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Sesame (*Sesamum indicum* sp) seed security and breeding programme to
improve resilience of small holder farmers in Somalia

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Abstract

Sesame (*Sesamum indicum* L.) notwithstanding is cultivated since more than 5,000 years still challenges the basic domestication criteria: grows indeterminately and its scalar fruit ripen generates abundant losses at harvest time. Sesame is grown in Somalia (one of the most social, political economic and environmental fragile country in the world) by small holder farmers living below the threshold of extreme poverty. General consensus exists about the scarce research and genetic improvement particularly on African accessions of sesame.

This work tested on field 5 sesame accessions to identify the most appropriate GAP and to have a phenotypic description of the most relevant morpho-productive traits in different ecosystems. Eventually through the adoption of SSR markers it has been measured the genetic distances among these accessions and 6 more from different African countries in order to design the most appropriate breeding programme per the different ecosystems considered.

The field trials conducted in Somalia revealed a strong interaction between site and variety. The correlation analysis performed showed that in three sites in Somalia, yield per plot resulted correlated to plant height, days 50% flowering, the number of seeds per capsule and the yield per plant. In Kenya trials conducted along two seasons confirmed a different behavior of the different varieties in the different environments through a highly significant correlation existing in Kilifi between yield per plant and number of capsule per plant and average weight of capsule, while in Busia yield per plant was correlated to plant height, number of capsules, number of seeds per capsule, number of branches per plant and average weight per capsule.

The genomic analysis revealed a high level of polymorphism among the considered 11 African accessions and a great plasticity and adaptation capacity to the different environments for the 5 varieties tested on field.

Being the sesame demand on the world market inelastic (it continues growing regardless the price growth), the adoption of the suggested GAP and improved sesame varieties, open a window of opportunity to improve the income of small holder farmers in Somalia. Those farmers in riverine on the Shabelle river who adopted the identified GAP (including the seasonal crop rotation with Maize) and best performing varieties increased their income at 1.04 USD/day/person.

1. Introduction

Somalia is a fragile country: under natural, social, political and economic aspects. This fragility is the main cause of the worst world famine in the last 20 years occurred in 2011 in the South Central Region of the country causing some 260,000 deaths. This terrible humanitarian catastrophe triggered the research presented below.

After 24 years of civil war, Somalia scores 113.9 out 120 points in Failed State Index being the first country in the world out of 178. In GDP per capita ranks 193 out of 195 (CIA with IMF data or estimate) with 600USD per capita per annum (in rural areas 56% of the population) farmers live with less than one dollar per person per day. In the Global Corruption Index ranks 175 out of 177 (shares the last position with two more countries scoring 8 points) while in the Human Development Index is not even ranked.

The natural environment is extremely fragile with floods and drought alternating often within the same season, with devastating effects on agricultural production and household income. Every season small holder farmers risk all they have and every season they are on the verge of famine or destitution. Farmers do agriculture following traditional patterns and lack the necessary knowledge about how to grow crops without contributing to desertification.

Under these conditions it is essential to develop an agricultural system supporting sustainable crop production not based on unsustainable intensification through adoption of hybrids and use of fertilizer but on local germplasm. There is no room in these pages to go into details to justify these statements: it is enough to say that general consensus exists on this approach among the scientific and practitioners' communities. Here is where sesame proves useful.

Sesame (*Sesamum indicum* L.) is a controversial crop and many contradictions pops up when it is closely observed. There are evidences that Sesame has been cultivated in Mesopotamia since 3500 BC to produce oil (see D. Bedigian 1986, 2010, 2011a), and is under cultivation in Asia for over 5000 years (Bisht et al., 1998)¹ thus it is probably the oldest grown oilseed². It cannot be considered a domesticated plant as though it is cultivated since more than 5,000 years it grows un-determinedly and keeps the shattering characteristic at maturity that causes significant losses at harvest time.

Sesame is important for human nutrition and economy (its seeds stores 40-50 % of their weight in oil and practically as much in protein) but ranks only ninth out of the thirteen oil crops producing 90% of the edible oil produced in the world. Its international market price grows constantly (possibly remaining low at farm gate) pulled by the improved economy in middle level class of the emerging countries (mainly India and China who are also two of the main producers in the world) but the production area and productivity do not, due respectively to the geographical/environmental constraints and to very limited research³.

¹ It seems to have originated in Africa (all wild sesame species are found in Africa, cf. Raemakers, 2001) but the largest production of sesame takes place in Asia.

² Yet it largely remains a mysterious plant with very low level of real domestication. It is mysterious because its intrinsic characteristics are not well known as well as its performances and responses to different agronomic practices, and contrasting information about the most appropriate cultivation methods and relatively poor information of its genome.

³ Sesame is grown in a narrow belt around the world (about 7 million ha) in tropical and subtropical area thus it is a developing country crop, grown mainly by small holder farmers (large farmers do not grow sesame as it is not mechanizable).

The uttermost contradiction is that sesame, in all countries of the world (the sole exception so far is United States) is a cash crop grown by subsistence farmers. It helps them to survive and is in itself a surviving crops adapted to environments where other crops may hardly survive. In Africa it is grown in most poor countries by the poorest farmers in the poorest environmental conditions generally under moisture stress and whenever the income level of farmers grows it is abandoned.

India and China are the world's largest producers of sesame, followed by Myanmar, Sudan, Uganda, Nigeria, Pakistan, Tanzania, Ethiopia, Guatemala (the only relevant country in the American continent with exception of USA) and Turkey (FAO stat on line) and the sole unshattering commercial variety is produced under patent in USA.

In 2011 8,7 Million of ha have been grown to produce sesame, producing about 3.9 M of tons with China, India and Myanmar producing about 45% of it. The main consumers are China, Japan, EU27 and India. The principal importers are China, Japan and the EU27. Even if among the ten major exporters there are 6 African countries, two thirds of exports come from Asian countries. The main exporters are India, Myanmar, Ethiopia, Nigeria, Sudan (former), and United Republic of Tanzania.

All the above results in an international trade summing up to 15.6 Million of Tons traded in 2011 at 21.2 Billion of USD⁴. Sesame cultivated area and trade are growing year by year since 2005 but yield (kg/ha) remain low. Probably the most relevant cause of poor yield is the mix of socio economic limitations (poor farmers with scarce financial resources i.e.: lack of possibility/willingness to buy commercial seed with limited access to GAP knowledge) and technical-scientific constraints (scarcity of breeding programme adapting high yielding varieties to the different geographical areas and ecosystems).

Notwithstanding the actual scenario, due to its high potential for household economy and nutrition, this crop is worth to be supported and this work will contribute demonstrating it. Some explanations about all the above mentioned contradictions will be provided along this research, but the underlying explanation for all of them is that sesame is a poor crop for poor farmers. *Subsistence farmers have grown sesame in Asia and Africa for several millennia, often intercropped with other essential cereal and legume species. Smallholders have safeguarded and created new biological diversity, availing themselves of environmental influences for selection, managing soil and water needs, and maintaining their livelihoods with the help of sesame, even under harsh conditions. Sesame is a crop that can succeed in locations where few others can, and without extraordinary inputs of fertilizer, pesticide, fossil fuels, or arduous labour. No university in the United States has any scientist doing research on sesame* (with the exception of a private company in USA) (Bedigian D. 2010).

Recently India and China are investigating on this crop and also some African countries (Ethiopia, Kenya, Mali, Namibia, Syria, Tanzania, Uganda, Yemen, Mozambique) are conducting same field research⁵, with their scarce available resources, pulled by the high demand and prices fetched in the international market. Anyhow results in terms of domestication and identification of GAP are still scarce.

⁴ Export Quantity: 8.5 MT; Import Quantity: 7.2 MT; Export Value: 11 BUSD; Import Value: 10.2 BUSD.

⁵ Several studies are reported in literature, conducted by researchers from African countries. More than often, even after contacting directly the author, these study resulted to be, at different levels, inconsistent or not reliable when not existent (e.g.: unshattering cultivars from Thailandia, male sterile plants in Colombia, cropping methods and weed control in Mozambique, genomic analysis in China). The latter probably due to research funded by international donors and to political pressure on researcher responding to a will of expanding this crop. The scenario is changing in the last few years and one significant exception is a private company in USA producing sesame hybrids and exploiting it commercially on a large scale.

This research aims to contribute to the above identifying the best agricultural practices to grow sesame, at least for East African environment, setting the basis for a locally developed breeding programme aiming at genetic improvement comparing phenotypic characters with genomic analysis results and finally measuring the impact in the livelihoods of smallholder farmers of cropping improved sesame varieties.

The overarching objective of this study is to improve the income level of Somali small holder farmers who grow sesame. This research on sesame is part of a wider germplasm investigation conducted along the last six years on other staple foods including maize aiming at improve the cropping system in Somalia, agricultural production and income at household level.

This dissertation consists of three different sections each one consistent on its own:

1. field trials to identify the best agricultural practices to grow sesame in Somalia;
2. phenotypic and genomic analysis to identify the best possible breeding programme considering different ecosystems and the available germplams;
3. finanacial analysis of sesame cropping to measure the impact of the identified Good Agricultural Practices (GAP) and germplasm on income growth at household level.

Each part may be read separately, but only appreciating the links among the three sections it might be valued the impact of this work in terms of food security, seed security and income growth.

2. General description

2.1. Morphological and productive characters

Sesame belongs to the Pedaliaceae family and comprises 13 genera and about 20 species, (Ihlenfeldt 2001) and an estimated 75 perennial herbs most of which are indigenous to tropical Africa with two distinct sections found in India.

Sesame is an annual short day plant. Depending on the variety and the environmental conditions, it flowers in 30-45 days, it is usually self-pollinated and mature between 70 and 150 days after sowing. Typically in Somalia sesame matures after 75 days and in Kenya after 90. It may grow between 1 and 1.5 m but in some cases do not pass 50 cm (personal trials in Kenya) or exceeds 2 m. It is grown from sea level to 1500 m asl in a narrow belt along the equator ranging from 0° to 35° S and N. It is very sensitive to soil temperature. With a soil temperature of 25-27 °C germination takes place in 6-7 days. Below 20°C germination is slow and below 10°C is inhibited. Sesame grows well in moderately fertile, well drained soils with pH ranging from 5.5-8. Growth and yield will be depressed in soil with poor moisture retention and as well with water logging: if water logs for more than two days sesame dies.

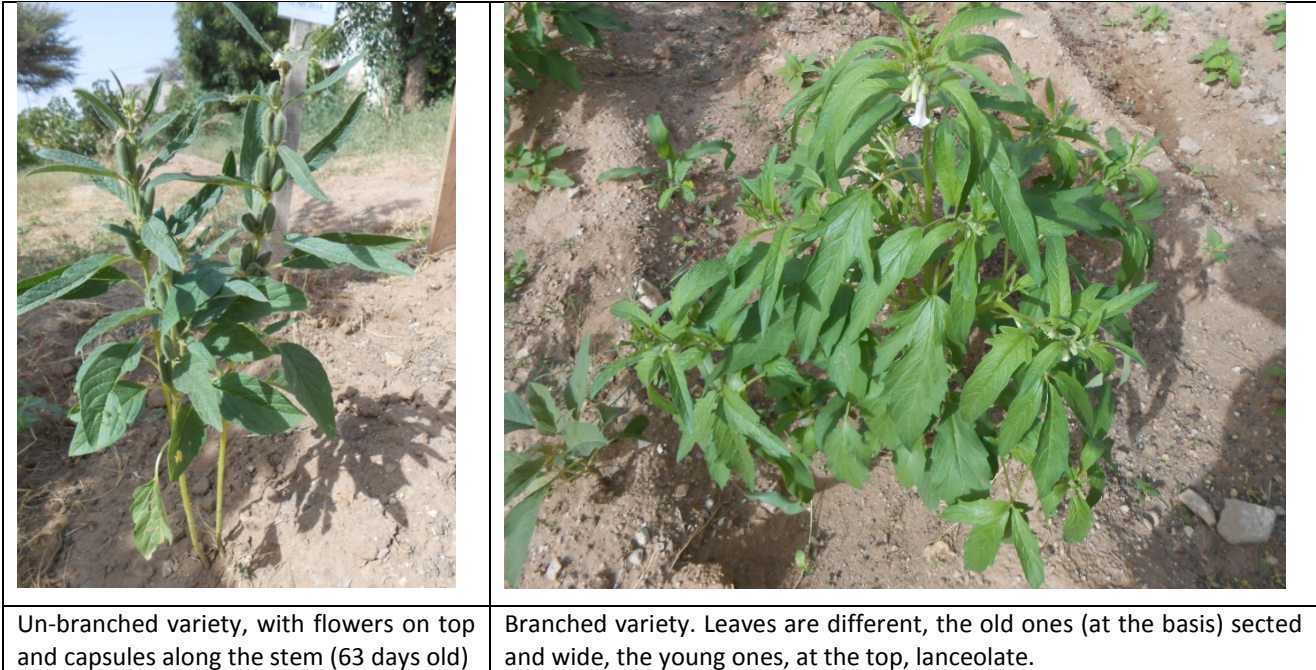
Sesame has an undetermined growth habit, producing leaves, flower buds, flowers and capsules continuously as long as weather conditions allow it. It is very slow in growing during early stage (initial 2-3 weeks) but then starts growing fast. This growing habit is also cause of the coexistence in the same plants of young flower buds close to the shoot apex, early capsules mature in the middle of the plant, and shattering capsules at the basis (Figure 6). Improving this growth habits by reaching simultaneous maturity with unshattering character is essential to improve productivity reducing harvest and post harvest losses, and when possible allowing the mechanization of harvest.

Sesame has generally square, erect and empty stem with marked furrows in it. Stem colour ranges from pale green to purple. Some varieties are branched and some not. Indeed some varieties show branched or un-branched character depending on the environmental conditions. This character is particularly relevant at sowing time as the spacing shall be reduced and sowing seed rate increased.

Sesame is moderately tolerant to drought thanks to a large, dense and deep rooting system.

Leaves are extremely variable in shape, size, margins and surface texture (Figure 1). This variability appears among different varieties but also within the same plant. The lower leaves are opposite, lobed, broad and palmate and sometime trifoliate. Higher up in the plant they are alternately arranged, narrow and lanceolate and toothed, measuring from 2 to 15 cm in length and 1 to 2 cm in large. They are hairy on both sides.

Figure 1: Sesame branched and unbranched varieties



Young leaves are rich in minerals and proteins and in Sub Saharan Africa and China are considered a vegetable food eaten during famine. Leaves may be dried and stored for use during food scarcity (Bedigian 2011).

Sesame leaves are also coated with a minute mucilage (trichomes) that seems to be an adaptation to resist to hydric stress offering resistance to wilting, insulate against heat and direct radiation (Ehleringer 1984).

Figure 2: sesame flower



Flowers are produced in the leaf axis bearing 1-6 flowers after 3-6 weeks from sowing, when the plant is as high as 20-30 cm (Figure 2). Their color ranges from pale green in its early stages to yellow and finally pink or purple: descriptors report 9 colors. Flower is campanular, with a tubular corolla long at maturity 3-4 cm. It is characteristic the lower lobe of the corolla which is longer and closes the campanula up to the maturity when it opens. In each flower there are four fertile stamens and one sterile fused at the basis of the corolla. Sesame is cleistogamous by nature, is predominantly self-pollinated before the flowers open, although crosspollination by insects may occur with an incidence variable from 1% (reported in cases where other crops attracting insects are nearby) to 68% (in isolated plot or in a dry area with minimal other vegetation)

(Ashri, A. 2007). The flowers usually open at dawn, and the pollen is shed shortly after and remains viable for about 24 hours. On cloudy or cool days, the flowers may open up to 3 hours after sunrise. Stigmas become receptive a day earlier and normally remain receptive for 2 more days if not fertilized. Sesame fertilization is compromised by temperatures below 15°C and above 40°C as they lead to pollen sterility and eventually cause reduced yield.

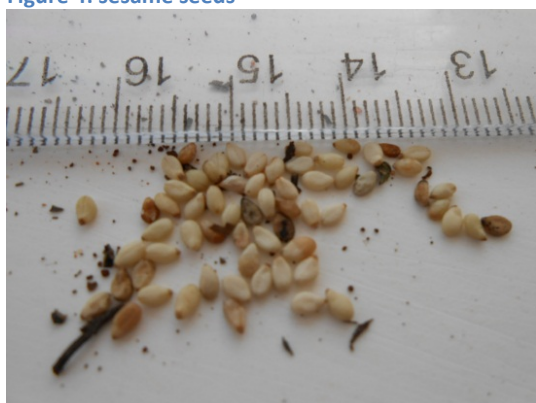
Figure 3: capsule before harvesting (while the plant is still flowering) and dehiscent capsule bi-carpellate



The fruit are erect, oblong quadrangular capsules bi, tri or tetra-carpellate (Fig. 3). Within each carpel there are two locules; thus, in a bicarpellate capsule there are four rows of seeds, six in a tricarpellate and 8 in a tetracarpellate capsules. Complete or incomplete false membranes (septa) cover each carpel and affect seed retention. Capsules are about 2.5-4 cm long depending from the variety. Each capsule may contain 50-120 seeds. It takes 4-6 six weeks from anthesis to fruit maturity. The number of capsules per plant depends on the variety, the environment and the size of the plant: the tallest the plant, the higher the number of capsules. In general each plant may have from 40 to 180 capsules. Even if exist indehiscent varieties, the vast majority of cropped sesame has dehiscent varieties that open automatically when dry, splitting from the top downwards for about two thirds of their length and shed their seeds, which without timely harvesting, leads to yield losses. Farmers growing sesame, minimize harvest losses due to shattering and uneven ripening by harvesting when 70-80% of branches are mature before the lowest capsules open, and then binding the harvested plants in vertical bundles to limit post- harvest loss (Figure 6).

SESACO patented a method for making non dehiscent sesame (Patent number 6,100,452 on August 8, 2000 in <http://www.freepatentsonline.com/6100452.pdf>).

Figure 4: sesame seeds



Seeds dicotyledon are small without endosperm (Fig. 4); their shape is flat, obovoid, 2-3 mm long, 0.5-1 mm thick the weight of 1000 seeds ranges from 2 to 3.5 g. Seeds have a smooth surface and a high variability in colours: from white (the most appreciated and used in bakery) to black with a wide range of tonalities (ivory, grey, tan, beige, brown, red). The same plant may produce seeds with almost all these tonalities. Seeds well stored remain viable for at least one year and are subject to dormancy.

The seeds are rich in nutrient and may be used in bakery industry (decorticated or not) or to produce oil. The cake remaining from the press is used as feed for animals with a 35% content in proteins, 5-6% of crude fibre from unhulled seed (about 3% in cake from hulled seed) and very rich in Ca and phosphate 100 g of dry decorticated sesame seed contains water (3.8 g), energy (2640 kJ; 631 kcal), protein (20.5 g), fat (60.2 g), carbohydrate (11.7 g), dietary fiber (11.6 g), Ca (60 mg), Mg (345 mg), P (667 mg), Pe (6.4 mg), Zn (6.7

mg), vitamin A (9 IU), thiamin (0.70 mg), riboflavin (0.09 mg), niacin (5.80 mg), folate (115 mg), and no ascorbic acid (USDA 2005 Dorothea Bedigian, 2011a).

2.2. Use of Sesame

Sesame seeds are an important source of oil (44-58%), protein (18-25%), and carbohydrates (13.5%) and are traditionally consumed directly. They are used as active ingredients in antiseptics, bactericides, viricides, disinfectants, moth repellents, and antitubercular agents as they contain natural antioxidants such as sesamin and sesamol. Among the primary edible oils, sesame oil has the highest antioxidant content and contains abundant fatty acids such as oleic acid (43%), linoleic acid (35%) (Wei et al. 2011).

Farmers in Somalia obtain from sesame edible oil (*ma'saro*) mainly used in season food. There is something sacred about sesame oil, as a traditional plate called *bun* usually prepared on Friday morning, made with sesame oil and coffee grains and used where there are religious services. People prepare also some sweets with sesame oil and sugar.

Sesame oil contains about 80% unsaturated fatty acids, with oleic (37-50%) and linoleic (37-47%) palmitic acid (11%), and stearic acid (7%). Sesame oil is important in the food industry because of its distinct flavour. The oil content of sesame is the most valued characteristic and one of the main reasons for its cultivation; this is why there are a lot of conjectures about the possibility to identify some phenotypic characters to be used as indicators of the oil content. In literature data about the predictability of oil content are discordant. Somali farmers assure that black sesame seed is richer in oil than the white ones. Parthasarathy and Kedharnath (1949) stated that black and brown seeds contain more oil, but that oil from white seeds is superior in quality. However, a study in Sudan of 20 exotic and 26 local strains of sesame of various seed colours did not confirm any of these contradictory claims. More recently Tabatabey et al (2011) did not find any correlation between seed coat colour and oil content in agreement with findings of El Tinay et al. (1976) and Bedigian (2010a). Finally it seems that there is no association between seed colour and oil content.

Sesame is also used in medicine (leaves are used to control vomiting, dysentery and other intestinal disorder), cookery and, as mentioned earlier, for practices related to religion or even superstition (in Jamaica wards off evil in voodoo rituals).

2.3. Genetic of Sesame

The basic chromosome numbers in *Sesamum* genus are $x = 8$ and 13. The $x = 13$ number probably resulted from ancient polyploidy (Ashri 2007) the diploid chromosome numbers is $2n = 26$ but also $2n=32$ and $2n = 64$. The chromosome number has been determined for 11 species only (Ashri A. 2007).

2n= 26	2n=32	2n=64
<i>S. indicum</i>	<i>S. prostratum</i>	<i>S. radiatum</i> <i>S. schinzianum</i>
<i>S. alatum</i>	<i>S. latifolium</i>	
<i>S. capense</i>	<i>S. laciniatum</i>	
<i>S. mabaricum</i>	<i>S. angolense</i>	
	<i>S. angusifolium</i>	

The goal of most sesame breeders is to achieve high-yielding, non-shattering, disease-resistant cultivars.

The dehiscence of the sesame seed pod is the principal obstacle to the widespread acceptance of sesame as a commercial crop as it inhibits the mechanization of harvest and causes severe losses at harvest time. In 1942, D. G. Langham (1946), the pioneer of genetic improvement of Sesame, found in Venezuela a natural

mutant on a sesame plant where capsules did not open at maturity and all the seeds were retained inside the unopened capsule. Langham showed, in the following generations of this plant, that indehiscence was produced by a recessive single gene *id/id*. Unfortunately the indehiscent characteristic could not be separated by negative traits (reduced number of seeds, lower yield, higher susceptibility to diseases) in addition capsules were too tough to effectively release the seed, as many of the capsules passed through a combine without opening and when a more rigorous combining was attempted more capsules opened but more seeds were broken and the broken seeds released free fatty acid leading to rancidity and undesirability of the harvested seed.

Ashri and Ladizinski (1964) found that splitting of the indehiscent capsules is prevented mainly by an increase in the number of mesocarp cell layers at the sutures. They concluded that capsule dehiscence, which is brought about by differential tensions in the capsule walls due to repeated moisture absorption and drying, is prevented by these extra cells. According to Day (2000) -only qualitative difference between the dehiscent and indehiscent (*idid*) materials consists in the presence of "many cell layers between the median vascular bundle and the epicarp" at the capsule sutures in the dehiscent varieties.

In 1982, SESACO produced the first non-shattering line (retaining 50-70% of the seeds set) and other varieties were developed between 1988 and 1997 which allowed for direct combining with 70-90% seed retention, notwithstanding, extensive loss of seed due to adverse weather conditions (wind and rain) continued to occur. Lines that generally yielded 80% of the seed under ideal conditions would yield only 45-65% under adverse conditions. New lines of sesame have now been discovered which are defined non-dehiscent. These lines retain most of the seed within the capsule despite adverse weather conditions and while mechanized harvested are competitive with manual harvesting. SESACO invention permits reduction of manual labour and concomitant economical and more rapid harvesting of sesame seed as a commercial crop (source <http://www.freepatentsonline.com/6100452.html>).

Sesame as mentioned earlier is mainly grown by small holder farmers in developing countries where food security is an issue and food production from staple food absorbs the limited investments in research for genetic improvements thus genetic and breeding improvement efforts in sesame have been limited and slow.

The spreading of genomic analysis tools in the last decade has boosted the research on genomic mapping and identification of markers for the most relevant characters using morphological markers.

Morphological markers are single genes with effects on the phenotype and are affected by environment, epistatic and pleiotropic interactions. These single genes often interact in a dominant/recessive manner so heterozygosis or homozygosis cannot be detected and for this reason often cannot fully reveal the genotype. They are inherited in a Mendelian manner but are limited in number (Seyitalioğlu, 2010)

Morphological markers have been used along this work in the genomic analysis of the studied varieties. Morpho-productive data collected on field have been crosschecked with a genomic analysis conducted on 11 different varieties/landraces in order to assess their genetic diversity.

