
10,13	6	0.064	0.0547	0.0740
10,23	6	0.064	0.0538	0.0732
10,33	6	0.062	0.0527	0.0720
15,13	6	0.071	0.0617	0.0810
15,23	6	0.077	0.0668	0.0862
15,33	**6**	**0.080**	**0.0698**	**0.0892**

*Variety x seed rate x nitrogen rate interaction has p value of 0.9385.

Author's declaration

I hereby declare that I have completed the dissertation independently, and this research is original. I have not been supported by any agent in writing this dissertation. Also no aids other than the sources indicated herein. This work has not been previously used fully or partly to achieve any academic degree.

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