2.4. Market of Sesame

Since around 2005 world sesame demand increased as a result of the economic growth of Asian countries that, being the major producer in the world are also the main consumers.

Demand demonstrated to be infinitely un-elastic with prices growing as well as supply.

This behavior of the demand may be an indicator of the incapacity of global supply to meet the demand. In fact, as mentioned earlier in this document, sesame may be cultivated only in a relative narrow strip along the equator due to its light and temperature requirements. Due to the fact that in the short run is not foreseeable any genetic improvement that may translate in increase of productivity, the growth in supply shall be reached through the expansion of cultivated land.

The constant growth of prices together with the constant growth of demand is opening a window of opportunity for African countries for sesame production.

In Somalia sesame is a cash crop partially used for self-consumption.

The potential area to grow sesame in Somalia is the same as maize in riverine and sorghum in rainfed: i.e.: some few hundred thousand of ha, with scarce competition with staple food due to the different cropping season (staple food, with longer growing cycle are cultivated in Gu while sesame, with a cropping cycle as short as 75 days is cultivated in Deyr). Actually sesame is grown along the Shabelle (in around 65,000 ha) and along the Juba, but also in rainfed areas of Bay Bakool and Somaliland with some 35,000 additional ha.

Sesame is cultivated as part of the risk mitigation strategies adopted by smallholder farmers. Indeed, the most important crops in Somalia are maize and sorghum usually grown during the long-rain season; vice versa, growing maize and sorghum in the short-rain season would be too risky: this is when sesame production is most appropriate.

Demand of sesame in Somali domestic market is high for direct consumption or processing to get oil. Pulled by international demand, sesame seed production is gradually increasing, and small holder farmers are benefitting of increased price, even if the quality only occasionally is adequate to international market.

Middlemen and traders in Bakara, the main grain market in Mogadishu, have created a trade flow of sesame, which is now constant and traditional, between Somalia and the Emirates. In Dubai sesame is sold on local market or re-exported with or without further cleaning process. The recently started exports in Europe are taking the same shape where the European traders buy to sell in domestic market or re-export (even to Arab Countries belonging to the South shore of Mediterranean sea) after a cleaning process.

3. Sesame cropping in Somalia

Along the previous pages emerged some of the many agriculturally favourable characters of sesame. It grows with residual soil moisture without supplemental irrigation under *deishék*⁶ conditions and is intolerant to waterlogging. It yields relatively well under high temperatures and dry conditions also on poor soils and marginal lands, where little else can survive demonstrating excellent adaptation capacity to stressful physical environments. The crop does best in warm temperatures with a long growing season, it is very sensitive to day length. All these characteristic have been noted along this research having tried several times to grow sesame in Nairobi (along dry and rain season) and comparing growth rate and performances from the coastal and the arid area of Kenya and of south central region of Somalia and of Somaliland.

⁶ Literally is recession, it is the agriculture based on sowing after the water recede. Some time, due to the high volume of water bringing the level of the water up to 50-80 cm, water remains on field during more than three weeks and this translates in a natural weed control system.

Almost all Somali farmers grow sesame in Deyr season in rotation with Maize grown in Gu season. Gu is the long rain season and allow for crop as long as 120 days while in Deyr, the short rain seasons allow short cycle crops as sesame. Sesame is planted soon after the rains (October, November), when the average temperature is between 29° and 34°C (the temperature requirement is 25°-35°C and sesame does not germinate below 18°C) and cropped as monoculture planted densely (200,000 plants/ha) to prevent competition from weeds. Sesame is drought tolerant, so it can grow and ripen in the dry season (Jilaal) and it can be harvested when no rains occur. It is sensitive to excessive rainfall and waterlogged soils, and does best on deep, free-draining sandy soils at pH 5.5 to 8. Sesame, being grown mainly by small holder farmers in Somalia, may be considered an organic crop as no fertilizer inputs and pesticides are used.

3.1. Cropping techniques

Sesame in Somalia is cropped in rotation with maize in irrigable land and with sorghum in rain fed areas. In the rest of the countries where it is grown, it participates in a number of rotation schemes. Due to its cropping pattern in early stages of development (roots growing fast and deep while shoot grows slowly) weeds represent a major problem and shall be kept under control tightly in the early phase of the cultivation. In South Central region of Somalia, in irrigated areas, farmers use to flood the field up to 40 and even 80 cm of water in mid-September so that water logging for 2-3 weeks has an herbicide effect and water reserves are assured during the entire cropping cycle. After the first 2 weeks of slow development plants start growing faster and in two more weeks start flowering and continue growing until the soil moisture, weather and soil fertility allow it. The advantage of the undetermined growth is that if adverse conditions (drought, cold) arise in the middle of the cropping season they stop just temporary the growth that will restart when the condition return optimal. As the cropping season proceeds apex grows carrying flowers buds so that youngest flowers stay on top of the plant and oldest at the basis. The same pattern is followed by the capsules determining a gradual maturing and shuttering starting from basis up to the apex.

Sesame in Somalia is grown as pure stand. In some other countries may be intercropped and everywhere is cropped in rotation with maize or sorghum. In Ethiopia, due to the booming of exports it is now being grown as monoculture.

3.2. Sowing

Due to the small size of the seeds an accurate land preparation is desirable. Seeding is generally done by hand mixing with sand at a ratio seed/sand ranging from 1:3 to 1:2. It is often broadcasted, and recently in Somalia is being introduced the sowing on rows drilled at 50 cm distance. Optimal density of about 180,000-200,000 plants per ha is reached with a distance between rows of 50 cm and a distance on the row of 10 cm. This density is reached within 2 weeks after emergence after thinning the seedlings. This is a very tedious and heavy work, normally done by hand by women selecting the best performing seedlings.

3.3. Irrigation

Irrigation is hardly practiced. As mentioned earlier the plot destined to sesame is flooded (water may be pumped or provided by gravity) and after receding of water it is sown. In some areas of Somaliland where spate irrigation is applied, depending on the rains, some additional irrigation may be applied, but this is an exception to the general rule.

3.4. Fertilization

Fertilizer in Somalia is rarely applied at small holder farmer level and different levels of fertilizer are applied in different countries). Data reported in literature about fertilization are not consistent and not necessarily related to the level of production or the nutrient content in the soil as may be noted in the following table

Some researchers (Adefris Teklewold, 2011, Ahmed Yakub Sidow, 2011, Bedigian, 2011, Bülent Usun, 2011, Mahdi Mortazavian S. M. and J. A. Kohpayegani, 2011, Wasana Wongyai. 2011) suggest that good responses in yield are obtained with 20-30 kg/ha of N and the same with P₂O₅. When N is deficient Sesame yields are depressed and oil content may reduce. Phosphorus is probably the most important nutrient to obtain high sesame yield. This information from bibliography does not necessarily match with the findings of our field work conducted in Somalia and Kenya.

Table 1 : different agricultural practices adopted in different countries

COUNTRY	LEVEL OF FERTILIZATION ADOPTED						SOIL TYPE	PLANTING METHOD (S)	SEEDING RATES	WATER REQUIREMENTS	SOIL TEMPERATURE (Degrees Celsius)
	YIELD	N	P ₂ O ₅	K ₂ O	OTHERS	PH	TEXTURE				
China	100Kg	7-8 kg (75-150 kg/ha)	2-3 kg	6-7 kg		6.5 to 7.5	Well drained fertile soil with medium texture	Broadcast sowing	4.5-6 kg/ha	301.2mm precipitation	24 to 32
								Row sowing	6-7.5 kg/ha		
								Spot sowing	3.75 kg/ha		
Ethiopia		23kg/ha	20kg/ha		Manure and crop rotation for small scale farmers	5.5-8	sandy loam	Broadcast sowing	4-5kg/ha	450mm (150mm during seedling establishment)	23-28
							Row sowing	5kg/ha			
Iran		200kg/ha	100kg/ha					Furrow to channel sowing	5-6kg/ha	To field capacity	20
								Grain sowing machine	2-5kg/ha		
								Broadcast sowing	8-10kg/ha		
Somalia	8-10 quintals per hactare	23kg/ha	15kg/ha			5.5 to 8.2	Well drained, fertile, and medium textured soil such as sandy loam to heavy black soil but it is also suitable with loamy soils	Broadcasted or, rarely sown on rows	6-8 kg / ha	390 to 490 mm	> 20° C
Turkey						7	Fertile, well drained and medium textured soils	Broadcast sowing	10kg/ha		
								Row sowing by machines	3 to 4kg/ha		
Thailand		62-187kg/ha						Broadcast sowing	6-12kg/ha		
								Row sowing by machines	12.5-15kg/ha		

3.5. Weeding

Weed control is necessary as sesame grows slowly at first and does not compete well with weeds when young. In Somalia herbicides are not used by sesame growers, in other parts of the world, literature reports that herbicides (alachor, diphenamid, prometon, trifluralin) rarely are used. As mentioned earlier as a weeding control measure, in Middle and Lower Shabelle, where sesame is grown in irrigated area and heavy soils, the plot previously prepared is flooded with a layer of 50-80 cm of water until the complete percolating. The percolation period lasts up to 20 days and this long period under the water, constituting the water reserves for the entire cropping period, works as herbicide. Sesame is sown immediately after the water percolated and the soil is still wet on its most superficial layer.

3.6. Harvesting

Harvest is a critical operation, due to the undetermined growth the right moment shall be chosen accurately and correspond to the moment when 75-80% of the capsules are mature and dehiscence did not start yet. The crop is harvested when leaves begin to shed, the lower capsules turn from green to yellow and the lowest capsules begin to open. The traditional harvest method consists in uprooting the plants or cutting them above ground level, bundling them in the field and keeping up to 15 days to dry and allow full dehiscence of the capsules. Then bundles are beaten and shaken on polyethylene sheets so that all seeds are released. This manual method is cause of high percentage of impurity (leaves, stems, stones and earth). Hand winnowing may follow to clean the seed, but still generally speaking a relative high level of impurity (above 35% persists).

3.7. Pests and disease

Hardly in Somalia pests and diseases are timely recognized and treated.

During the dry Jilal season, sesame is only sporadically affected by two pests, the cutworm (*Agrotis* sp.) and occasionally chafer beetles (*Schizonycha* spp.), also commonly known as white grubs.

Depending on weather conditions, during Gu and Hagai, season sesame is susceptible to several pest and diseases (this is also the reason why is mainly grown in Deyr –the same applies in Kenya).

Practically all Hagai crops are attacked by webworm (*Antigastra* sp.), with the most serious damage occurring during early growth. Major symptoms are the death of seedlings, damage of leaves, buds, flowers and capsules, with the larvae damaging the newly formed leaves and growing points resulting eventually in reduced yield estimated by 10-25% and, in severe attacks, more than 50%. The larvae of several species of pod borers attack and damage ripening pods after stoking the most common *Chilo*, *Sesamia*, and *Antigastra catalaunalis*. Occasional light damage is caused by red spider mites on isolated crops but always in association with predatory ladybird larvae.

Most common diseases (ref. Balestra, 2004 and Sidow 2011) are:

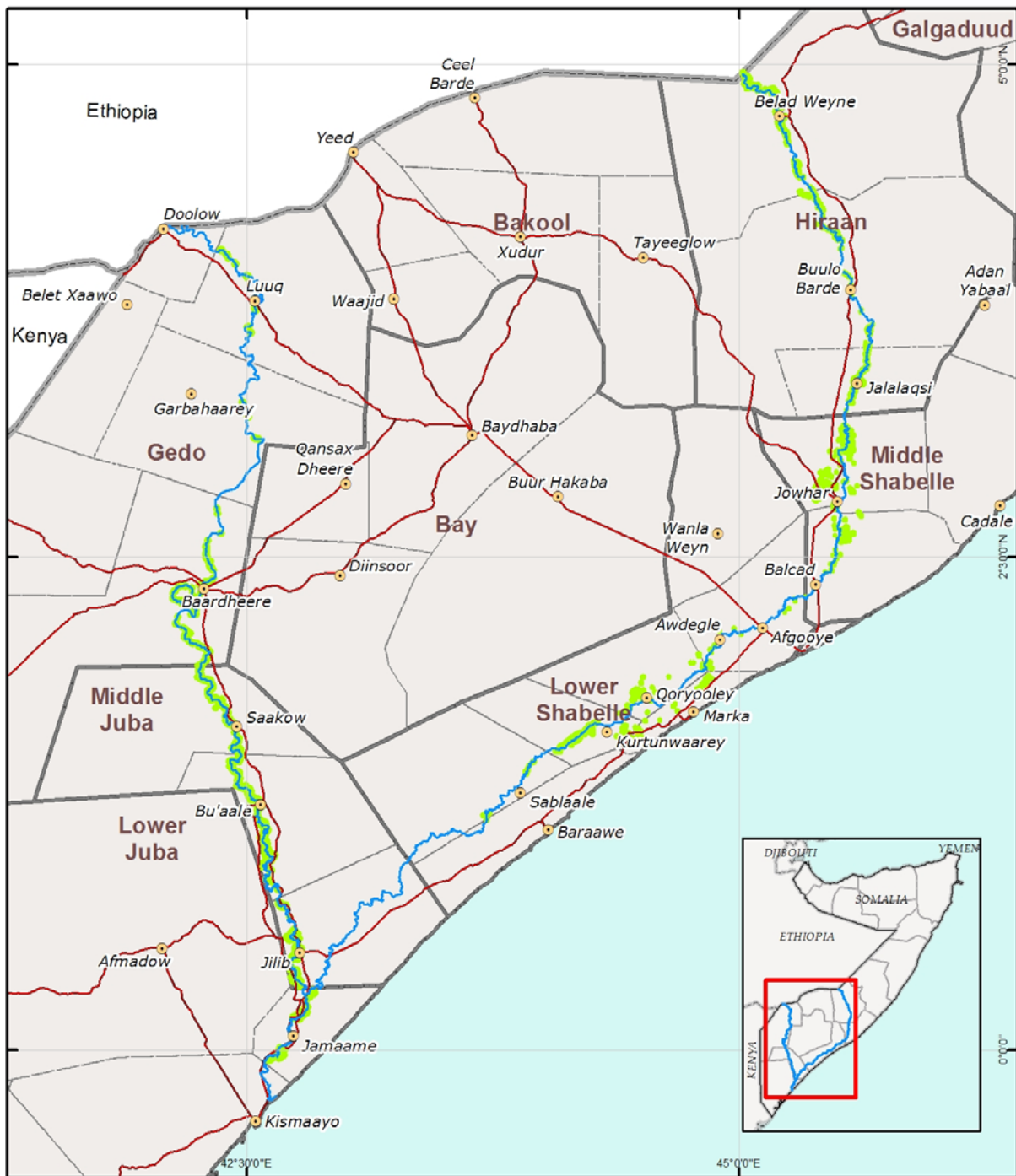
- Leaf spot disease (*Cercospora sesami*) During wetter weather, isolated incidences of damping off and brown leaf spot (or affects seedlings, but with minimal damage)
- Blight of sesame (*Alternaria sesami*) that attacks the leaves, stems and capsules of sesame. It is a seed borne disease causing brown to black, round to irregular and often zonate lesions measuring up to 1 cm diameter on the leaves. In severe attacks the leaves dry out and fall off.

- Collar rot (*Aspergillus niger*) who has a rapid growth rate, with a capacity of quick development and contamination under conditions of high temperature and relative humidity. It is a seed borne disease.
- Fusarium wilt (*Fusarium oxysporum f. sp. vasinfectum*) is a seedborne pathogen causing yellowing of the leaves and loss of foliage. Vascular discoloration, wilting. Sesame is predisposed to infection of Fusarium, when the roots are invaded by nematodes. Soils in which Fusarium wilt occurs also favour root knot nematodes and the two are often found together.

4. Background of the study

Sesame is grown, with different intensity in several part of Somalia (mainly in irrigated areas of South central region namely Middle and lower Shabelle, but also in rainfed areas such as Baki and Bakool, and in some rainfed areas of Somaliland where spate irrigation systems are available).

Figure 5: Map of Somalia showing sesame cropping area



In the above picture, only Land use/Land cover dataset detailing Sesame cropped areas was digitized/derived from Aerial Photo data of 2008. This data covered only parts along the Juba and Shabelle river (5-10 km radius) explaining the coverage contained herein.

Somalia is one of the most food insecure countries in the world. The civil war since 1991, recurrent drought in the whole country and floods in the riverine areas or in proximity of the numerous wadis⁷, clan conflicts, instability and lack of a functional government has brought Somalia in a situation of protracted crisis which eroded livelihoods and households assets increasing vulnerability to malnutrition and food insecurity of small holder farmers.

After two consecutive failed cropping seasons due to the most severe drought in the last 20 years a state of famine was declared in July 2011 in six geographical areas of Southern Somalia.

It is in this context that some NGOs raised the issue with International Donor Agencies that the extended cropping of sesame has reduced the food security of the most vulnerable population in the country alleging that where in the past sorghum was grown, since sesame demand and prices are growing worldwide, farmers sow sesame thus reducing food security at household and country level.

While it is evident some level of confusion between food security and food sovereignty this study aims, among others, to verify if this assertion is grounded or not considering how the markets (domestic, regional and international) work in Somalia. At the same time with this research will be explored the boundaries of sesame production and commercialization for Somalia identifying best varieties and agricultural practices in relation to the natural, social, cultural and economic environment of South Central Region of Somalia and some parts of Somaliland.

4.1. Literature review

This research would have been much more complex and difficult without an outstanding literature review Sesame, The genus Sesame edited by Bedigian, 2011. There it is compiled the status of art of sesame on history, botanic, agronomy, molecular genetics and use of sesame. The wide collection of topics and authors with their relevant references helped to find more and more related papers and researchers.

Based on this solid ground, more authors have been investigated; some researches from all of Africa, China and India are referred in this work. Some of them resulted very sound and reliable, some debatable. Along this work several researchers have been contacted personally, some have been very helpful some less, some, perhaps nourishing some expectations after an initial promise of support declined.

In several old publications, references are made about gene banks, one kept by FAO but memory has been lost about it and notwithstanding many efforts I have not been able to track it. Another one is held in Kenya but the curator keeps it as a private good and nor information neither seed have been possible to get from him. Finally another one, legacy from an Israeli researcher, held in Uganda, as well is treated by the curator as a private good and again neither seed nor information have been got from him.

⁷ Wadi is literally the bed of the seasonal rive created by the occasional rains. There may be systems in place to divert water (spate irrigation) or not. When the system is not in place, this may be the cause of large losses if consecutive floods happen.

This research is based on a 5 years work with Somali farmers, while serving FAO as agronomist in several projects, and on several trials conducted privately, during several seasons, in Kenya and in Somalia. The sesame varieties (if any) and landraces (most of them) come from a personal collection of seeds that has been growing along these last three years gathered during missions in African countries or through friends traveling around the world.

4.2. Statement of the problem

This research wishes to address two kinds of problems:

1. Strategic: is sesame competing with staple food thus increasing food insecurity in the country?
2. Operational: is there the possibility to improve the poor agronomic performance of sesame? If yes how?

4.3. The strategic problem

The bread basket in Somalia is traditionally South Central Region (Figure 5) where three livelihood zones coexist: pastoralist, agropastoralists and agriculture farming.

Agriculture farming is practiced in the riverine areas around Shabelle and Juba rivers. Agropastoralists are mainly based in the immediate proximity of the agriculture farming area and pastoralists, which are nomadic, are mainly moving along the migration routes to the livestock markets and occasionally clash with agropastoralists and farmers for natural resources (namely water and fodder).

Agriculture follows the rain seasons. Southern Somalia has a weak bimodal rainfall pattern: the long rain season in Gu (April – May) with 300-350 mm and the short, less reliable, rain season, Deyr, (September to November) with about 200-250 mm. Based on the precipitations two cropping systems are clearly defined: rainfed, between the two main rivers, and irrigated in the riverine area along the two rivers (a strip of land extended from few hundred meters to about 8 km where irrigation schemes are operational). During Gu in riverine area the main crop is Maize, while in Deyr sesame cropping is prevailing. In rainfed area, during the two seasons only sorghum is grown (with some legumes intercropped i.e.: cowpea or mungbean) and in some very limited areas sesame is grown during Deyr.

In Somaliland and in some rainfed areas of South Central Region (Bay and Bakool) sesame is grown along the wadis in a sort deisheck growing, describe this method is out of the scope of this work, but it consists in a water harvesting system, sometime sophisticated also known as spate irrigation, where fields are flooded with rain water collected from the entire water catchment (often extended by 100-200 sq Km) and as soon as water recedes farmers start sowing and gradually sown the entire field. If another one or two floods arrive, they are a blessing but normally the cropping cycle will be completed with this initial flood.

The *philosophy* behind this cropping pattern is the risk mitigation approach of the farmer. His agriculture is mainly subsistence agriculture where he balances the risk of the production for the market with the risk of the production for self-consumption. Indeed this copying strategy is more complex and based on other factors such as the hiring of labour to medium and large scale farmers, or small trading activities or remittances from abroad but to what the cropping scheme concerns the staple food production is concentrated during the long rain season while cash crops are grown

during the short rain season. The staple food cropping season lasts 105-125 days (maize and sorghum) the cash crops last 75 days (sesame or groundnuts and or *beans*). Sesame crop failures due to drought hardly happens because it is a crop relatively drought tolerant and because, having a short cycle, even if rain season would end 30 days after sowing, the harvest would be possible in the following 45 days. In addition labour demand in sesame cropping is relatively limited and allows the household to sell labour to other farms should demand be there (this labour market is a bit complicated by the contemporaneity of cropping and the labour peaks demand). Eventually a particular gender observation shall be done, the labour sold by the household is the male labour, thus sesame is in some measure a *female* crop, with some beneficial socio economic impact exceeding the financial ones.

Thus sesame cropping is particularly attractive for Somali small holder farmers being a short cycle cash crop with high domestic and international demand and low input demand.

When the 2010 drought arrived, it was the 7th consecutive year of growing demand and increasing price of sesame and many farmers, in rainfed areas shifted from sorghum to sesame. Seasons were favorable and they invested their earnings in the sole possible asset in the rural areas of Somalia: livestock. When the drought arrived and livestock started dying, some external observers attributed the gravity of the famine to the reduced sorghum production. In addition the loss of the farmers' assets, in their opinion, justified the lack of sense of growing sesame.

The problem this research would address on the strategic side is to determine if cropping sesame in Somalia contributes to mitigate the risk of crop failure, to increase resilience and, at the end of the day, to improve food security at household and country level.

In different terms: it will be examined if the food security problem in Somalia is due to the limited production of staple food or to the lack of financial resources of farmers. The former conducting to reply to the question if the alleged food security problem is not confused with food sovereignty?

4.4. The operational problem

Sesame cropping in Somalia faces two challenges: the phenotypic characteristics of the varieties/landraces cropped together with their genetic purity and the agronomic practices adopted.

4.4.1. Agronomic dimension

Sesame in Somalia (but it is not different in many other parts of the world) is generally grown by small holder farmers, in marginal areas (in Somalia almost never exceeding 2 ha) in riverine areas with some possibility of irrigation, in riverine areas under rainfed conditions (i.e.: under moisture stress) or rainfed areas with low or no management input during the short rain season. These conditions are the main cause for low yields while the potential is significantly higher (anecdotal data collected from different farmers from different areas of Somalia during different seasons with different level of precipitation).

Low production and productivity is exacerbated by the lack of clearly identified good agricultural practices in terms of sowing, fertilization, weeding and pest control.

In addition to the lack of knowledge about the GAP two more constraint to get good yield need to be considered:

1. The depletion of natural resources, namely soil erosion and soil salinization related to a traditional farming particularly in the rainfed areas the former and in irrigated areas the latter.
2. the lack of financial resources of small holder farmers to invest in good quality inputs.

Thus the issue of good agricultural practices this research addresses, considers some smart agriculture practices environmental friendly and sustainable (reference is made to conservation agriculture) and the financial constraints faced by the small holder farmers.

Thus the objective for this improved cropping of sesame is not an increase in production and productivity tout court but a *sustainable* increase of productivity. We may call it *resilience agriculture* whose objective won't be to push the production to a maximum (along the initial years of its implementation) but the increase and stabilization of income at household level through the adoption of different set of technical solution relevant for the different agro-ecosystems where sesame is grown.

The problem this research would address on the agronomic side thus is to identify the best good agronomic practices environmentally sustainable and financially affordable by farmers and explore their adaptation to Somali context should they be too expensive for the small holder farmer.

4.4.2. Genetic dimension

Sesame grown in Somalia belongs mainly to one local landrace: Dunyar (among other this study will try to determine if this Dunyar landrace and the Mombasa variety –probably originated in Kenya-are the same). This landrace, is well adapted, drought tolerant and resistant to pests. On the other side has a very low productivity (300-350 kg/ha) and is *dirty* (black and white with a ratio of about 35-65). Black sesame, allegedly rich in oil content in the local people perception, has a high demand on the domestic market while the white one, apart from local consumption, is also much appreciated in the international market.

There is great diversity within the several varieties of sesame existing in the world. However, one of the main traits is dehiscence. As mentioned earlier dehiscence or indehiscence of the capsules seems due to the number of cell layers in the capsule between the carpelli (Ashri and Ladizinski, 1964; Day, 2000).

In indehiscent varieties, the number of layers in the capsule affects also the result of thrashing and seed collection, so if dehiscent varieties represent a problem for the pre-harvest and harvest losses, not all the dehiscent varieties are welcome when post-harvest handling starts.

In dehiscent varieties when sesame approaches to maturity the oldest capsules, at the bottom branches of the plant, start opening while those on the top are still closed, and possibly flowers are still blossoming on the top of the plant. This maturing pattern is cause of significant losses at harvest time and harvest time shall be accurately chosen.

It shall be considered that due to the traditional harvest and post harvest handling (always manual harvesting), harvested plants are gathered in bundles on the field and left there to dry about 15 days. Once dried capsules dehisce and the plants are shaken and beaten so that capsules release all the seeds that successively may be further dried and/or cleaned. In fact the traditional harvesting

method is cause of contamination with earth, stones, leaves and stems reaching up to 35% in weight.

Figure 6: sesame flowering with capsule and sesame harvested and drying on field



The problem this research would address on the genetic side is to identify the steps for a breeding programme leading to high yielding varieties locally adapted through two different approaches: crossing among different varieties/landraces and mutagenesis through treatment with Ethylene Meta Sulfonate.

4.4.3. Market and socio-economic dimension

The international sesame market demand is pulling production all along Asia and Africa. There is a window of opportunity for sesame small holder farmers to gain some benefits of the increasing demand taking advantage of the sesame cropping favorable conditions in Somalia linked to the traditional expertise of farmers in cultivating this crop. This research will investigate the potentiality of the market for the Somalia producers, the agronomic (yield) and financial parameters (cost, benefit and breakeven of production) to be reached to have a profitable crop.

4.5. Purpose of the research

As mentioned earlier, the low yield is caused on one side by low inputs and poor management (e.g low or non-fertilization, irrigation, pest control etc.), biotic and abiotic stresses: in one word the environmental constraints. On the other side the mentioned lack of research and of breeding programs is the cause of the poor available genetic material.

Based on the previous, the purposes of this research are:

1. to identify best practices in cropping sesame;
2. to initiate a process for genetic improvement based on:
 - a. evaluation of the morpho-productive traits of sesame varieties/landraces/population with different origins, which could be used to initiate a breeding programme to improve sesame performances.
 - b. Test some mutagenic treatment by EMS;
 - c. Crossing different varieties/landraces from different sites of East Africa.
3. To support the field evaluation with genomic analysis in order to check the genetic distance and variability of the available varieties and design the appropriate breeding programme according to the different environmental systems (rainfed or riverine).
4. To provide a first assessment of this crop's contribution to small holder farmers' income growth and food security.

4.6. Research questions

The leading question of this research is:

1. does sesame cropping increase or reduce food security at small holder farmer household level in Somalia?

In order to reply properly to this question some ancillary questions shall find an answer:

2. What are the best agricultural practices to be adopted?
3. What are the best characteristics of sesame or, in other words, what sesame varieties shall be cropped where?
4. What is the financial impact at HH level of cropping improved varieties of sesame.

4.7. Limitations of the study

This study started in Somalia before the famine of 2011 when most parts of South Central Region were under the control of Al Shabab and security conditions did not allow to visit the plots where the trials and performance tests were conducted.

Due to the security constraints, and in order to assure all the necessary replication to minimize the risk of poor data collection in remote areas of Somalia, and to assess the universal validity of the conclusions found, the same experimental design has been implemented during several seasons in different locations of Kenya whose ecological conditions were comparable to those in Somalia. Notwithstanding the institutions selected to provide the daily follow up of the cropping were university institutions the results of two seasons of cropping were poor: due to drought and lack of the appropriate facilities to irrigate.

It has been only during the last season of cropping that a full set of data has been collected for all the landraces/varieties tested.

A plot, after several failed attempts in Nairobi, has been set in Hargeisa for crossing different varieties/landraces and crossing scheme designed and implemented.

5. Materials and methods

Data collected from trial plots and performance tests conducted in Somalia and in Kenya during more than 5 years are gathered in this work.

The research interested three areas: identification of good agricultural practices, genetic improvement and financial and market analysis.

The design aiming at testing the impact in terms of performance included three levels of fertilization for N and 2 levels of fertilization for P. In a strip plot design as described below.

6 varieties of sesame have been tested on field along this research. The characteristic of the design and the number of accessions fully tested suffered some slight change along the years due to the lack of homogeneity of situations in the different sites where the trials have been implemented. The number of varieties grew along the years as well as the contact with other researchers in East Africa. The biggest elements contributing to the variability of the experiments have been the different level of supervision applied (low in Somalia even if compensated by large and intensive training) and the differences in environmental conditions between Kenya (three sites) and Somalia (three sites). These elements have been considered in the statistical analysis.

5.1. Experimental design

Two experiment plans have been set, one in Somalia during Deyr 2011 (based on experiences earned in 2010) and one in Kenya (Kitui, in the central region of semiarid land, Kilifi, on the coast where the climate is more similar to the Somalia) one in 2012 and a third one in Busia (near Victoria Lake, where the temperatures are lowest but water is more available) in 2013.

In 2011 in Somalia the trials were aimed to identify the best cropping method, comparing the traditional and the improved system reported in Table 2. The experimental design was a complete randomized block with three replications applied in three localities (Barire, Deresalam and Jannale).

Table 2: cropping protocol and trial design adopted in Deyr 2011 In Somalia

	Traditional cropping	Improved cropping
Ploughing	Yes	Yes
Spacing	Broadcasting	60cm *25 cm
Flooding	Yes	No
Arrowing	No	Yes
Furrowing	No	Yes
Sowing	5-6 seeds per pocket (about 6-7 kg/ha) or broadcasting (following the most common practice among farmers)	5-6 seeds per pocket (about 6-7 kg/ha)
Irrigation	1 before sowing (this is the flooding mentioned above) and 1 within 25 days after sowing, depending on rains	1 after land preparation 1 within 25 days after sowing, depending on rains
Weeding	About 3 times (according to needs)	3 times
Thinning	Only if necessary	Yes
Fertilization	No	Yes (100 kg ha in two moments sowing and flowering)
Spraying	Only for very hard pest attacks	When necessary

The trial's design applied in Somalia along Deyr 2011 is reported as follow in each site:

- each experimental area was divided in the two levels of crop factor: traditional and improved.
- Three different varieties were tested in each site;
- Each thesis per each site was replicated in three blocks.

Each thesis, in a 20 m x 20 m plot, contained 33 rows and in each row there were 80 plants (20/0.6=33 and 20/0.25=80). In traditional cropping sows were broadcasted or sown following the tractor according to the most common local practice.

The varieties tested during two season in Somalia are: Dunyar Clean (i.e.: white seeds only as the brown have been manually separated), Dunyar Dirty (using seeds withe and brown –i.e.: grain from previous season not cleaned-), Humera (provided by a local grower).

Data were collected from 10 plants taken from the two central rows per thesis. The data collected are reported in the table 3.

Table 3: traits of data collected

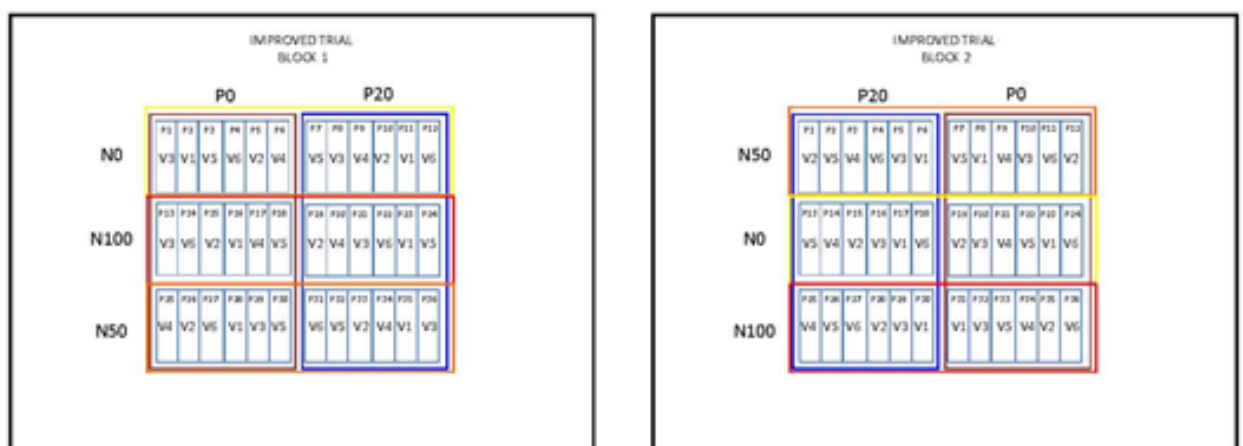
Plot No.	Plant No.	Plant height (cm)	Days to 50% flowering	No. of capsule per plant	No. of seeds per capsule	1000 seed weight (gram)	Yield per plant (gram)	Yield of all plants in the plot (kg)
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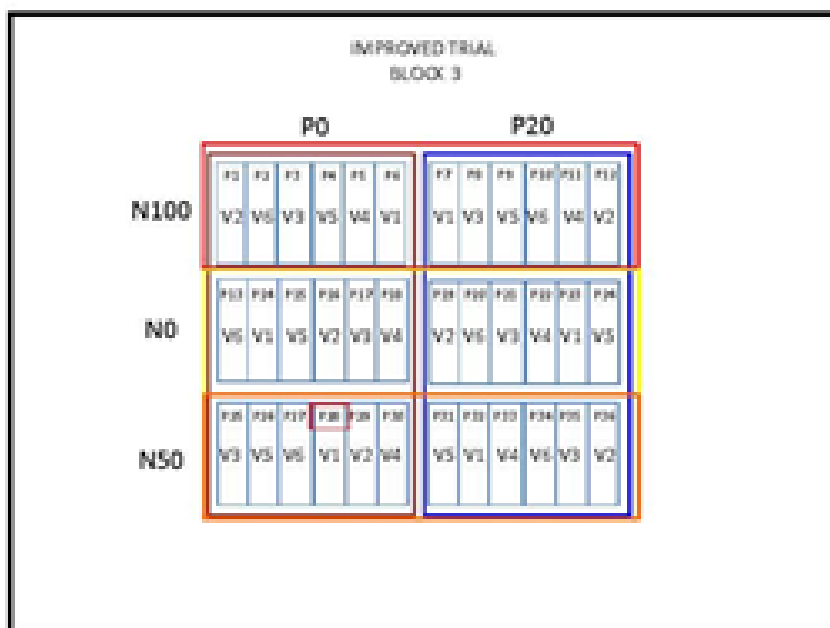
In Kenya the purpose was to identify the more appropriate level of fertilization for the 5 varieties tested. In Kenya the adopted design was more complex than in Somalia and during three following seasons sesame was grown in: Kitui, Kilifi and Busia. The first two sites were selected considering the environmental conditions closest to those of Somalia. The third one, Busia, was selected because during the two previous seasons the cropping of sesame was severely affected by the drought and data collected only partially complete. Thus, to minimize risks, Busia was selected for the third and last season. This is a site where farmers traditionally grow sesame, where water is available and rains are normally sufficient to complete a cropping cycle

In Kitui during the season of the trials there was a drought and no irrigation scheme was in place. The results from this season are not considered reliable and significant and thus not considered in this work. In parallel a similar trial was conducted in Nairobi, but also in this case data are not significant and reliable: the ecological conditions in Nairobi are not adequate for sesame (it is too cold and to wet). In Kilifi and in Busia, during Deyr 2011 an Deyr 2012 respectively, 6 varieties were tested: Dunyar, Ethiopian D2, Ethiopian IS, ICEASE00019, Humera, Tanzania.

The adopted experimental design was a split plot, where: nitrogen and phosphorous are the main plot (row and column) and in the sub plot are randomized the six levels of variety (Figure 7).

Figure 7: Experimental design split strip plot with three blocks





Due to lack of appropriate facilities, irrigation has not been performed apart from some emergency irrigation in Kilifi in one block only.

The improved trials too are implemented as a Strip Plot, where the nitrogen and phosphorus are the main factors and varieties are organised in sub-plot.

Below is a summary of the schema adopted for the sesame improved trials conducted in 2012

Table 4: Sesame improved Trials 2012, (STRIP PLOT)

1	Three Blocks
2	Two levels of Phosphorous (P0 = 0 kg/ha; P20 = 20 kg/ha)
3	Three levels of Nitrogen (N0 = 0 kg/ha; N50 = 50 kg/ha; N100 = 100 kg/ha)
4	Six varieties ⁸

The sources of variance with the corresponding degree of freedom are reported below together with the factor effect per each of the considered variable.

Table 5: Source of variance

Source of variance	d.f.	Factor effect
Between Block	2	Random effect
Between Nitrogen (N)	2	Fixed effects
Between Phosphorous (P)	1	Fixed effect
Interaction N x P	2	Fixed effect
Error a	10	
Between Varieties (V)	5	Fixed effect
Interaction V x N	10	Fixed effect
Interaction V x P	5	Fixed effect
Error b	70	
Total	107	

Varieties utilized in the evaluation are:

⁸ One variety, ICEASE, has not been considered in the final analysis as the seeds were not available for planting at the beginning of the following cropping season in Busia.

Table 6: Varieties tested and corresponding code

Denomination	Name of the variety
V ₁	Ethiopian d2
V ₂	Humera from Somalia
V ₃	Dunyar from Somalia
V ₄	Tanzania
V ₅	Ethiopian IS
V ₆	ICEASE

One variety, ICEASE, has not been considered in the final analysis as the seeds were not available for planting at the beginning of the following cropping season in Busia thus the final analysis considered only 5 out of the initial six varieties.

5.1.1. Data collected

Fifteen morphological and productive characters were recorded on 5 randomly selected plants for each of the considered sesame varieties, collected in the combination thesis (site, block, level of N and levels of P).

The traits measured were: days at 50% flowering, height at 50% flowering (cm), height at physiological maturity (cm), weight of capsules per plant (g), grain yield (weight of seeds per plant g), number of capsules per plant, average number of seeds per capsule, colour of seeds⁹, number of branches per plant, stem thickness at physiological maturity (mm), average capsule length calculated on the basis of three randomly chosen capsules in the plant, average of capsule thickness (mm) calculated on the basis of three measures of the thickness of the previously selected capsules, number of capsules per axil, average internode length in cm measured based on the average length of 1st, 2nd and 3rd internode length), and the weight of 1000 seeds.

5.1.2. Analysis of data

The differences of the means of each agronomic trait between varieties, locations and fertilization levels, were compared through the analysis of variance using Systat 9. The same SW has been used for Multivariate discriminant analysis, to analyze the phenotypic relationships between the different varieties landraces/populations. To visualize the phenotypic relationships existing between the varieties analyzed, the Euclidean distance matrix and the cluster analysis based on Sahn algorithm were performed using the software NTSYSpc 2.2.

In order to make comparable data from Kilifi and Busia, only five varieties (available during both years) and all the variables whose data were complete have been considered (i.e.: variable with data lost due to the drought or too subjective –as seed color or plant vigor- have been excluded).

5.2. Genetic improvement and breeding methods explored

5.2.1. Mutagenesis

To improve some characteristics as capsule indehiscence and uniformity in flowering, several attempts have been done to generate mutants using EMS.

⁹ This trait eventually has not been analysed due to the subjective variability related to the field technicians belonging to different groups (site and years).

Varieties Dunyar, Ethiopian IS, Ethiopian ID, Tanzania, Humera and ICEASE 0019 have been treated in two successive seasons with EMS. Different EMS concentration (from 0.05% to 1 % EMS solution) and different soaking times (from 2 h to overnight) have been applied. The best combination that gave some alive and growing plants was 0.05 % solution with 4 hours of soaking time. All plants germinated and only Ethiopian IS completed the cropping cycle producing seed. These seeds have been planted during Gu 2014 in Somaliland and none of the plants grown arrived to maturity. This is to be attributed to a prolonged period of growth where no emergency irrigation was supplied. This test needs to be repeated considering that literature reports successful experiences in producing indehiscent varieties following treatments with EMS (Wongyai W., 2011).

5.2.2. Crossing

During one cropping season crossings have been conducted among different varieties/landraces in order to improve the genetic variation and produce a segregating gene pool to introduce in a breeding program with the aim to have new varieties locally adapted with improved and stable production tested to be used for all purposes (direct consumption and for oil production).

During Gu season 2014, in Hargeisa (Somaliland), a crossing scheme has been implemented for the 9 varieties/landraces of sesame available at that time following the design reported in Table 7. The methodology adopted to cross the different varieties/landraces of sesame is the soda-straw method. The entire sequence is reported in Figure 8 and described below.

In order to cross two different varieties/landraces, the flowers to be used as female are emasculated stripping the corolla where 5 stamens are fused in (epipetalous). The flower bud which is expected to open in the next morning is selected in the previous evening between 3 P.M. and 6 P.M. and emasculated by just removing the corolla tube. The flowers that are expected to open next morning are recognizable for the size about 2-3 cm length, the colour (yellowish) and the shape: they are still closed in their typical tubular shape. Then, the emasculated flower buds are covered with a piece of soda-straw tube and, bent at the top in order to avoid contamination from foreign pollens. The corolla with the stamens of the emasculated flower is stored in a Petri dish during the night at room temperature. During early hours of the next day, between 7 A.M. and 9.A.M., pollen from the desired male parents are dusted gently on the surface of the stigmas of the emasculated flower buds after removing the soda-straw and covered again. Individual crossed flowers are tagged with labels reporting the parents. The unemasculated flowers have not been removed from the female parent to avoid stress to the plant (it shall be considered that they are several dozens). It has been noted that a better rate of success is obtained when the plants selected for emasculation are in full bloom, i.e.: about 55-60 days after sowing.

The soda straw is removed permanently after three days from the fecundation to allow the proper development of the ovarium.

The combinations obtained crossing the 9 varieties without self-cross of sesame, available at the moment of the cross, were 72 and are reported in the table below.

Table 7: cross combinations







Variety Name	id	FULL CROSSING SCHEME (72 COMBINATIONS –in Yellow the successful ones)								
ETIS	A									
Sudan Dirty	B	AB	BA	CA	DA	EA	FA	GA	HA	IA
Sudan Cream	C	AC	BC	CB	DB	EB	FB	GB	HB	IB
Humera	D	AD	BD	CD	DC	EC	FC	GC	HC	IC
Local Burao	E	AE	BE	CE	DE	ED	FD	GD	HD	ID
Local SL	F	AF	BF	CF	DF	EF	FE	GE	HE	IE
ETD2	G	AG	BG	CG	DG	EG	FG	GF	HF	IF
ICEASE	H	AH	BH	CH	DH	EH	FH	GH	HG	IG
Dunyar	I	AI	BI	CI	DI	EI	FI	GI	HI	IH

Successful crossing are indicated in yellow.

The protocol adopted for crossing is reported in the following photographic sequence:

Figure 8: Cross pollination process: Straw method

<p>In the afternoon the flowers, still closed are selected.</p>	<p>Stripping the corolla the flower is emasculated. The flower is still closed and fecundation did not happen yet.</p>
<p>Once emasculated the stilo remains "naked"</p>	<p>Free stilo</p>
<p>The stilo is covered With a straw ...</p>	<p>And protected from any possible fertilization</p>

	
<p>Branches whose flowers have been emasculated are marked for the fecundation to happen the day after</p>	<p>Corollas from the same variety/plant are stored during the night in Petri dishes at room temperature. At harvesting their color is yellowish/green</p>
	
<p>During the night the color shift to pink/purple.</p>	<p>The day after, early in the morning, the corolla is opened...</p>
	
<p>And anthers left opened</p>	<p>Each opened corolla will be used as a brush to fecundate the stilo of the selected female plants</p>

5.2.3. Genetic characterization

For sesame little is still known about genetic variability of African accessions. Building on genetic diversity to find suitable varieties and breeding material for stressed conditions is of top priority to continue sesame cultivation in traditional areas (Tabatabaei et al. 2011). One of the scopes of this work is to initiate a process of genetic improvement in African sesame aiming at superior genotypes through breeding.

Some DNA segments used as molecular markers demonstrated to be valuable tools in the characterization and evaluation of genetic diversity between species and among populations. They

are used to identify the genes expressing desirable traits and thus to map important genes and assist with the breeding of oil crops (Wei et al 2011).

Amplification of DNA segments through specific primers allows identifying varieties and segregating them. The sizing of these segments eventually permits to draw a unique profile specific per each variety, a real fingerprint.

Several types of molecular markers exist and the most useful for DNA characterization and building of genetic maps are those highly polymorph, i.e.: those whose individuals from the population in exam present a high number of differences. Among those markers, present in specific chromosome loci, microsatellites or simple sequence repeats (SSRs) are tandem repeats one to six bp in length and have been proven to be the most powerful polymerase chain reaction (PCR)- based DNA markers in plant diversity analysis because of their abundance, high variability, co-dominant nature, ease of scoring and high reproducibility (Dixit et al. 2005).

Unfortunately, so far, genetic structure of only a few sesame traits has been revealed (Tabatabaei, et al. 2011) and in addition sesame diversity analysis shall reckon lack of information about African sesame populations and varieties.

Due to the previous sesame marker assisted selection and molecular breeding show a significant delay compared with other crops.

Some relatively recent genetic studies on sesame have addressed quantitative genetics (Wei et al., 2009), traditional genetic breeding (Were Bai 2006), and genetic relationships and diversity among different sesame germplasm collections (Ali et al., 2007; Laurentin and Karlovsky, 2006, Laurentin et al., 2008); while other studies focused sesame accessions from specific regions: i.e.: China (Zhang et al., 2007), India (Bhat et al., 1999; Kumar and Sharma, 2009), Korea (Kim et al., 2002), South- East Asia (Pham et al., 2009), and Turkey (Ercan et al., 2004; Tabatabaei, et al. 2011). Notwithstanding some African accessions have been tested in some of the above reported researches, no comprehensive studies on genomic variability of African varieties are reported in literature.

In sesame, only 10 genomic simple sequence repeat (SSR) (Dixit A, et al 2005) and 44 EST-SSR (Wei L- B et al. 2008) markers have been developed. Genetic relationships and diversity among germplasm collections have been investigated mostly using AFLP, ISSR, and RAPD markers. In sesame, marker assisted selection and molecular breeding lag behind other crops owing to a lack of effective molecular markers (Wei et al. 2011).

In this work 11 accessions from 6 African countries with wide geographical coverage have been examined in lab by genomic SSR markers as described below.

The varieties observed in this study are:

1. Humera (originary from Ethiopia)
2. Icease 00019 (provided by ICRISAT)
3. Dunyar (from South Central Somalia)

And 8 accession from different African countries most of them bought in the local markets

1. Etiope D2 (kindly provided by the Department of Agricultural and Forest Sciences of Palermo University)
2. Etiope is (kindly provided by by the Department of Agricultural and Forest Sciences of Palermo University)
3. Tanzania (grown in Nyanza region close to Victoria lake kindly provided by CEFA NGO)
4. Somaliland (from Burao)
5. Uganda Local 1 (bought close to Kampala)
6. Uganda common (bought at the border with Kenya)
7. Uganda Local (bought in a local market)
8. Sudan local (bought in a local market)

The seeds of the different sesame varieties/accessions were initially sterilized in a solution of hypochlorite of sodium 2%, stirring during 2 minutes and washed several times and then germinated in autoclave sterilized tissue paper, inside disinfected germination trays in an incubator at 30° C. This methodology sometimes caused mildew and the germination process needed to be repeated but the alternative, i.e.: sowing outdoors in the greenhouse would have implied a longer time for germination and reaching the necessary size of the plants for the successive phase of the DNA extraction.

After about one week the germinated seedlings reached about 10 cm height. From the bud and young leaves of these seedlings about 20-30 mg of DNA have been extracted. The limited green material available from such young seedlings caused low yield of DNA.

Per each variety 6 seedlings have been selected. DNA has been extracted following the protocol indicated in the Machery-Nagel kit with the exception of the grinding of the samples: being the available material per each seedling so little, grinding took place in eppendorf containing the buffer in the kit, using glass rods made on purpose rough at the tip.

Once the DNA has been extracted, we proceeded to the visualization of the bands by electrophoresis. Samples and marker 1kb (Fermentas) have been loaded on Agarose gel (0.32 g of Agarose and 40 µl of TBE. The solution has been warmed in the microwave in order to solve the Agarose. The gel once cooled down to room temperature has been loaded with 0.4 µl of ethidium bromide to allow the visualization of the bands to ultraviolet rays. The gel obtained, still in liquid form, was poured inside the cot where were placed the combs, which will form the wells within which the samples will eventually be loaded. Finally 8 µl of DNA mixed with 2 µl of dye (bromophenol blue) and 2 µl of markers have been loaded. The electrophoresis has been set at 50 volts and 50 minutes. At the end of the run the gel was examined using the BIORAD Gel Doc XR + Gel Imaging to verify the presence and the quality of the DNA (Fig. 9).

Figure 9: Extracted DNA quality test



The amount of DNA is very important as it is one of the factors that determine the repeatability of amplification products. Thus DNA has been quantified by Invitrogen Qubit fluorometer. 10 μ l samples were loaded from the extracts, and the intercalating was added in the buffer at the rate of 1: 200.

The primers used for this work have been synthesized by Invitrogen, following the sequences developed by Dixit et al. and found in the literature (Dixit et al. 2005).

The primers used are listed below:

Table 8: list of primers

locus	sequenza	repeat	range bp
GBssr-sa-05F	TCATATATAAAAAGGAGCCCAAC	(CT) ₁₃	158-172
GBssr-sa-05R	GTCATCGCTTCTCTCTTCTTC		
GBssr-sa-08F	GGAGAAATTTTCAGAGAGAAAAA	(AG) ₁₇	150-164
GBssr-sa-08R	ATTGCTCTGCCTACAAATAAAA		
GBssr-sa-09F	CCCAACTCTTCGTCTATCTC	(CT) ₁₈	217-231
GBssr-sa-09R	TAGAGGTAATTGTGGGGGA		
GBssr-sa-33F	TTTTCTGAATGGCATAGTT	(AG) ₂₄	263-275
GBssr-sa-33R	GCCCAATTTGTCTATCTCCT		
GBssr-sa-72F	GCAGCAGTCCGTTCTTG	(CT) ₉	289-307
GBssr-sa-72R	AGTGCTGAATTTAGTCTGCATAG		
GBssr-sa-108F	CCACTCAAAATTTTCACTAAGAA	(GA) ₇ ,(GA) ₁₅	204-218
GBssr-sa-108R	TCGTCTTCCTCTCTCCCC		
GBssr-sa-123F	GCAAACACATGCATCCCT	(TC) ₂₁ ,(TC) ₁₅	272-282
GBssr-sa-123R	GCCCTGATGATAAAGCCA		
GBssr-sa-173F	TTTCTTCCTCGTTGCTCG	((G) ₅ CTAGT(G) ₃ (A) ₂) ₂	218-245
GBssr-sa-173R	CCTAACCAACCACCCTCC		
GBssr-sa-182F	CCATTGAAAACACTGCACACAA	(AT) ₁₁ ,(TC) ₁₈ ,(TG) ₁₂	221-259
GBssr-sa-182R	TCCACACACAGAGAGCCC		
GBssr-sa-184F	TCTTGCAATGGGGATCAG	(TC) ₂₀	179-193
GBssr-sa-184R	CGAACTATAGATAATCACTTGGAA		

Successively, some PCR were performed, to test the efficiency of the primers, at different temperatures, based on the annealing temperatures of each of them.

To perform PCR was used: HotStar-Taq Plus Master Mix Kit from Qiagen company.

- The protocol per each sample is reported below:
- Taq 10 µl
- Primer Fw 0,5 µl
- Primer Rw 0,5 µl
- H₂O 4 µl
- DNA 5 µl

The total final volume per sample is 20 µl.

After the initial trials, Thermocycler has been set as follows:

- 95° C for 5 minutes x 2 times (preheating to activate the polymerase and denaturing DNA Repetition of 30 times the following cycle):
 - 95° C for 1 min (DNA denaturation),
 - 55°-61° C for 1 minute (annealing – the temperature chosen was changed according to the primers-)
 - 72° C during 30" (extension)
- Finally the extension at 72° C for 5 mins (to complete the last cycle).

To visualize the bands electrophoreses were performed on agarose gel 1%. 5 µl of amplified material were loaded per each well and 2 µl of marker used (Fermentas 100 bp). The UV rays visualization showed the efficiency of only some of the primers used. The more efficient primers were procured to "Applied Biosystems" with the extension of the M13 sequence. This is to allow the differentiated

detection through the fluorochromes: NED, FAM, PET and VIC, as indicated in literature (Schuelke, 2000).

The fluorochromes are molecules which, when energized, can absorb energy, subsequently decay to a lower energy level, thus emitting a part of the absorbed energy in the process, usually in the form of visible light or even greater wavelength. In this case the fluorochrome has been attached to the primer's sequence. The marking has been introduced at the time of synthesis of the primers.

Table 9: list of primers with tail

Locus	GeneBank	sequence	repeat	range bp	With tail
GBssr-sa-08F	AY838905	GGAGAAATTTTCAGAGAGAAAAA	(AG) ₁₇	150-164	TGT AAA ACG ACG GCC AGT GGAGAAATTTTCAGAGAGAAAAA
GBssr-sa-09F	AY838907	CCCAACTCTTCGTCTATCTC	(CT) ₁₈	217-231	TGT AAA ACG ACG GCC AGT CCCAACTCTTCGTCTATCTC
GBssr-sa-72F	AY838913	GCAGCAGTTCCGTTCTTG	(CT) ₉	289-307	TGT AAA ACG ACG GCC AGT GCAGCAGTTCCGTTCTTG
GBssr-sa-108F	AY838915	CCACTCAAATTTTCACTAAGAA	(GA) ₇ ,(GA) ₁₅	204-218	TGT AAA ACG ACG GCC AGT CCACTCAAATTTTCACTAAGAA
GBssr-sa-123F	AY838916	GCAAACACATGCATCCCT	(TC) ₂₁ ,(TC) ₁₅	272-282	TGT AAA ACG ACG GCC AGT GCAAACACATGCATCCCT
GBssr-sa-182F	AY838921	CCATTGAAAACACTGCACAAA	(AT) ₁₁ ,(TC) ₁₈ ,(TG) ₁₂	221-259	TGT AAA ACG ACG GCC AGT CCATTGAAAACACTGCACAAA
GBssr-sa-184F	AY838922	TCTTGCAATGGGGATCAG	(TC) ₂₀	179-193	TGT AAA ACG ACG GCC AGT TCTTGCAATGGGGATCAG

Successively we proceeded with marked PCR specific per each primer.

The protocol per each sample is the following:

- Taq 10 µl
- Primer Fw con coda 0,24 µl
- Primer Rw 0,5 µl
- M 13 0,5 µl
- H2O 3,76 µl
- DNA 5 µl

The samples of PCR were sized at CIBIACI through the AB 1310 of Applied Biosystems.

5.3. Profitability assessment of the sesame cropping

In order to assess the financial impact at household level of improved germplasm and GAP adoption, a three steps procedure has been adopted:

1. Data Gathering on cost and benefit of production at household level considering the average data available from FSNAU (Food Security and Nutrition Analysis Unit in FAO), field reports from agricultural project's implementing agencies (not published) and personal interviews. Data collected refer to the small holder farmer (1 ha) in the three most typical possible scenarios of sesame cropping in Somalia:
 - a. rainfed traditional: 6 kg of seed per ha, sowing broad casted and minimum crop caring;
 - b. rainfed improved: 8 kg of seed per ha, sown in rows (generally 60 cm x 18 cm), with at least two weedings (riverine traditional is in between the rainfed improved and the other two systems (rainfed improved and riverine traditional) with 6-8 kg of seed per ha, broadcasted and without weeding but with some additional irrigation if gravity irrigation is available or pumped irrigation if affordable by the farmer);
 - c. riverine improved: 8 kg of seed per ha, sown in rows (generally 60 cm x 18 cm), with two to three weedings and some irrigation when gravity irrigation is available or pumped irrigation if affordable by the farmer.

2. A market analysis at international and domestic level has been conducted using field reports, personal interviews and data from FAO stat.
3. Eventually the profitability analysis of sesame cropping (expected level of production, costs and benefits and break even) has been carried out.

6. Results and discussion

6.1. Agronomic trials findings

6.1.1. Field test year 1 (2011 Barire, Daresalam and Jannale)

The varieties tested in this trial were actually two: Dunyar and Humera. The difference between Dunyar clean and Dunyar dirty refers to the colour of sown seed: Dunyar clean is constituted by seed sorted by colour and it is all white or cream; Dunyar dirty is the natural one white and black, brown and cream seed with a ratio of around 65% (white and cream) -35% (black). By sowing the clean Dunyar, It was explored the possibility to increase the rate of white sesame in following generation by planting only white sesame (the clean Dunyar).

The variables examined are reported in table 10.

Table 10: variables examined in the trials of 2011 and their relative cod

Name cod	Analysed variables
PlantHeightcm	Plant height in cm
Days50%Flow	n. of days after sowing when 50% of the plants in the plot are flowering
NCapsPlant	Number of capsules per plant
NSeedsCapsule	Number of seeds per capsule
Weight1000Seed	Weight of 1000 seeds
YieldPlantg	Yield per plant in g
YieldPlotkg	Yield per plot in kg

6.1.1.1. Plant Height

Plant height has been recorded at the moment of physiological maturity.

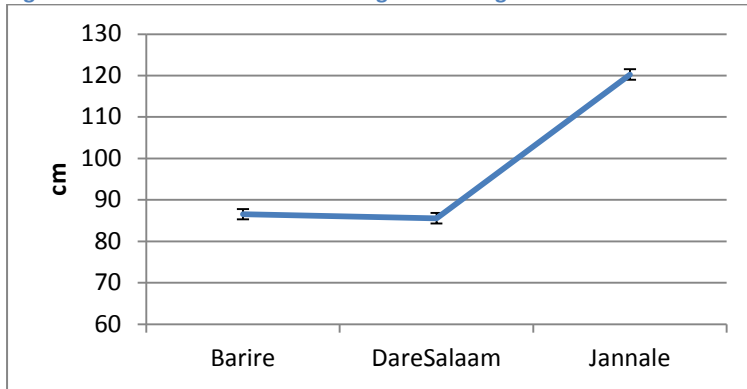
The results of the ANOVA (Tab. 11) shows the significant F test for the variance of Site, Interaction Site x Varieties and Interaction Site x Crop System.

Table 11: ANOVA for plant height year 2011

source of variation	sum of square	df	mean square	F test	P
Site (S)	140530.193	2	70265.096	111.640	**
Error a	3776.333	6	629.389		
Varieties (V)	3285.559	2	1642.78	0.403	n.s.
Crop System (C)	383.38	1	383.38	0.121	n.s.
Interaction S*V	16296.307	4	4074.077	14.468	**
Interaction S*C	6315.57	2	3157.785	11.214	**
Interaction V*C	427.781	2	213.891	0.760	n.s.
error b	146432.719	520	281.601		

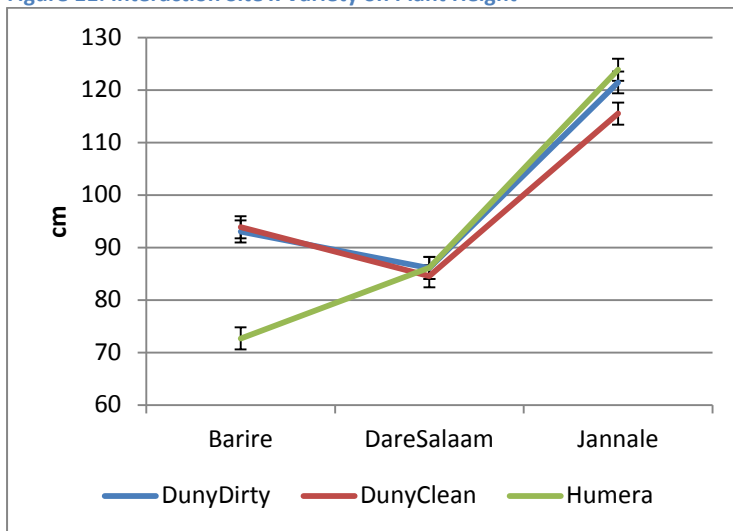
The variance due to the Site is evidenced in figure 10, where it is possible observe the difference influence on the plant height of the climate condition in Jannale.

Figure 10: influence of Sites on Average Plant Height



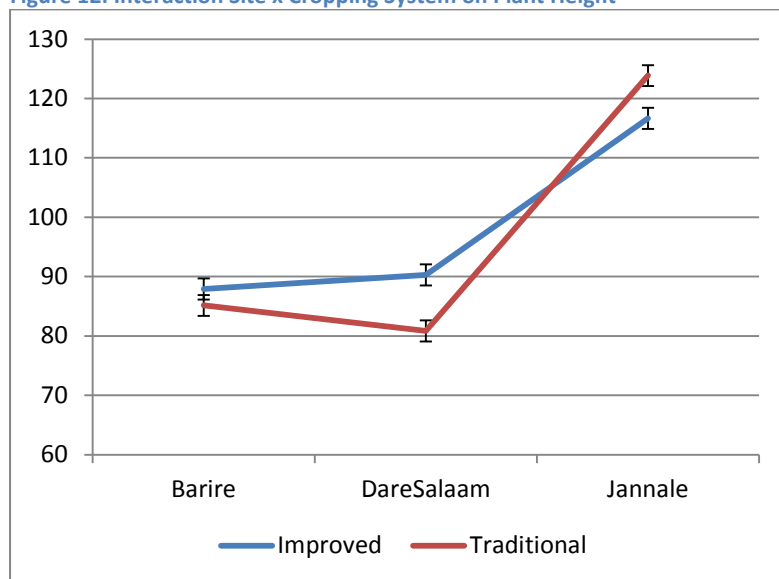
Different varieties performed differently in the different sites with Humera being the highest (Fig. 11).

Figure 11: Interaction Site x Variety on Plant Height



In all the trials Jannale performed better than the others (Fig. 12) possibly due to the more frequent irrigation provided to the crop. It shall also be noted that Jannale is the only site where N fertilization has been provided. In Barire and Daresalam, nonetheless the same was planned, urea was not available at the time of the trial and no fertilizer has been applied.

Figure 12: Interaction Site x Cropping System on Plant Height



Traditional system in Jannale performed better than improved (this is in line with all the trials conducted: sesame does not seem to appreciate N fertilization). This trait is modified prevalently by the water availability, and it is constant whenever some fertilizer is applied.

6.1.1.2. Number of days at 50% flowering

This trait has been measured when 50% of the plant in the plots flowered; it is an indicator of the precocity of sesame. From the ANOVA (Tab. 12) the sources of variation resulted significant at the F test are Site and all the interaction considered in the ANOVA model.

Table 12: ANOVA of Number of Days at 50% Flowering year 2011

source of variation	sum of square	df	mean square	F test	P
Site (S)	62.593	2	31.296	24.148	**
Error a	7.778	6	1.296		
Varieties (V)	62.593	2	31.296	3.558	n.s.
Crop System (C)	15	1	15	0.278	n.s.
Interaction S*V	35.185	4	8.796	19.590	**
Interaction S*C	107.778	2	53.889	120.020	**
Interaction V*C	21.111	2	10.556	23.510	**
error b	233.333	520	0.449		

In figure 13 it is reported the variance of this trait observed among the sites. Even if there is not a big variation between plants (lesser than one day), the variation due to Site is highly significant .

Figure 13: Influence of Sites on Number of Days at 50% Flowering

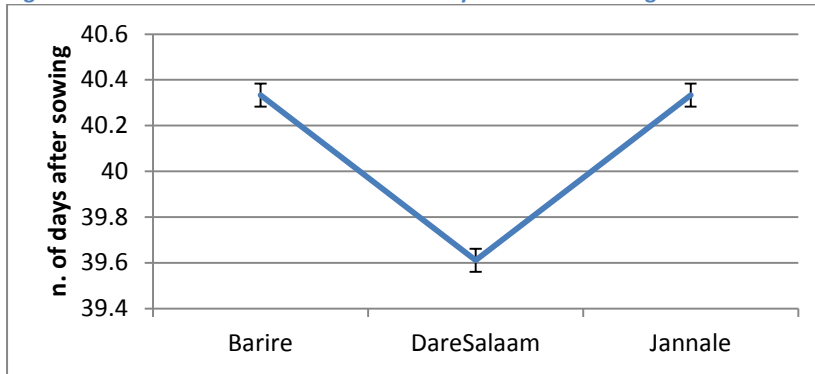
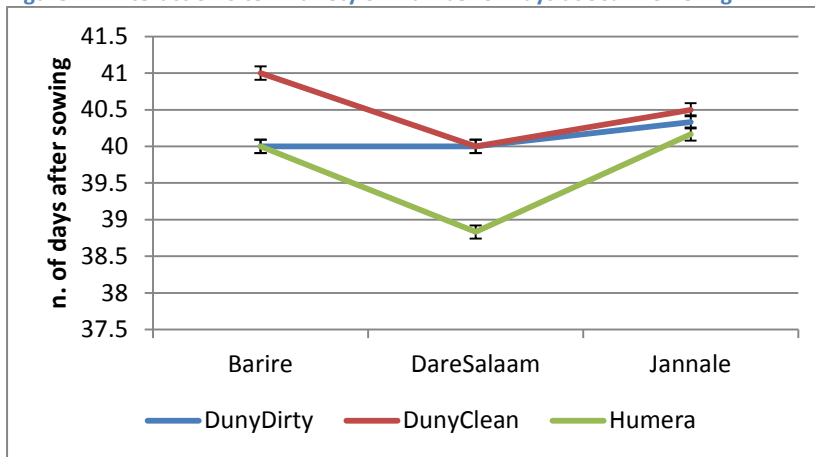
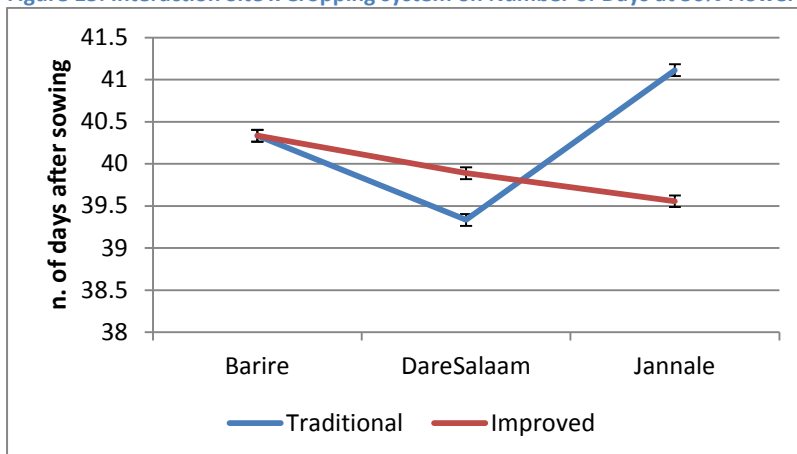


Figure 14: Interaction Site x Variety on Number of Days at 50% Flowering



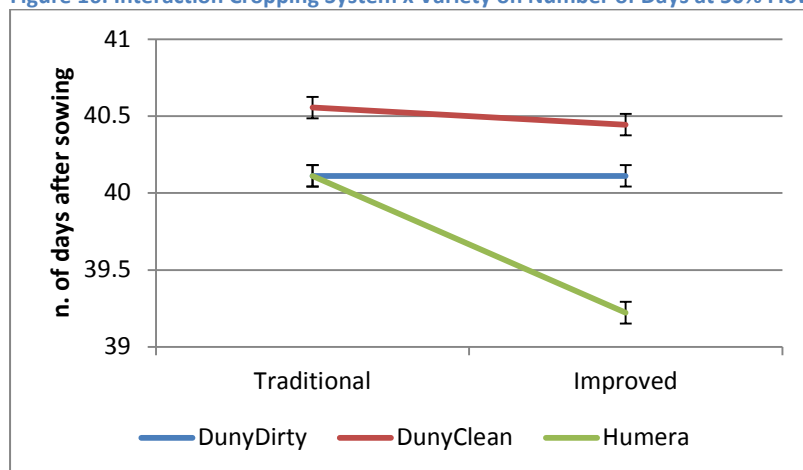
In Daresalaam all the varieties show a tendency to anticipate the flowering (Fig. 14). This could be related to some harsh conditions respect to the other two sites. This seems to be confirmed by the fact that in almost all the other variables sesame in Daresalam performed different from the other sites.

Figure 15: Interaction Site x Cropping system on Number of Days at 50% Flowering



Nonetheless, improved cropping system seems to shorten the time needed for flowering (Fig. 15). This applies also in Jannale possibly because as fertilizer was applied at flowering stage, fertilization had no impact on flowering.

Figure 16: Interaction Cropping System x Variety on Number of Days at 50% Flowering



Humera demonstrated to be the variety benefitting the most from improved cropping system in terms of precocity (Fig. 16).

6.1.1.3. Number of capsules per plant

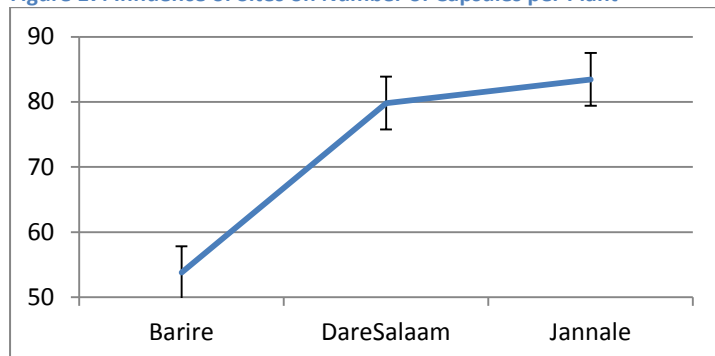
Also in this case (see Table 13) the variance due to Site factor is significant at the F test, although with the probability of 5%. The other source of variation resulted significant is Interaction Site x Crop System.

Table 13: ANOVA for Number of Capsules per Plant year 2011

source of variation	sum of square	df	mean square	F test	P
Site (S)	94277.737	2	47138.87	9.665	*
Error a	29262.456	6	4877.076		
Varieties (V)	613.581	2	306.791	0.104	n.s.
Crop System (C)	64397.424	1	64397.42	2.618	n.s.
Interaction S*V	19270.207	4	4817.552	1.630	n.s.
Interaction S*C	49187.47	2	24593.74	8.322	**
Interaction V*C	1255.048	2	627.524	0.212	n.s.
error b	1536830.319	520	2955.443		

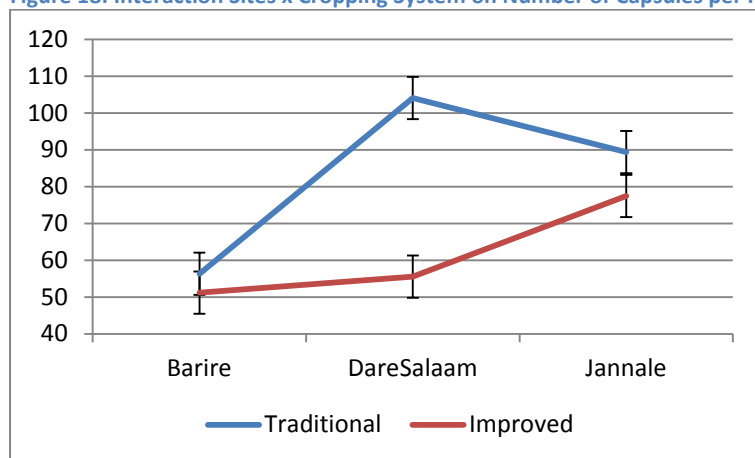
The influence of the localities on the variation of the number of capsules per plant is reported in figure 17.

Figure 17: Influence of Sites on Number of Capsules per Plant



It is interesting to observe the behavior of this variable in function of the crop system in the different localities (Fig. 18): The improved system of cropping had a negative impact on the number of capsules per plant, particularly in the harsh condition of Daresalaam.

Figure 18: Interaction Sites x Cropping System on Number of Capsules per Plant



This observation shall be read probably jointly with the next: number of seeds per capsules.

6.1.1.4. Number of seeds per capsule

This demonstrated to be one of the variables more relevant related to plant and plot yield.

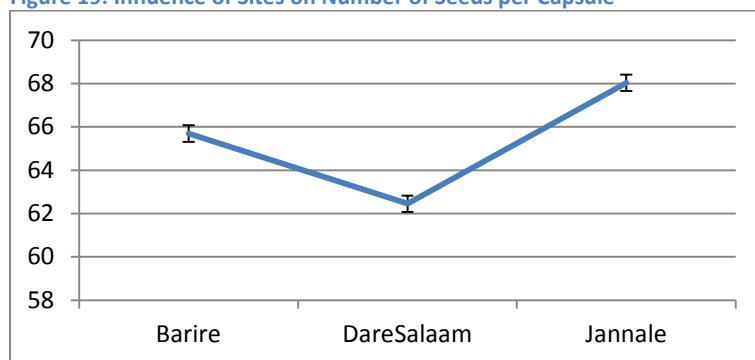
The ANOVA results (Tab. 14) show three sources of variation are statistically significance (F test with probability lesser than 0.01%): Site, Crop System and Interaction Site x Varieties.

Table 14: ANOVA for Height at 50% Flowering year 2011

source of variation	sum of square	Df	mean square	F test	p
Site (S)	2830.226	2	1415.113	20.589	**
Error a	412.378	6	68.73		
Varieties (V)	157.526	2	78.763	0.636	n.s.
Crop System (C)	201.667	1	201.667	7.728	**
Interaction S*V	495.585	4	123.896	4.748	**
Interaction S*C	97.478	2	48.739	1.868	n.s.
Interaction V*C	93.733	2	46.867	1.796	n.s.
error b	13570.178	520	26.096		

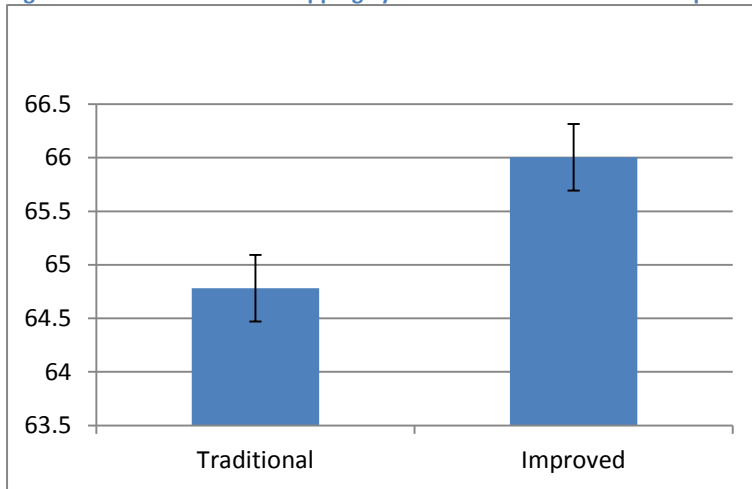
In figure 19 is reported the variance of number of seed per capsule determined by the three localities tested. The observed variation ranged from 63 to 68 seed per capsule.

Figure 19: Influence of Sites on Number of Seeds per Capsule



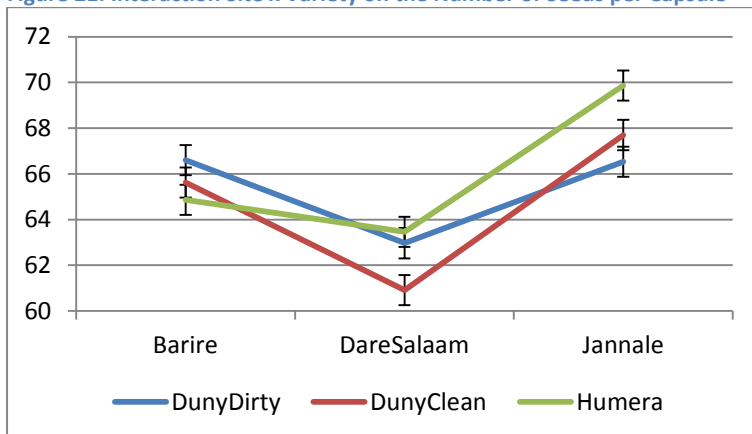
The influence of Cropping System on the number of seed per capsule is reported on the histogram of figure 20. The improved system increased the number to 66 seeds per capsule.

Figure 20: Influence of the Cropping System on the Number of Seeds per Capsule



The interaction Site x Variety reported in the graphic of figure 21, shows the different behavior of the considered varieties in the three localities.

Figure 21: Interaction Site x Variety on the Number of Seeds per Capsule



The variety Humera in Jannale, produces a larger number of seeds per capsule. Dunny Clean shows a reduction of the number of seeds per capsule in the location DereSalaam, where the grow condition are more restrictive, demonstrating a minor rusticity respect to the same genotype but with colored seed genotypes. In Barire Dunny phenotypes are growing as Humera, this behavior could be explained by the better adaptation to the site that is the central of origin of this variety.

6.1.1.5. Yield per plant

The ANOVA table (Tab. 15) shows two sources of variance statistically significant: Site ($p < 0.01$) and Interaction Sites x Crop System ($p < 0.05$)

Table 15: ANOVA for Yield per Plant year 2011

source of variation	sum of square	df	mean square	F test	P
Site (S)	3937.604	2	1968.802	32.198	**
Error a	366.878	6	61.146		
Varieties (V)	225.07	2	112.535	2.836	n.s.
Crop System (C)	66.15	1	66.15	0.415	n.s.
Interaction S*V	278.641	4	69.66	1.756	n.s.
Interaction S*C	319.144	2	159.572	4.022	*
Interaction V*C	69.233	2	34.617	0.873	n.s.
error b	20630.778	520	39.675		

In figure 22 is represented the variation due to the Site levels, the weight of seeds per plant ranged from 8.0 to 14.5 g, confirming the importance of the environment for the plant yield.

Figure 22: Influence of Sites on Seed Production per Plant

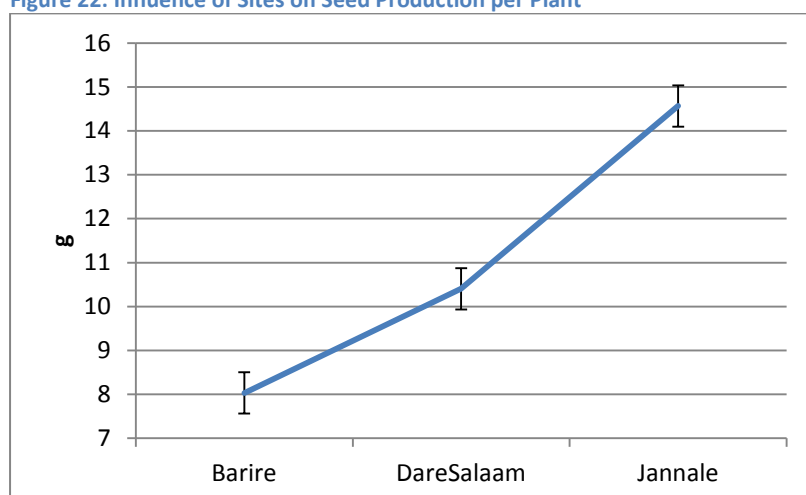
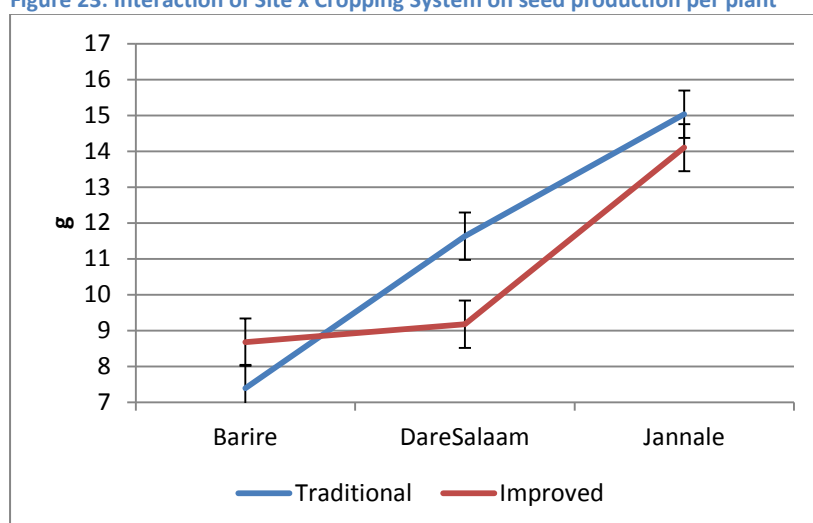


Figure 23: Interaction of Site x Cropping System on seed production per plant



In figure 23 is reported the different behavior of the two Cropping Systems in function of the three localities. In Daresalaam it shows the maximum difference between the two Cropping System with the traditional showing the highest production of seed per plant, while in Barire and Jannale there is not so evident different also if there is a slightly increment of plant seed production for Improved Crop System in Barire.

6.1.1.6. Yield per plot

The plot area was 400 m². Yield per ha may be reached multiplying by 25 the data per plot. The ANOVA table (Tab. 16) reports five sources of variation highly significant ($p < 0.01$): Site, Varieties, Interaction Site x Varieties, Interaction Site x Crop System and Interaction Varieties x Crop System. Jannale is the best site for production (Fig. 24); Humera is the best yielding variety (Fig. 25), independently by Site (Fig. 26) and by Cropping System (Fig. 28).

Table 16: ANOVA for Yield per Plot year 2011

source of variation	sum of square	df	mean square	F test	P
Site (S)	2952.629	2	1476.314	81.014	**
Error a	109.339	6	18.223		
Varieties (V)	5062.365	2	2531.182	28.554	**
Crop System (C)	3290.831	1	3290.831	10.200	n.s.
Interaction S*V	354.585	4	88.646	27.343	**
Interaction S*C	645.258	2	322.629	99.515	**
Interaction V*C	773.39	2	386.695	119.277	**
error b	1685.91	520	3.242		

Figure 24: Influence of Site on Yield per Plot

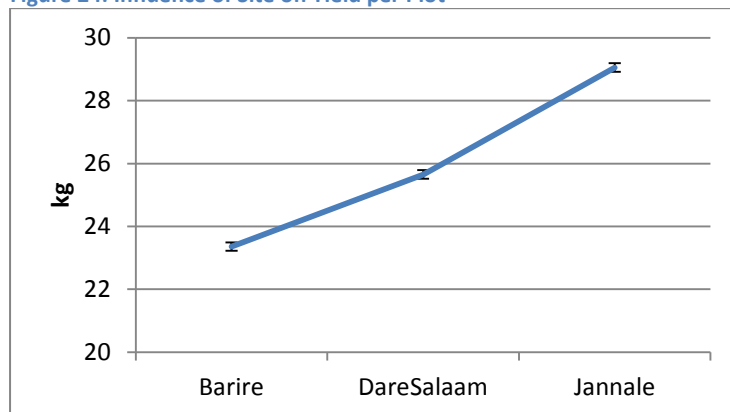


Figure 25: Influence of Varieties on Yield per Plot

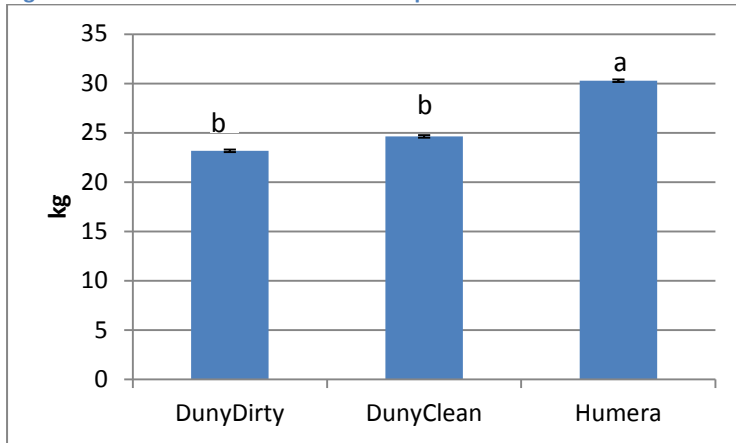
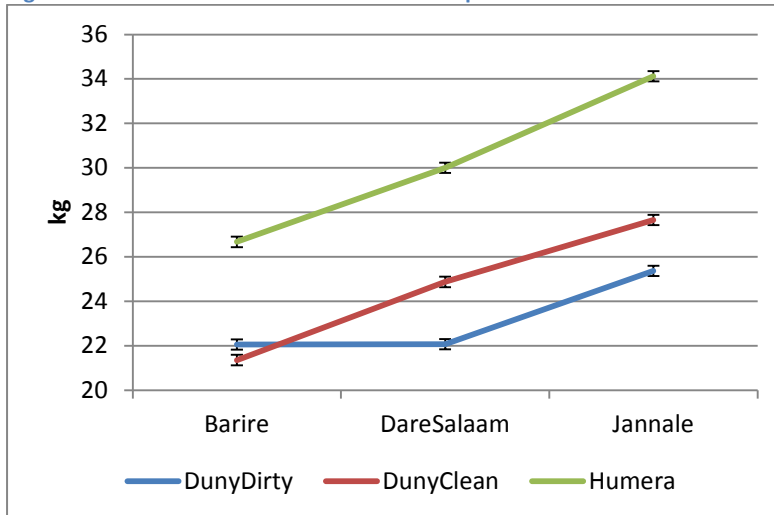


Figure 26: Interaction Site x Varieties on Yield per Plot



Also if the F test for Cropping System is not statistically significant, the figure 29 shows the interaction between Site and Cropping System, where it is possible to observe a superior production obtained with traditional Cropping System.

Figure 27: Interaction Site x Cropping System on Yield per Plot

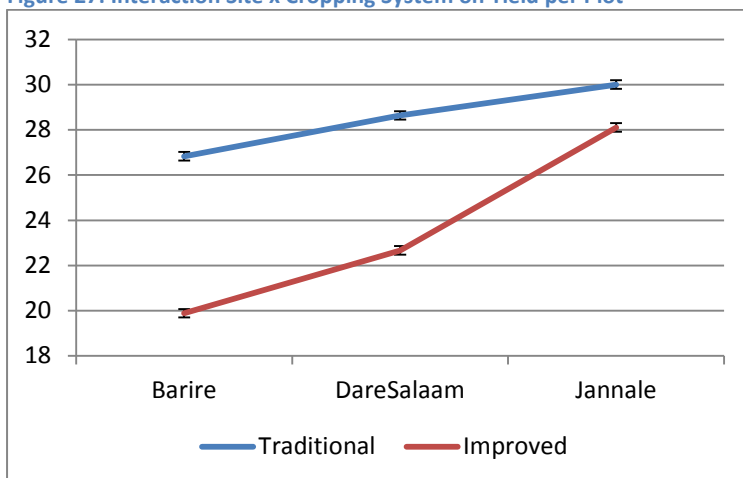
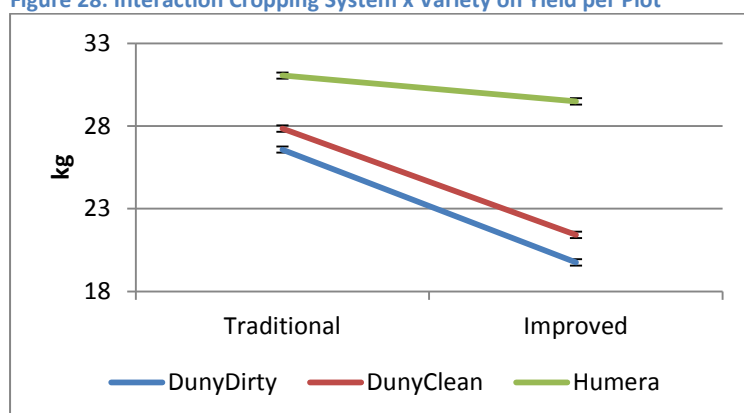


Figure 27 shows again that traditional system performs better than improved, the difference between the two cropping systems is not the same in the considered localities: its maximum in Barire and it is reduced in Jannale.

Figure 28: Interaction Cropping System x Variety on Yield per Plot



The most relevant observation on data gathered in 2011 in the three different sites in South Central Region of Somalia is a significant interaction between sites and between cropping systems. Confirming the high level of variability of sesame depending on the environmental conditions reported in literature. Results demonstrated that no appreciable difference exists in the colour ratio of the two Dunyar phenotypes.

The summary of results is reported in the table 17, where the averages of the considered variables are referred to each level of the factors included in the ANOVA model.

Table 17: ANOVA summary of results (average) year 2011

Factors	Plant Vigour	Plant Height cm	Days 50% Flow	N Caps Plant	N Seeds Capsule	Weight of 1000 Seed	Yield Plant g	Yield Plot kg
Site	*	**	**	*	**	n.s.	**	**
Barire	3.77	86.53	40.33	53.78	65.69	4.00	8.03	23.36
DareSalaam	3.33	85.57	39.61	79.82	62.45	4.00	10.41	25.65
Jannale	3.82	120.26	40.33	83.44	68.03	3.98	14.57	29.05
Varieties	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**
DunyDirty	3.69	100.19	40.11	71.23	65.37	3.99	11.10	23.17 b
Dunylmpr	3.61	97.96	40.50	72.02	64.74	3.99	10.17	24.63 b
Humera	3.61	94.21	39.67	73.78	66.07	4.00	11.74	30.27 a
Crop System	**	n.s.	n.s.	n.s.	**	n.s.	n.s.	n.s.
Improved	3.86	98.30	39.93	61.43	66.00	4.00	10.65	23.55
Traditional	3.41	96.61	40.26	83.27	64.78	3.99	11.35	28.49

6.1.1.7. Pearson Correlation Analysis

The Pearson correlation analysis performed to understand the connection between the analyzed variable, shows (Tab. 18) that yield per plant resulted correlated (significance <0.01) with plant height and number of seeds per capsule. While the yield per plot resulted correlated to plant height, yield per plant, days50% flowering, the number of seeds per capsule and the number of capsules per plant. Based on the coefficients and the significance reported in table 12 the characters to be pursuit in order to increase the yield per plot are plant height, n. of capsules per pant and n. of seeds per capsule. The other variables even if significant contribute only in low measure to the yield per plot. These data are in line with the literature.

Table 18: Pearson correlation matrix

	plant height cm	days 50% flow	n caps plant	n seeds capsule	weight1000 seeds	yield plant g	yield plot kg
plant height cm	1						
days 50% flow	0.205**	1					
n caps plant	0.423**	-0.018**	1				
n seeds capsule	0.463**	0.144**	0.22**	1			
weight1000 seeds	-0.096	-0.043	0.051**	-0.025	1		
yield plant g	0.558**	0.054	0.753	0.307**	0.025	1	
yield plot kg	0.19**	-0.168**	0.171**	0.087	0.01	0.243**	1

6.1.2. Field Tests year 2012 and 2013 (Kilifi and Busia)

The variables considered in the two experiments conducted in 2012 and in 2013 in Kilifi and in Busia are reported with the relevant legend key in table 19. The ANOVA model, as reported in the Material and Methods chapter, considers two localities as random effect factor, while five varieties, three levels of nitrogen and two levels of phosphorous as fixed effect factors.

Table 19: examined variable in the trials of 2012 and 2013 and relative legend key

H50%Fl	Height when 50% of the plant in the plot are flowering
Plheig	Plant height at physiological maturity
Wcap	Weight of the capsules in the plant
Pyieldg	Plant yield in g
Ncap	Number of capsules pe rplant
NSXCap	Number of seeds per capsule
CapLeng	Length of the capsule
CapThickn	Thickness of the capsule
StThickn	Thickness of the stem
InterL	Internode length

6.1.2.1. Height 50% flowering

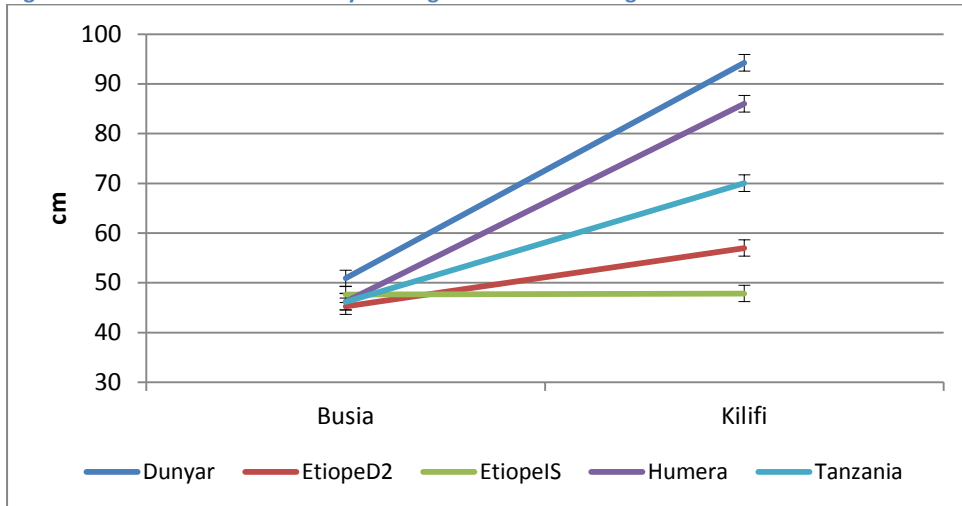
In table 20 are reported the results ANOVA. There are four sources of variance with F test statistically significance: Site ($p < 0.05$), Phosphorous ($p < 0.01$), Interactions Site x Varieties ($p < 0.01$) and Site x Nitrogen ($p < 0.01$).

In Busia the plant height at 50% of flowering is less than the one observed in Kilifi (Fig.29). The graphic of the interaction Site x Varieties shows that EthiopianIS is the sole variety whose performance was not significantly different between Kilifi and Busia, while all the other varieties in Kilifi performed better than in Busia, with Dunyar being the highest plant when 50% of plants flowered.

Table 20: ANOVA for Height at 50% Flowering years 2012-13

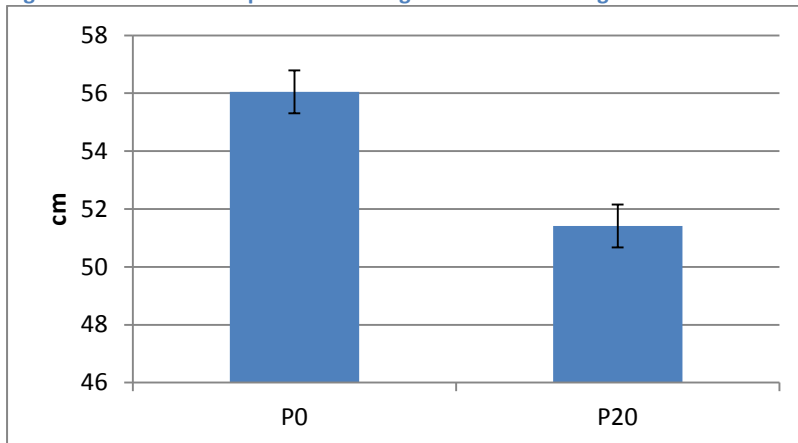
Source of variance	Sum of Square	d.f.	Mean Square	F-test	Sign.
Site (S)	53957.699	1	53957.699	59.98	*
Error a	1799.157	2	899.579		
Between Varieties (V)	33759.445	4	8439.861	1.22	n.s.
Between Nitrogen levels (N)	4370.298	2	2185.149	2.20	n.s.
Phosphorus levels (P)	1261.027	1	1261.027	9.15	**
Interaction SxV	27669.69	4	6917.422	50.19	**
Interaction SxN	1985.633	2	992.816	7.20	**
Interaction SxP	31.903	1	31.903	0.23	n.s
Interaction VxN	1667.449	8	208.431	1.51	n.s
Interaction VxP	321.336	4	80.334	0.58	n.s
Interaction NxP	299.57	2	149.785	1.09	n.s
Error b	65186.295	473	137.815		

Figure 29: Interaction Site x Variety on Height at 50% Flowering



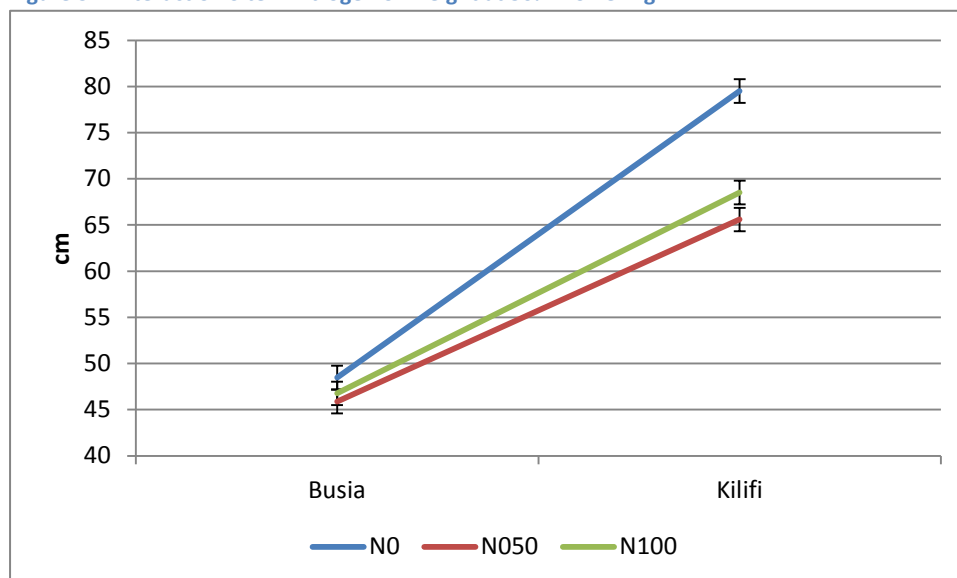
The P fertilization contributed reducing the height at 50% of flowering time (Fig. 30)

Figure 30: Effect of Phosphorous on Height at 50% Flowering



The interaction Site x Nitrogen reported on the graphic of figure 31, shows the effect of the different nitrogen levels especially in Kilifi where the N0 improve the height of the plants at 50% flowering, while such difference is not observed in Busia.

Figure 31: Interaction Site x Nitrogen on Height at 50% Flowering



6.1.2.2. Plant height

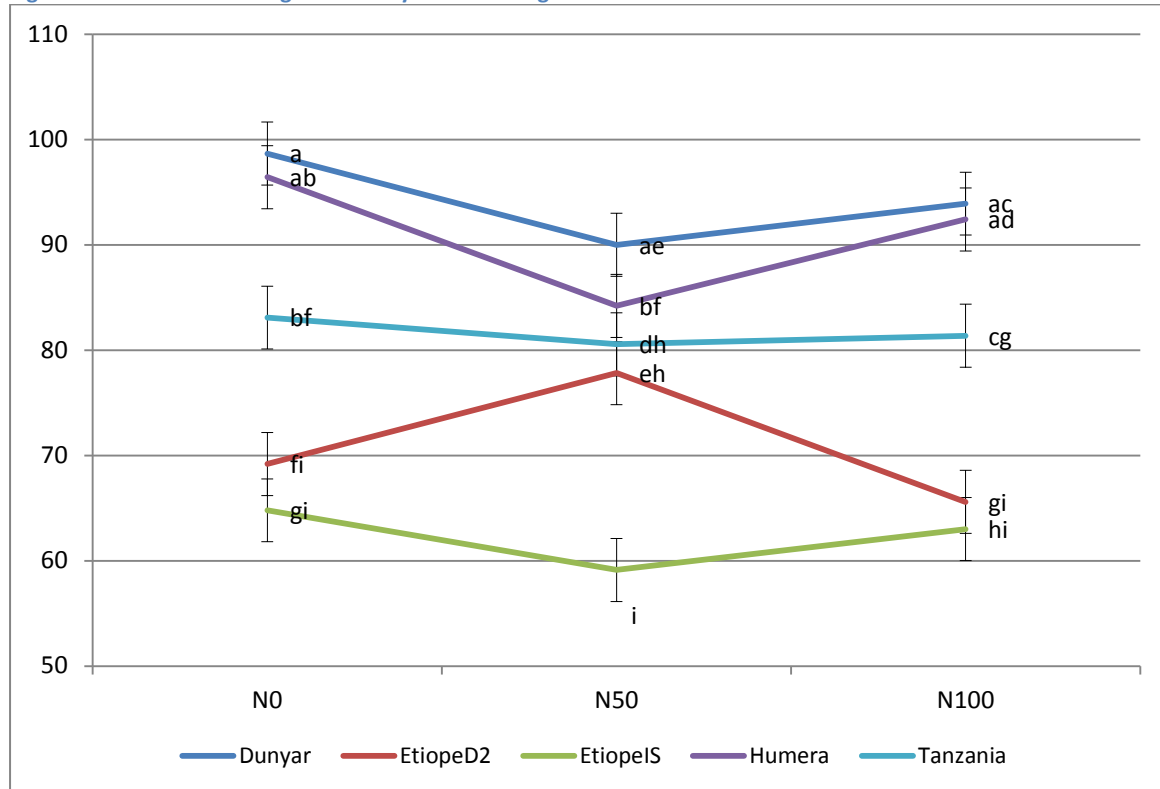
The height of plant at harvest time, shows little difference compared to the height of plant at 50% of flowering, in fact the differences observed in the two sites of cultivation are reduced at plant maturity. The ANOVA results for this variable do not show any statistical significance for the Site factor (Tab. 21).

Instead the variance between Varieties resulted statistically significant ($p < 0.05$).

Table 21: ANOVA for Plant Height years 2012-13

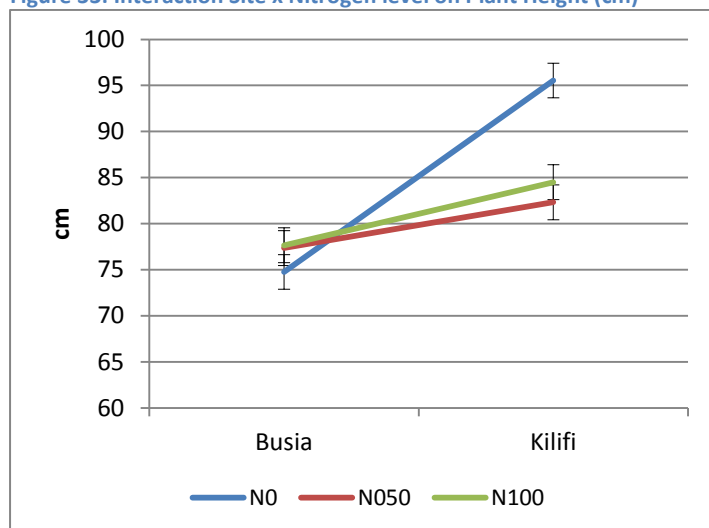
Source of variance	Sum of Square	d.f.	Mean Square	F-test	Sign.
Between Sites (S)	9543.839	1	9543.839	3.75	n.s.
Error a (blocco entro siti)	5093.063	2	2546.532		
Between Varieties (V)	69664.001	4	17416	8.77	*
Between Nitrogen levels (N)	2947.462	2	1473.731	1.15	n.s.
Phosphorus levels (P)	872.636	1	872.636	2.90	n.s.
Interaction SxV	7946.177	4	1986.544	6.61	**
Interaction SxN	2559.759	2	1279.88	4.26	*
Interaction SxP	174.737	1	174.737	0.58	n.s.
Interaction VxN	5911.046	8	738.881	2.46	*
Interaction VxP	2163.224	4	540.806	1.80	n.s.
Interaction NxP	1358.888	2	679.444	2.26	n.s.
Error b	142221.049	473	300.679		

Figure 32: Interaction Nitrogen x Variety on Plant Height



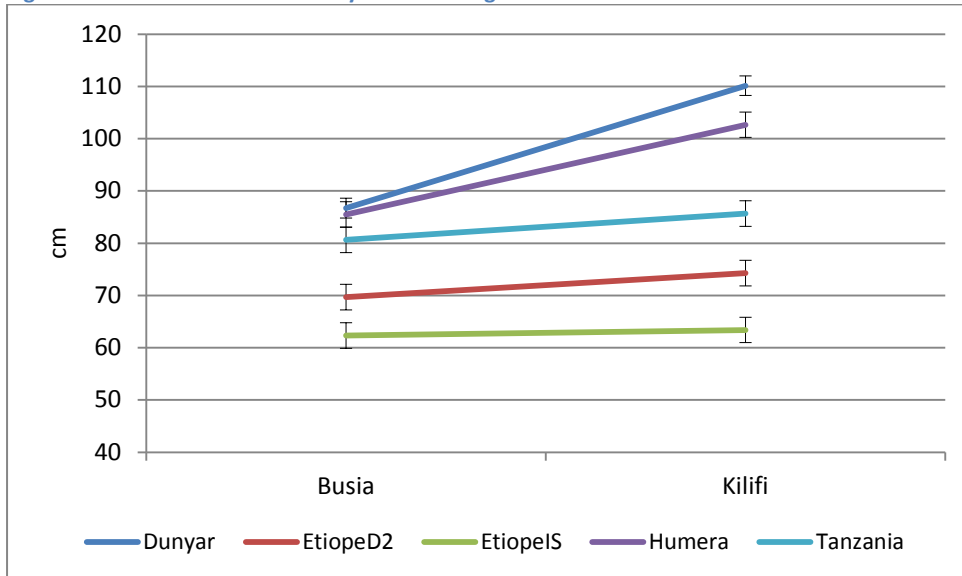
The interaction Nitrogen x Varieties, reported in the graphic of figure 32, shows a controversial response to the N fertilization. EthiopianIS and D2 confirmed their propensity to be short plants and the fertilization with 50kg/ha being the one that always, except in Ethiopian D2, are the shortest plants compare to the other nitrogen levels.

Figure 33: Interaction Site x Nitrogen level on Plant Height (cm)



It is interesting to note as the nitrogen levels have different effects for the two considered localities (Fig. 33). The N0 level shows broad positive effect in plant height in Kilifi, while no differences are observed between nitrogen effects in Busia. It is likely that the abundant rains, which a depressing impact on general performances of the crop, also washed away the fertilizers.

Figure 34: Interaction Site x Variety on Plant Height



The different behaviour, of the analysed varieties in the two localities, is shown in graphic of figure 34. In Kilifi the height of plants ranges from 62 cm for EtiopIS to 110 cm for Dunyar, while in Busia the plant height interval starts from 62 cm for again EtiopIS, to 86 cm for Dunyar and Humera.

6.1.2.3. Weight of Capsules

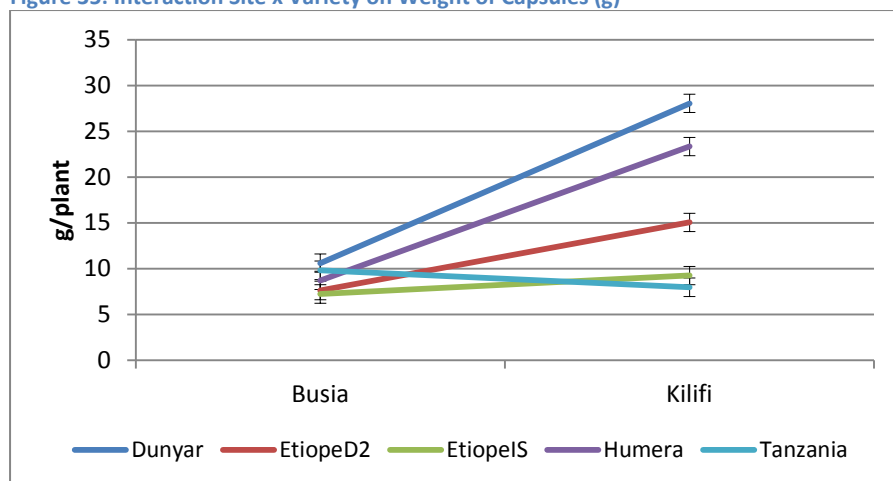
The results of ANOVA (Tab. 22) give a significant F-Test for three sources of variation: the sites (< 0.05) and the Interactions Site per Variety and Site per Nitrogen (< 0.01).

Table 22: ANOVA for Weight of Capsules years 2012-13

Source of variance	Sum of Square	d.f.	Mean Square	F-test	Sign.
Between Sites (S)	5773.116	1	5773.116	64.40	*
Error a	179.289	2	89.645		
Between Varieties (V)	7104.408	4	1776.102	1.43	n.s.
Between Nitrogen levels (N)	1637.086	2	818.543	0.99	n.s.
Phosphorus levels (P)	0.108	1	0.108	0.00	n.s.
Interaction SxV	4979.923	4	1244.981	24.48	**
Interaction SxN	1659.729	2	829.864	16.32	**
Interaction SxP	25.736	1	25.736	0.51	n.s.
Interaction VxN	345.492	8	43.187	0.85	n.s.
Interaction VxP	429.282	4	107.32	2.11	n.s.
Interaction NxP	121.037	2	60.519	1.19	n.s.
Error b	24055.18	473	50.857		

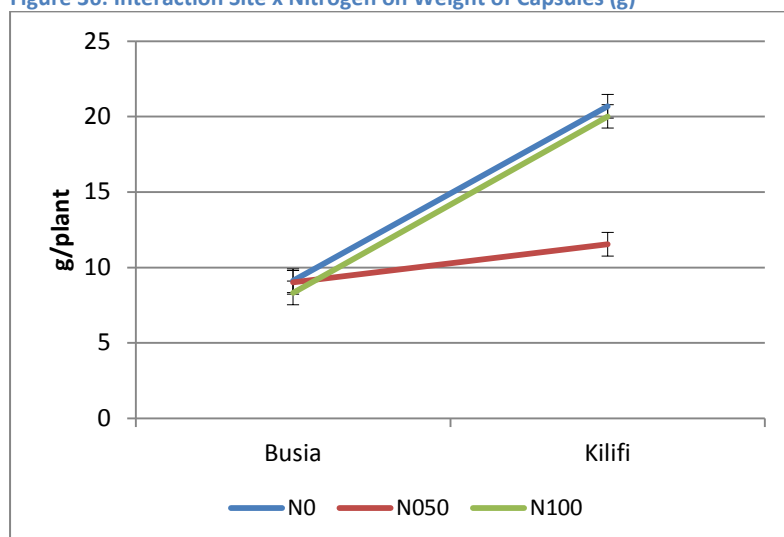
Figure 35 shows that Tanzania and Ethiopian IS performed in the same way in the two sites while the others varieties performed better in Kilifi. Dunyar confirms the best response to fertilization (in line with previous trials).

Figure 35: Interaction Site x Variety on Weight of Capsules (g)



While no appreciable differences among the levels of fertilization may be noted in Busia (Fig. 36), in Kilifi the nitrogen levels that performed better are N0 and N100.

Figure 36: Interaction Site x Nitrogen on Weight of Capsules (g)



It must be underline the effect of N50 level in Kilifi, whose effect is depressing compared to the others.

6.1.2.4.Plant Yield

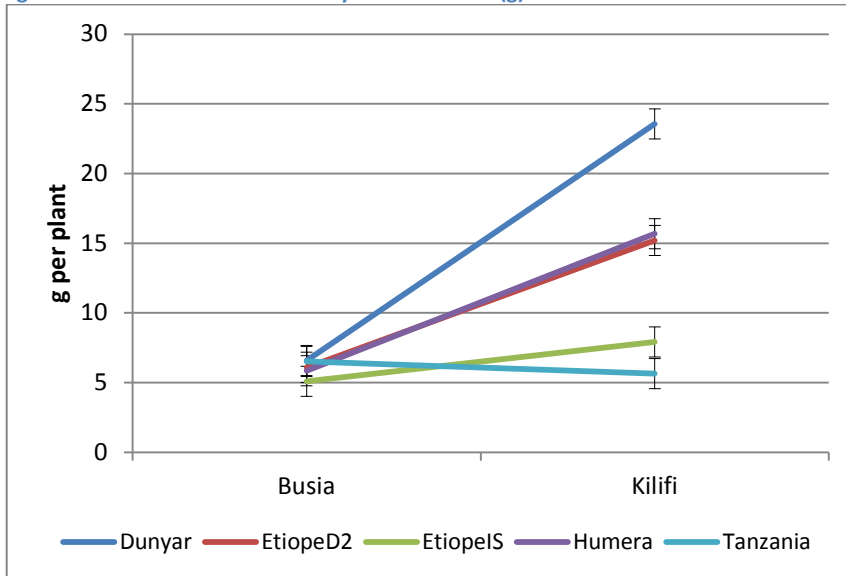
Table 23 reports the results of the ANOVA analysis and again the variance among Sites is significant at the probability level of 0.05 to F Test, while the interaction Site per Variety and Site per Nitrogen are highly significant ($p < 0.01$).

Table 23: ANOVA for Plant Yield years 2012-13

Source of variance	Sum of Square	d.f.	Mean Square	F-test	Sign.
Between Sites (S)	5337.2	1	5337.2	50.82	*
Error a	210.0	2	105.0		
Between Varieties (V)	4109.1	4	1027.3	1.15	n.s.
Between Nitrogen levels (N)	983.2	2	491.6	0.90	n.s.
Phosphorus levels (P)	35.8	1	35.8	0.61	n.s.
Interaction SxV	3581.8	4	895.4	15.33	**
Interaction SxN	1086.7	2	543.4	9.31	**
Interaction SxP	39.5	1	39.5	0.68	n.s.
Interaction VxN	685.7	8	85.7	1.47	n.s.
Interaction VxP	107.6	4	26.9	0.46	n.s.
Interaction NxP	101.9	2	51.0	0.87	n.s.
Error b	27621.6	473	58.4		

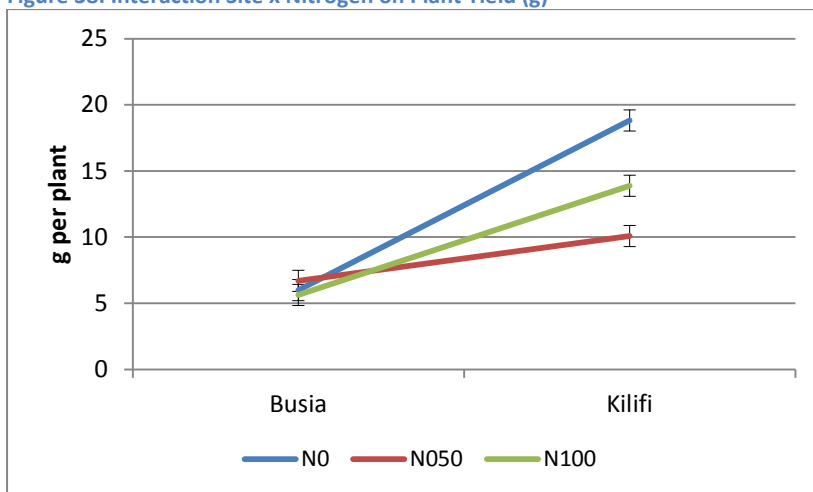
Figure 37 shows that only Tanzania performed better in Busia than in Kilifi and Dunyar was the best performing variety followed by Humera. It seems that the stressing conditions in Busia flattened all the production to the minimum not allowing the manifestation of any variability among the different varieties, while in Kilifi they had the opportunity to express it.

Figure 37: Interaction Site x Variety on Plant Yield (g)



Between Busia and Kilifi (Fig. 38) is noted the particular behaviour of the levels: no Nitrogen level (N0) performs as the high (N100), while N50 performs as the worst (the same behaviour was noted for the trait of the capsule weight).

Figure 38: Interaction Site x Nitrogen on Plant Yield (g)



6.1.2.5. Number of Capsules per plant

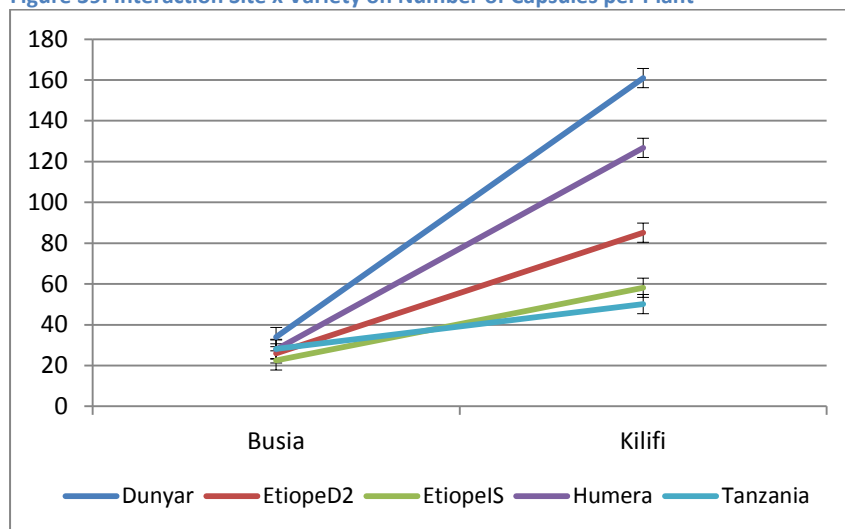
ANOVA results (Tab. 24) shows that the variance between Sites is highly significant as well as the interaction Site per Variety and Site per Nitrogen.

Table 24: ANOVA for Number of Capsules per plant year 2012-13

Source of variance	Sum of Square	d.f.	Mean Square	F-test	Sign.
Between Sites (S)	437414.455	1	437414.455	229.51	**
Error a	3811.66	2	1905.83		
Between Varieties (V)	197805.938	4	49451.484	1.36	n.s.
Between Nitrogen levels (N)	25394.961	2	12697.48	1.06	n.s.
Phosphorus levels (P)	2228.794	1	2228.794	1.98	n.s.
Interaction SxV	145905.416	4	36476.354	32.40	**
Interaction SxN	23897.229	2	11948.614	10.61	**
Interaction SxP	471.47	1	471.47	0.42	n.s.
Interaction VxN	10359.84	8	1294.98	1.15	n.s.
Interaction VxP	6439.709	4	1609.927	1.43	n.s.
Interaction NxP	4419.785	2	2209.893	1.96	n.s.
Error b	532492.807	473	1125.778		

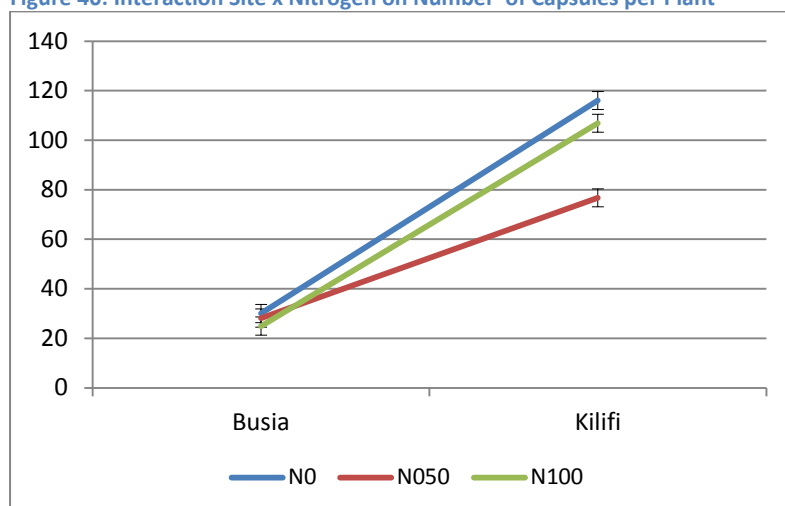
The highest number of capsules was produced by Dunyar and Humera in Kilifi. No significant differences have been noted between the varieties in Busia (Fig. 39).

Figure 39: Interaction Site x Variety on Number of Capsules per Plant



Again while there are no appreciable differences in the performances of this variable in Busia; in Kilifi N0 and N100 are the best performing levels and N50 is the worst (Fig. 40).

Figure 40: Interaction Site x Nitrogen on Number of Capsules per Plant



6.1.2.6. Number of Seeds per Capsule

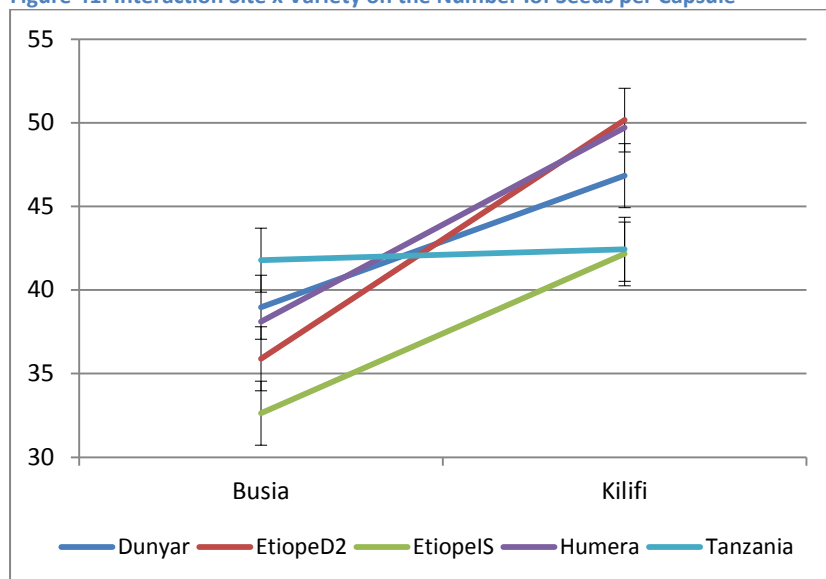
For the Number of Seeds per Capsule trait, only the interaction Site per Variety shows significant F Test (Tab. 25).

Table 25: ANOVA for Number of Seeds per Capsules years 2012-13

Source of variance	Sum of Square	d.f.	Mean Square	F-test	Sign.
Between Sites (S)	7053.674	1	7053.674	6.80	n.s.
Error a	2074.055	2	1037.027		
Between Varieties (V)	1650.113	4	412.528	0.81	n.s.
Between Nitrogen levels (N)	47.469	2	23.735	0.13	n.s.
Phosphorus levels (P)	10.911	1	10.911	0.06	n.s.
Interaction SxV	2041.616	4	510.404	2.77	*
Interaction SxN	374.654	2	187.327	1.02	n.s.
Interaction SxP	509.769	1	509.769	2.77	n.s.
Interaction VxN	1824.353	8	228.044	1.24	n.s.
Interaction VxP	80.487	4	20.122	0.11	n.s.
Interaction NxP	441.432	2	220.716	1.20	n.s.
Error b	87050.01	473	184.038		

Tanzania once more showed no differences in the performance between the two sites while all the other varieties performed better in Kilifi than in Busia. Ethiopian IS and Humera are the best ones (Fig. 41).

Figure 41: Interaction Site x Variety on the Number .of Seeds per Capsule



6.1.2.7.Length of Capsules

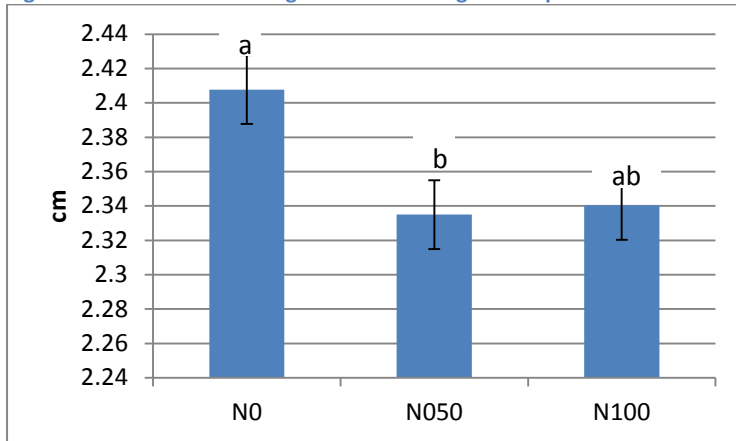
Table 26 reports the results of ANOVA for the Length of Capsule character; four sources of variation showed significance variance: Sites, Nitrogen, Phosphorus ($p < 0.05$) and the interaction Site per Variety ($p < 0.01$).

Table 26: ANOVA for Length of Capsules years 2012-13

Source of variance	Sum of Square	d.f.	Mean Square	F-test	Sign.
Between Sites (S)	6.697	1	6.697	61.44	*
Error a	0.218	2	0.109		
Between Varieties (V)	0.39	4	0.098	0.09	n.s.
Between Nitrogen levels (N)	0.486	2	0.243	3.57	*
Phosphorus levels (P)	0.297	1	0.297	5.03	*
Interaction SxV	4.351	4	1.088	18.55	**
Interaction SxN	0.136	2	0.068	1.16	n.s
Interaction SxP	0	1	0	0.01	n.s
Interaction VxN	0.853	8	0.107	1.82	n.s
Interaction VxP	0.386	4	0.096	1.65	n.s
Interaction NxP	0.299	2	0.149	2.55	n.s
Error b	27.73	473	0.059		

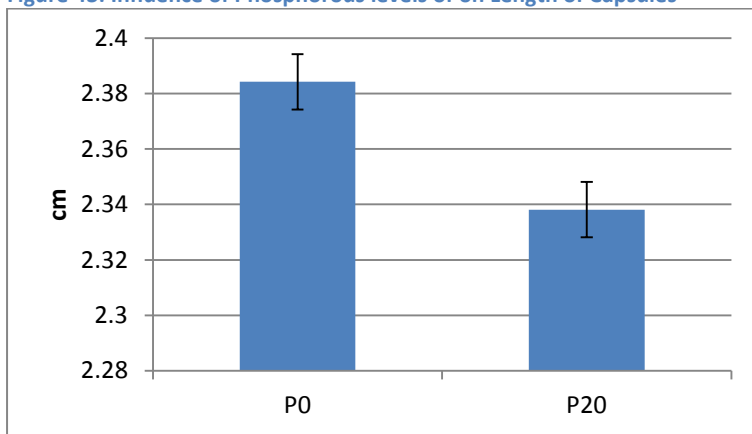
Figure 42 shows how fertilization influenced negatively the length of the capsules while best performances were observed with N0.

Figure 42: Influence of Nitrogen levels on Length of Capsule



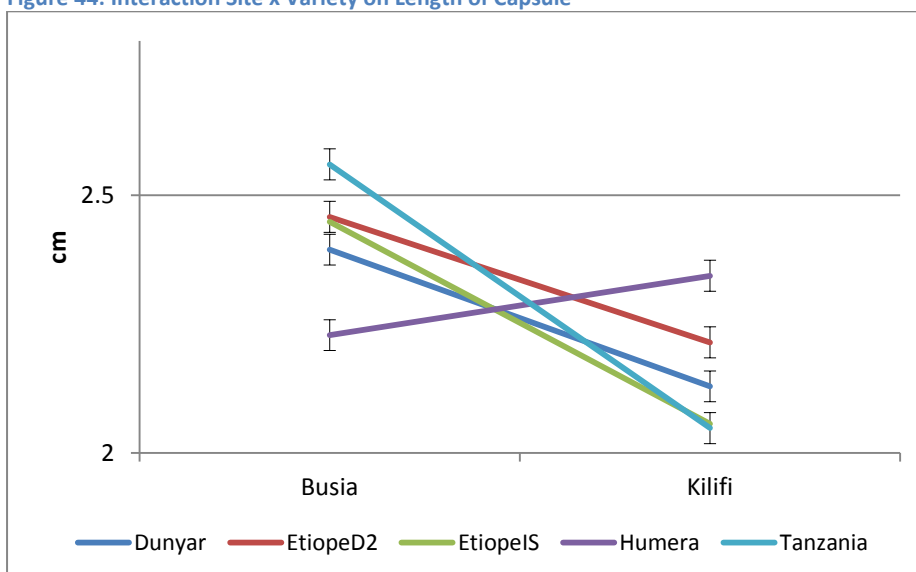
The same depressing effect was observed with the Phosphorous fertilization (Fig. 43).

Figure 43: Influence of Phosphorous levels on Length of Capsules



With the exception of Humera, the length of the capsules in all varieties was greater in Busia than in Kilifi (Fig. 44). This is clearly a controversial information as capsule length has impact on yield per plant and this information needs to be considered together with the Number of Seeds per Capsule.

Figure 44: Interaction Site x Variety on Length of Capsule



6.1.2.8. Thickness of Capsules

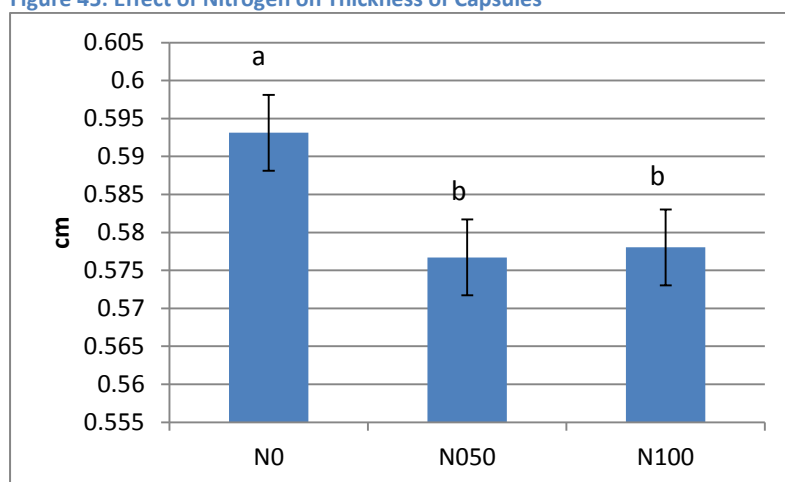
ANOVA results (Tab. 27) show three significant sources of variation to F Test: the level of Nitrogen, the Interaction Site per Variety and the Interaction Site per Phosphorus.

Table 27: ANOVA for Thickness of Capsules years 2012-13

Source of variance	Sum of Square	d.f.	Mean Square	F-test	Sign.
Between Sites (S)	0.001	1	0.001	0.33	n.s.
Error a	0.005	2	0.003		
Between Varieties (V)	0.053	4	0.013	1.08	n.s.
Between Nitrogen levels (N)	0.03	2	0.015	7.50	*
Phosphorus levels (P)	0.009	1	0.009	1.80	n.s.
Interaction SxV	0.049	4	0.012	2.53	*
Interaction SxN	0.003	2	0.002	0.36	n.s.
Interaction SxP	0.021	1	0.021	4.34	*
Interaction VxN	0.039	8	0.005	1.00	n.s.
Interaction VxP	0.039	4	0.01	2.00	n.s.
Interaction NxP	0.006	2	0.003	0.63	n.s.
Error b	2.29	473	0.005		

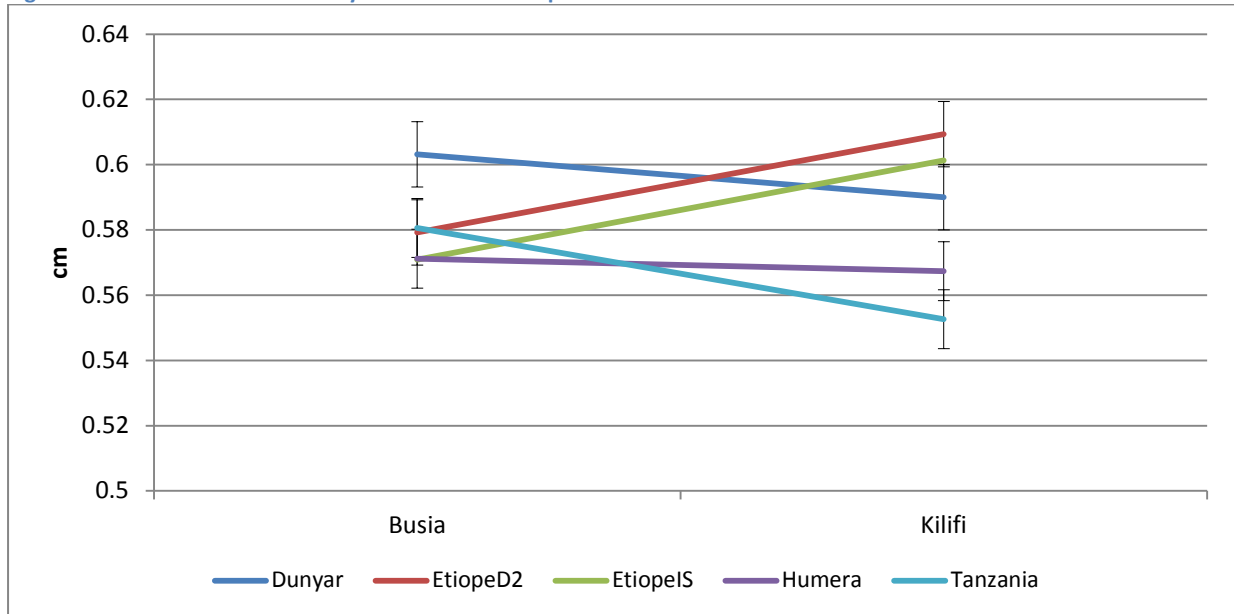
The behaviour of this variable respect to the levels of N is in line with all the other variables so far considered, N0 is the best performing and N50 and N100 are the worst (Fig. 45).

Figure 45: Effect of Nitrogen on Thickness of Capsules



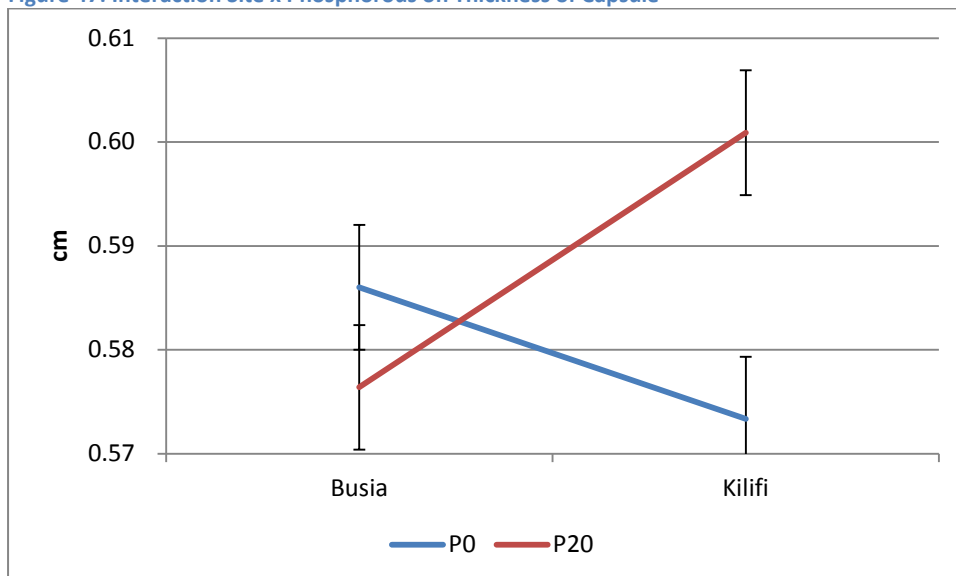
The 5 varieties performed in very different way. Some of them show a reduction of Thickness of Capsule from Busia to Kilifi, (Tanzania and Dunyar), while others, as EtiopD2 and EtiopIS, show an increase (Fig. 46). The only variety that remains stable is Humera

Figure 46: Interaction Site x Variety on Thickness of Capsule



As shown in figure 47, the highest difference between the two levels of Phosphorous for Thickness of Capsule is verified in Kilifi. While in Busia the effect of Phosphorous fertilization does not have effect. It seems that Phosphorous may have effect only when the plant is in a favourable environment.

Figure 47: Interaction Site x Phosphorous on Thickness of Capsule



6.1.2.9. Stem Thickness

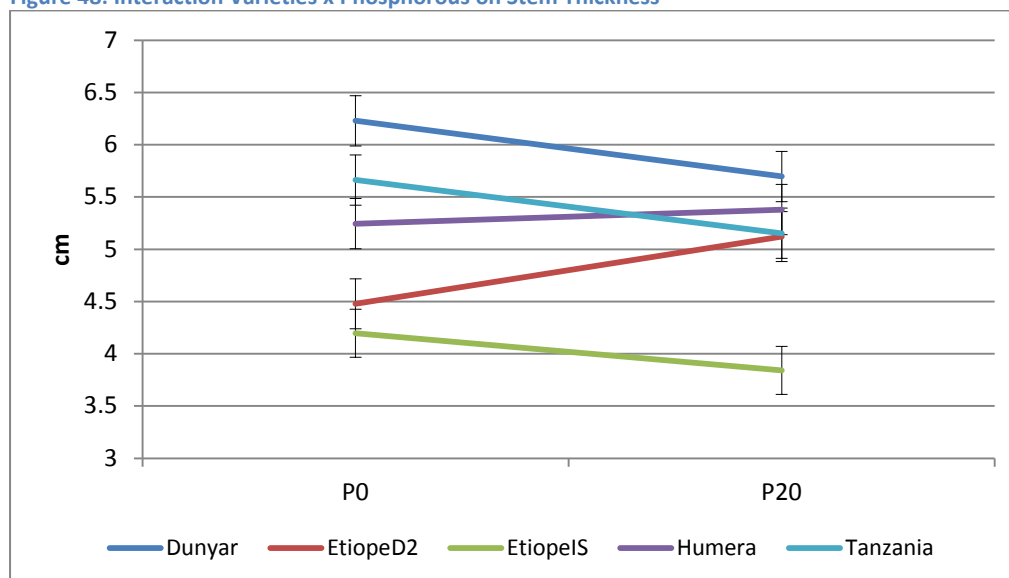
According to ANOVA results, the variability of Sites and among varieties are significant and highly significant respectively (Tab. 28). Also the interaction variety per levels of Phosphorous is significant. In Busia the value of the Stem Thickness is larger than the value observed in Kilifi (Tab.31)

Table 28: ANOVA for Stem Thickness 2012-13

Source of variance	Sum of Square	d.f.	Mean Square	F-test	Sign.
Between Sites (S)	1718.364	1	1718.364	56.23	*
Error a	61.116	2	30.558		
Between Varieties (V)	148.428	4	37.107	13.13	**
Between Nitrogen levels (N)	4.438	2	2.219	0.80	n.s.
Phosphorus levels (P)	3.52	1	3.52	1.25	n.s.
Interaction SxV	21.963	4	5.491	1.94	n.s.
Interaction SxN	5.528	2	2.764	0.98	n.s.
Interaction SxP	0.965	1	0.965	0.34	n.s.
Interaction VxN	23.258	8	2.907	1.03	n.s.
Interaction VxP	34.078	4	8.52	3.02	*
Interaction NxP	4.298	2	2.149	0.76	n.s.
Error b	1336.317	473	2.825		

For three varieties (Tanzania, Ethiopian IS and Dunyar), to the increase of levels of Phosphorous fertilization corresponded a decrease in the stem thickness, Humera kept constant and EthiopianD2 increased (Fig. 48).

Figure 48: Interaction Varieties x Phosphorous on Stem Thickness



6.1.2.10. Capsules per axil

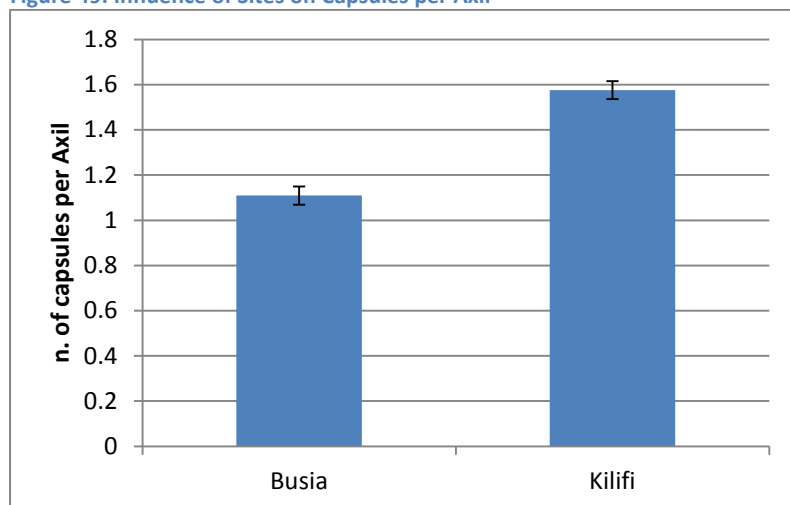
Two sources of variance were significant to F test (Tab. 29) in this trait: the sites and the Interaction Site per Nitrogen. The Interaction site per Variety was highly significant.

Table 29: ANOVA for Capsules per Axil 2012-13

Source of variance	Sum of Square	d.f.	Mean Square	F-test	Sign.
Between Sites (S)	16.818	1	16.818	96.66	*
Error a	0.348	2	0.174		
Between Varieties (V)	60.86	4	15.215	2.08	n.s.
Between Nitrogen levels (N)	1.688	2	0.844	0.57	n.s.
Phosphorus levels (P)	0.745	1	0.745	2.27	n.s.
Interaction SxV	29.229	4	7.307	22.25	**
Interaction SxN	2.941	2	1.47	4.48	*
Interaction SxP	0.166	1	0.166	0.51	n.s.
Interaction VxN	1.809	8	0.226	0.69	n.s.
Interaction VxP	0.769	4	0.192	0.59	n.s.
Interaction NxP	0.691	2	0.346	1.05	n.s.
Error b	155.353	473	0.328		

In Kilifi the number of capsules per axil was significantly higher than in Busia (Fig. 49).

Figure 49: Influence of Sites on Capsules per Axil



The graphic below (Fig. 50) shall not mislead: it reports the 5 varieties. Due to the fact that three varieties had 1 capsule per axil, two varieties overlap completely with the third and are not visible (the table may help understanding their behaviour). Only EthiopianD2 and EthiopianIS have more than 1 capsule per axil and show a significant variability between the two sites.

Figure 50: Interaction Site x Variety on Capsules per Axil

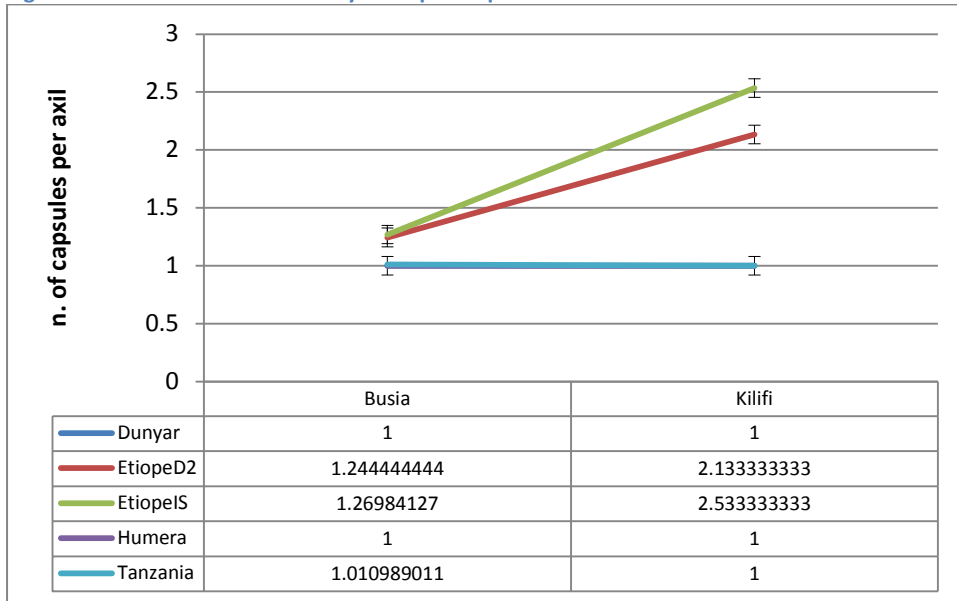


Figure 51: Interaction of Site x Nitrogen on Capsules per Axil

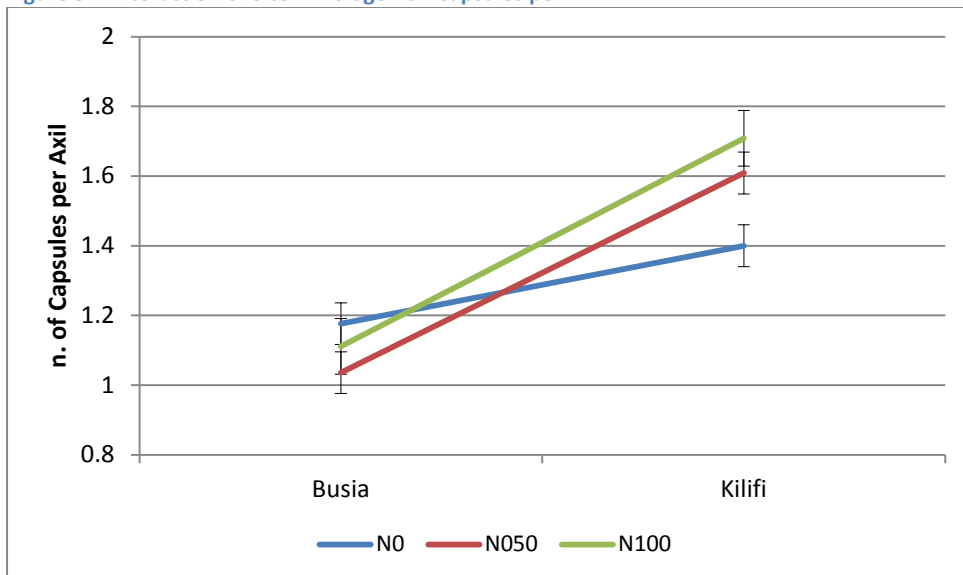


Figure 51 shows one more time that in Busia the different levels of N do not determine significant variation on the variable examined, in Kilifi the best performing is the 100 kg/ha of Nitrogen and the worst the N0 level.

6.1.2.11. Internode length

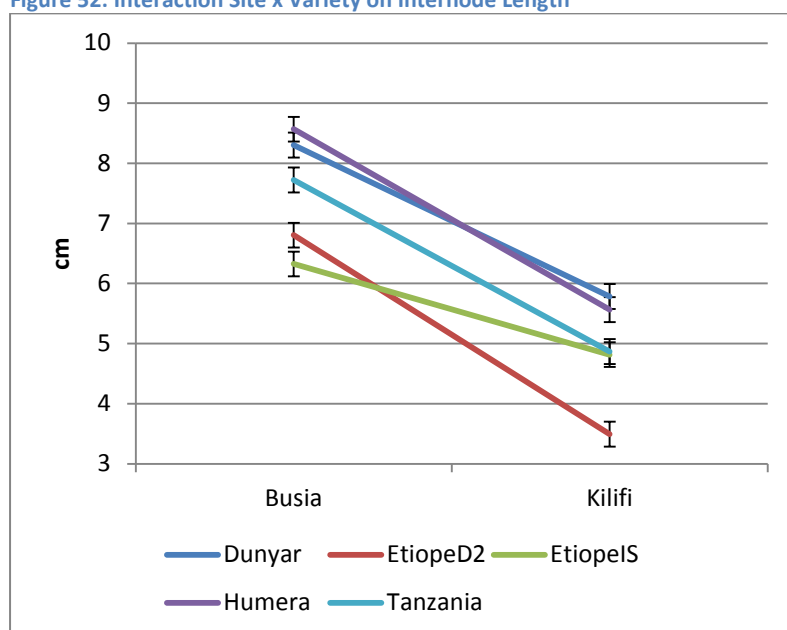
The ANOVA results in table 30 shows high significance of three sources of variation: levels of Nitrogen fertilization, Interaction Site per Variety and Interaction Nitrogen per Variety. The sites and the Interaction Site per Phosphorous is significant < 0.05.

Table 30: ANOVA for Internode Length 2012-13

Source of variance	Sum of Square	d.f.	Mean Square	F-test	Sign.
Between Sites (S)	668.504	1	668.504	24.66	*
Error a	54.228	2	27.114		
Between Varieties (V)	234.826	4	58.707	6.38	n.s.
Between Nitrogen levels (N)	21.17	2	10.585	1.80	**
Phosphorus levels (P)	3.096	1	3.096	1.44	n.s.
Interaction SxV	36.781	4	9.195	4.27	**
Interaction SxN	11.793	2	5.896	2.74	n.s.
Interaction SxP	4.027	1	4.027	1.87	n.s.
Interaction VxN	46.519	8	5.815	2.70	**
Interaction VxP	6.191	4	1.548	0.72	n.s.
Interaction NxP	18.087	2	9.044	4.20	*
Error b	1019.199	473	2.155		

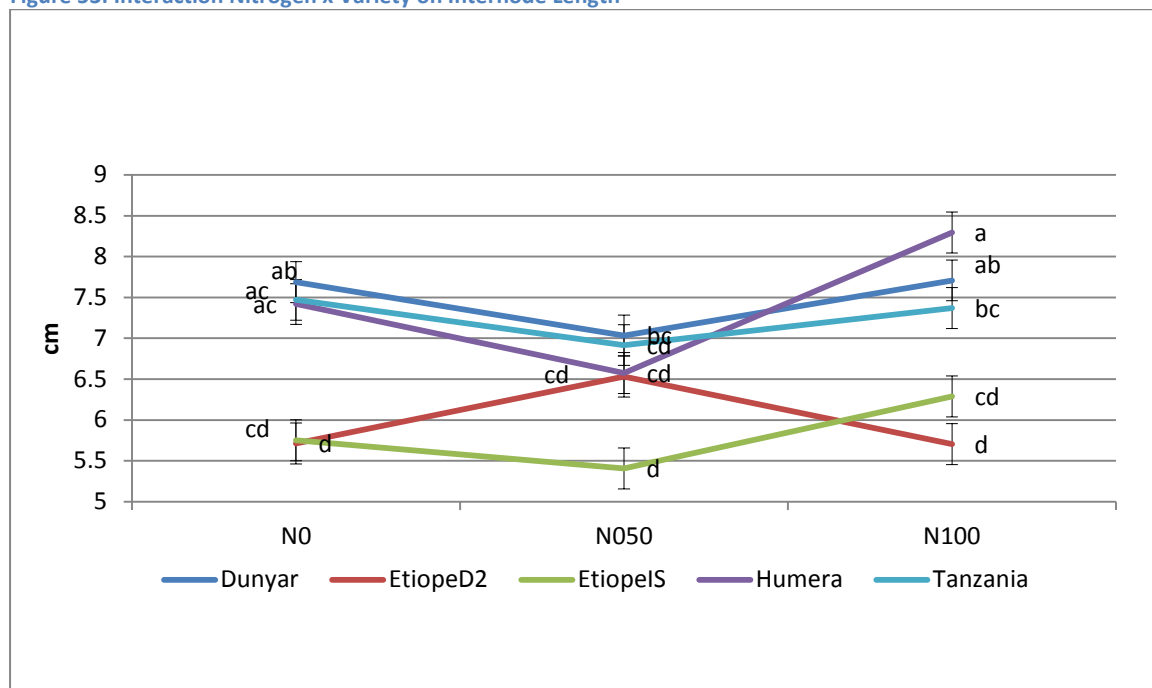
The internode length for all the varieties considered is shorter in Kilifi than in Busia (Tab. 31). Being the conditions more favourable the plants grow faster and produce more level of branches (Fig. 52).

Figure 52: Interaction Site x Variety on Internode Length



It is not surprising to find the behaviour of the varieties in function of the nitrogen levels for this variable is very similar to the one showed for the height at 50% flowering as reported in figure 32 and 53. N50 causing the shortest internode in all the varieties, with the sole exception of EthiopianD2, while the performances of N0 and N100 are very close.

Figure 53: Interaction Nitrogen x Variety on Internode Length



The variable internode length shows a significant interaction Nitrogen per Phosphorous (Fig. 54). It is only N50 showing an increasing of internode length when the Phosphorous level increases. In the other cases when the levels of Phosphorous increase the internode length decreases. It seems that N100 and N0 contribute to the reduction of the internode length (grow of lateral branches) in presence of high levels of Phosphorous).

Figure 54: Interaction Nitrogen x Phosphorous on Internode Length

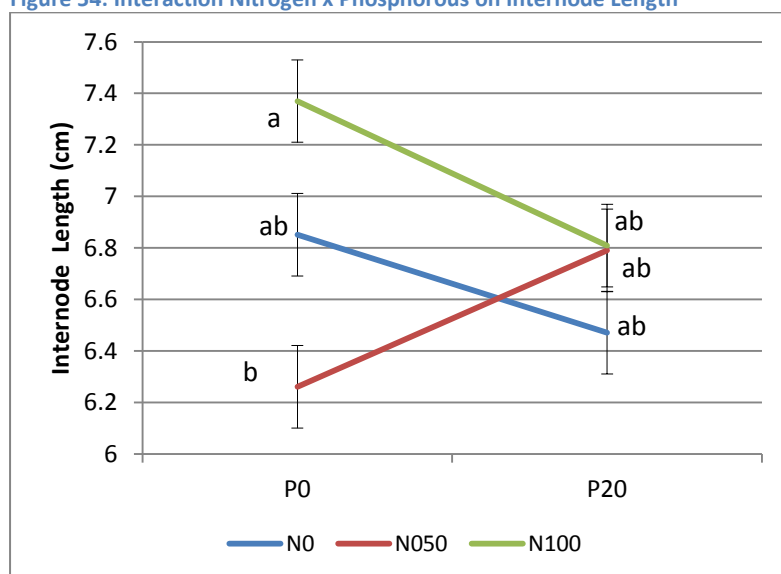


Table 31: Means and ANOVA summary results year 2012 and 2013

Factors	Height 50% Flow	Plant Height		Weight of Capsule	Plant Yield g	N of Capsules	N of seed X Capsule	Length Capsule		Thickness Capsule		Stem Thickness		Capsules X Axil	Internode Length	
Between Sites (S)	*	n.s.		*	*	**	n.s.	*		n.s.		*		*	*	
Busia	47.05	76.62		8.79	6.07	27.59	37.68	2.43		0.58		6.23		1.11	7.49	
Kilifi	71.11	87.35		17.43	14.23	99.85	46.56	2.17		0.59		2.12		1.58	4.91	
Between Varieties (V)	n.s.	*		n.s.	n.s.	n.s.	n.s.	n.s.		n.s.		**		n.s.	n.s.	
Dunyar	64.89	94.27	A	16.23	12.06	74.88	41.51	2.31		0.60		5.98	a	1.00	7.49	
EtiopD2	48.23	70.83	Ab	9.48	8.37	40.73	39.46	2.40		0.59		4.83	ab	1.47	5.98	
EtiopIS	47.73	62.67	B	7.89	6.00	34.01	35.71	2.32		0.58		4.00	b	1.68	5.84	
Humera	59.64	91.28	Ab	13.64	9.16	61.19	42.01	2.27		0.57		5.31	ab	1.00	7.56	
Tanzania	50.32	81.50	Ab	9.50	6.37	31.96	41.89	2.47		0.58		5.41	ab	1.01	7.23	
Between Nitrogen levels (N)	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.	*		*		n.s.		n.s.	**	
N0	56.99	80.46		12.29	9.51	53.62	39.78	2.41	a	0.59	a	5.11		1.24	6.67	ab
N050	51.61	78.80		9.75	7.68	42.32	41.39	2.33	b	0.58	b	5.23		1.20	6.55	b
N100	52.47	79.45		11.39	7.80	46.43	39.34	2.34	b	0.58	b	4.98		1.27	7.08	a
Phosphorus levels (P)	**	n.s.		n.s.	n.s.	n.s.	n.s.	*		n.s.		n.s.		n.s.	n.s.	
P0	56.04	81.48		11.51	8.60	50.54	40.91	2.38		0.58		5.18		1.26	6.87	
P20	51.42	77.76		10.85	8.05	44.57	39.38	2.34		0.58		5.02		1.21	6.70	

6.1.2.12. Pearson Correlation (Kilifi and Busia)

All varieties grew and developed well. Unfortunately, due to some losses on field mainly related to pest attacks, drought or water logging, some plants among those selected at the beginning of the cropping cycle have been lost. Also some variables (days of 50% flowering, yield per plot and number of branches) have been lost or not considered due to discrepancies of data among different seasons and different sites (different recording teams). As well the information about the seed weight is practically uniform due to the poor scale (no decimals) available on field.

Theoretically the traits more relevant related to yield (considered in this study) are n. of capsules, n. of seeds per capsules, plant height, intermodal length and number of capsules per axils and number of branches per plant (unfortunately this character cannot be considered for the reasons mentioned earlier). The interaction among these characters, contribute in the yield per plant and all of them are heavily influenced by the environment. Due to the poor quality of the scales available on field, the weight of 100 seed recorded showed a limited variability among varieties and thesis and no further analysis are possible to estimate if this variable has any impact on the variability in the yield. Also in the cases of Kilifi and Busia the most evident result from the analyses conducted is the strong interaction site per variety. This is in line with the relevant literature (Pham Duc et Al. 2010). As well it has been noted in Kilifi and Busia a limited impact of the use of fertilizer on the morphological and productive traits.

Varieties with the traits above mentioned (greater height, short intermodal length, high number of capsules per axil), are expected to produce more capsules per plant and potentially generate a higher seed yield. This demonstrated to be not always the case in this research and is not surprising considering the relevant literature. The low seed yield, even in presence of high performance of the other variables above mentioned, has been explained, by different researchers, by a lower number of seeds per capsules resulting in a lower yield. Baydar (2005) reported that highest yields were obtained from plants with relatively less number of capsules with highest number of seeds than from plants with a greater number of capsules having less seeds. Not always we found a positive relationship between number of seeds per capsule, capsule number per plant and seed yield per plant.

Correlation analysis has been conducted to see the connections between the considered variables and to understand the influence of these on the Plant Yield. The relevant coefficients together with their significance are reported in table 32.

Table 32: Total Pearson correlations

	plant yield g	height 50% flowering	plant height cm	weight of caps	n of capsules	n seed x capsule	length capsule cm	thickness capsule cm	stem thickness	internode length cm
plant yield g	1									
height 50% flowering	,484**	1								
plant height cm	,428**	,699**	1							
weight of caps	,723**	,621**	,559**	1						
n of capsules	,690**	,674**	,482**	,841**	1					
n seed x capsule	,321**	,304**	,443**	,410**	,333**	1				
length capsule cm	-,009	-,024	,126**	,085	-,079	,264**	1			
thickness capsule cm	,081	,044	,052	,096*	,043	,110*	,069	1		
stem thickness	,288**	,438**	,714**	,408**	,326**	,322**	,092*	,069	1	
internode length cm	-,084	-,079	,367**	-,052	-,228**	,003	,230**	-,042	,348**	1

** Correlation is significant at 0,01 (2-code).

*. Correlation is significant at 0,05 (2-code)

The yield per plant resulted correlated with the height at 50% flowering, plant height (due to the behavior of this variable the second just confirms the first), number of capsules, weight of capsules and stem thickness.

The evident different behavior of all the varieties in the two sites, lead us to focus the correlation of the traits on a site by site analysis. Table 33 and table 34 below report the Pearson correlation analysis in Kilifi and Busia respectively.

Table 33: Pearson correlation matrix for sesame crop in Kilifi

	plant yield g	height 50% flowering	plant height cm	weight of caps	n of capsules	n seed x capsule	length capsule cm	thickness capsule cm	stem thickness	capsules x axils	internode length cm
plant yield g	1										
height 50% flowering	0.36**	1									
plant height cm	0.376**	0.983**	1								
weight of caps	0.714**	0.487**	0.474**	1							
n of capsules	0.687**	0.487**	0.486**	0.861**	1						
n seed x capsule	0.186	0.167	0.181**	0.226	0.212	1					
length capsule cm	0.208	0.281**	0.274**	0.363**	0.348**	0.441**	1				
thickness capsule cm	0.019	-0.036	-0.066	0.003	-0.013	0.026	0.035	1			
stem thickness	0.212	0.647**	0.636**	0.355**	0.364**	0.203	0.188	0.019	1		
capsules x axils	-0.147	-0.423**	-0.417**	-0.198	-0.213	-0.08	-0.13	-0.031	-0.456**	1	
internode length cm	0.184	0.449**	0.434**	0.266**	0.243	0.004	0.102	-0.112	0.321**	-0.332**	1

In Kilifi yield per plant was highly correlated to the height of the plant (both at maturity and at 50% flowering, the number of capsules and the weight of the capsules (these two variables were also correlated among them and with the *heights* of the plant).

It is interesting to note a negative correlation between the *heights* of the plant recorded with the number of capsules per axil.

Table 34: Pearson correlation matrix for sesame crop in Busia

	plant yield g	height 50% flowering	plant height cm	weight of caps	n of capsules	n seed x capsule	length capsule cm	thickness capsule cm	stem thickness	capsules x axils	internode length cm
plant yield g	1										
height 50% flowering	0.699**	1									
plant height cm	0.484**	0.428**	1								
weight of caps	0.674**	0.482**	0.69**	1							
n of capsules	0.304**	0.443**	0.321**	0.333**	1						
n seed x capsule	-0.024	0.126	-0.009	-0.079	0.264**	1					
length capsule cm	0.044	0.052	0.081	0.043	0.11	0.069	1				
thickness capsule cm	0.438**	0.714**	0.288**	0.326**	0.322**	0.092	0.069	1			
stem thickness	-0.056	-0.171**	0.029	0.046	0.038	-0.19**	0.008	-0.127	1		
capsules x axils	-0.079	0.367**	-0.084	-0.228**	0.003	0.23**	-0.042	0.348**	-0.313**	1	
internode length cm	-0.247**	-0.116	-0.072	-0.297**	-0.071	0.119	0.098	-0.037	-0.108	0.202**	1

In Busia the same trends and correlations may be noted in what refers to plant yield but the level of correlation is in some way weaker, beside there is a negative correlation between Plant Yield and Internode length that is not observed in Kilifi.

The two sites are very different in soil and agroclimatic conditions, Kilifi is close to the coast, with relatively warmer temperatures and soils sandy and loose, these conditions are more similar to those where sesame is grown in Somalia. In Busia, water availability through rain is greater, temperature is relatively lower, the condition are more favourable for the development of diseases and weeds, while soils are heaviest and in one block water logging caused significant losses. Busia, on the shore of Victoria lake, where sesame is traditionally grown by local small holder farmers, was chosen assuming a similarity with the riverine conditions of Somalia along Shabelle river but the temperature, diseases and abundant moisture available translated in a crop depressing environment, that stressed the plants and flattened their performances reducing the manifestation of the variability as happened in Kilifi.

In our trials Sesame demonstrated to be very sensible to the origin's site and the site of cultivation. These data corresponds to those in literature where it is reported that several factors may contribute to the yield variability of the observed landraces/varieties to the final production including climatic reasons such as temperature (day/night), day length, light intensity, precipitation, altitude and latitude. Photosynthesis is influenced by various biotic and abiotic stresses during grain filling, therefore, that decreasing or increasing photosynthesis capacity is a major limiting factor for yield and all yield components (Beheshti and Fard, 2010). There are reasons to believe that the less performing varieties not adjusted to the field conditions and therefore gave a low yield in this study. Basu and coworkers (2009) reported that seed yield is known to be a complex trait governed by polygene and therefore is influenced more by environmental factors. As well our observations on sesame behavior in different environments are in agreement with previous studies, showing how sesame is highly sensitive to day length since it is a short day plant (Narayanan and Reddy, 1982). Suddhiyam and coworkers (1992) also reported about the effect of the interactions between temperature and day length on the flowering rate.

In our study the difference of the behavior of the different varieties in the different environments was confirmed by a highly significant correlation existing in Kilifi between yield per plant and plant height (height 50% flowering and plant height), number of capsule per plant and weight of capsule, while in Busia yield per plant was correlated with plant height (height 50% flowering and plant height), number of capsules, , weight per capsule, thickness capsule and negatively correlated with Internode length.

Again it is evident that the ideotypes are different for the different sites and different environmental conditions.

6.1.3. Discriminant analysis of morpho-productive traits

Following the field data collection, a discriminant analysis has been conducted to identify the main sources of differences to draw the dendrograms of the phenotypic differences.

Initially the discriminant analysis was conducted considering the group as combination of Varieties cultivated in the two Sites with the three levels of Nitrogen. The phosphorous levels were omitted because of their little influence observed in the ANOVA. The new coordinates obtained by the

discriminant functions have been utilized to compare the 30 identified different groups (five varieties x two sites x three level of nitrogen). After the Matrix rotation the eigenvalues have been found and are those reported in table 35.

Table 35: Eigenvalue

Function	Eigenvalue	% of variance	% cumulated	Canonical Correlation
1	5,010 ^a	69,8	69,8	,913
2	,809 ^a	11,3	81,1	,669
3	,507 ^a	7,1	88,2	,580
4	,244 ^a	3,4	91,6	,443
5	,204 ^a	2,8	94,4	,411
6	,133 ^a	1,9	96,3	,343
7	,109 ^a	1,5	97,8	,314
8	,072 ^a	1,0	98,8	,259
9	,048 ^a	,7	99,5	,215
10	,036 ^a	,5	100,0	,187

a. for the analysis the first 10 canonical functions have been used

It is possible to note that the first three discriminant functions describe around 88% of total variance; in particular the first has the eigenvalue describing around 70% of the total variance.

Since the first assessment it was evident that two different groups existed, each one related to the site where they belonged. The distribution of the centroids in the 3D diagram (Fig. 55) based on discriminant functions 1, 2 and 3 clearly shows the above.

Figure 55: Tri-dimensional plot defined by the first three discriminant functions describing 88.2% of the total variance

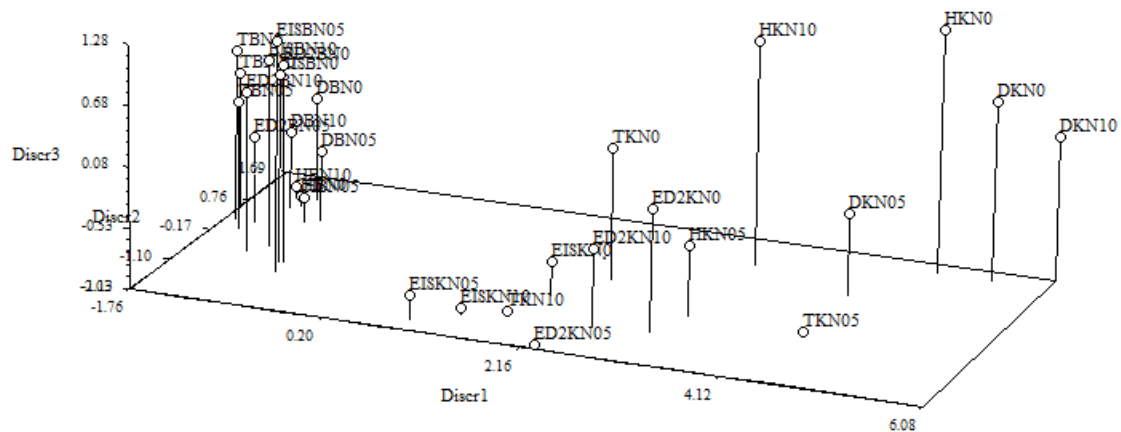


Figure 55 clearly shows the distance between the two groups, the one in Kilifi (with K in the code) and the one in Busia (with B in the code) and the different behaviour in the two sites: high variability in Kilifi and relative concentration in Busia.

The variables associated to the discriminant functions (Tab. 36) are: number of capsules for the first function, internode length, plant height, height at 50% flowering and weight of capsule for the second function while capsule length is associated to the third discriminant function.

Table 36: Matrix of association between original variables and the discriminant functions

Matrix of structure										
Discriminant Functions										
Variables	1	2	3	4	5	6	7	8	9	10
Ncap	,530*	,381	,183	,524	-,351	-,147	,070	-,310	-,014	-,143
InterL	-,313	,805*	-,085	-,057	,034	,219	,009	-,194	,314	,242
Plheig	,197	,764*	-,105	,057	,452	-,384	,089	,000	-,002	,063
H50%Fl	,541	,545*	,379	-,295	,345	-,085	,063	,075	,194	,085
Wcap	,322	,474*	,278	,383	-,424	-,439	,044	,136	-,072	,223
CapLeng	-,196	,102	,682*	,296	,326	-,430	,201	-,191	,171	-,036
Pyieldg	,282	,269	,163	,677*	,022	,147	,029	,143	-,242	,512
NSXCap	,124	,044	-,097	,311	,201	-,576*	,021	-,141	,552	,423
StThickn	,096	,495	-,173	-,036	,138	-,233	,772*	-,079	-,034	,196
CapThickn	,011	,027	-,022	,321	,033	,055	,255	,685*	,472	-,366
Correlations common within groups between discriminating variables and standardized canonical discriminant functions										
Variables ordered by absolute size of correlation within each function.										
*. Largest absolute correlation between each variable and any discriminant function										

Based on this finding, it was then decided to proceed to two parallel discriminant analyses, one based on the data from Kilifi and one from the data from Busia analogously to what was done for the correlation analyses.

In each of the two sites then 15 groups have been identified corresponding to the combination of the 5 varieties with the three levels of Nitrogen fertilization. Based on the phenotypic differences gathered in Kilifi the table of the eigenvalues has been obtained and it is reported below (Tab. 37).

Table 37: Eigenvalues Kilifi

Function	eigenvalues	% of variance	% cumulated	Canonical Correlation
1	5,206 ^a	63,2	63,2	,916
2	1,272 ^a	15,4	78,7	,748
3	,665 ^a	8,1	86,7	,632
4	,384 ^a	4,7	91,4	,527
5	,262 ^a	3,2	94,6	,456
6	,206 ^a	2,5	97,1	,414
7	,145 ^a	1,8	98,8	,356
8	,065 ^a	,8	99,6	,247
9	,024 ^a	,3	99,9	,153
10	,006 ^a	,1	100,0	,079

In Kilifi the first three functions explain 86.7 %. We could have proceeded in this case too drawing a tri-dimensional diagram of the centroids but due to the fact that in Busia, to reach a similar level of the described variance 4 functions were needed (Tab.39). To visualize the distribution of the 15 groups, instead of 2 tri-dimensional graphs (one per site), two dendrograms have been drafted (Fig. 58 and 59).

Table 38: Matrix of association between original variables and the discriminant functions for Kilifi data

Matrix of structure										
Discriminant functions										
Variables	1	2	3	4	5	6	7	8	9	10
Plheig	,729*	,139	,047	-,256	,336	,068	-,234	-,455	-,048	,012
H50Fl	,728*	,077	,057	-,299	,319	,125	-,340	-,295	,070	-,215
StThickn	,573*	,162	-,318	-,201	-,354	,039	,285	,527	,113	,074
InterL	,413	-,658*	,456	,164	-,097	-,331	,078	,053	-,110	,146
NSXCap	,096	,565*	,366	,277	-,379	-,476	-,219	,022	,179	-,106
CapLeng	,139	,314	,750*	-,079	-,210	,196	,370	-,068	,053	-,295
Ncap	,354	,087	,030	,600*	-,160	,431	,088	-,380	,010	-,377
Wcap	,331	,065	,174	,423	-,386	,568*	-,297	-,191	-,239	-,156
CapThickn	-,027	,076	,123	,223	,262	,338	-,132	,412	,633*	,396
Pyieldg	,229	,171	,117	,600	,254	,267	-,097	,120	-,601*	-,154

The above matrix of structure in Kilifi (Tab. 38) shows the variables associated to the 10 discriminant functions. The first function is associated to plant height, height at 50% flowering and stem thickness. The second one is associated to internode length and number of seeds per capsule. Finally the third discriminant function is associated to the length of the capsule.

The following bi-dimensional centroid's diagram (Fig. 56) obtained showing a high level of dispersion of the 15 groups (5 varieties per 3 levels of N).

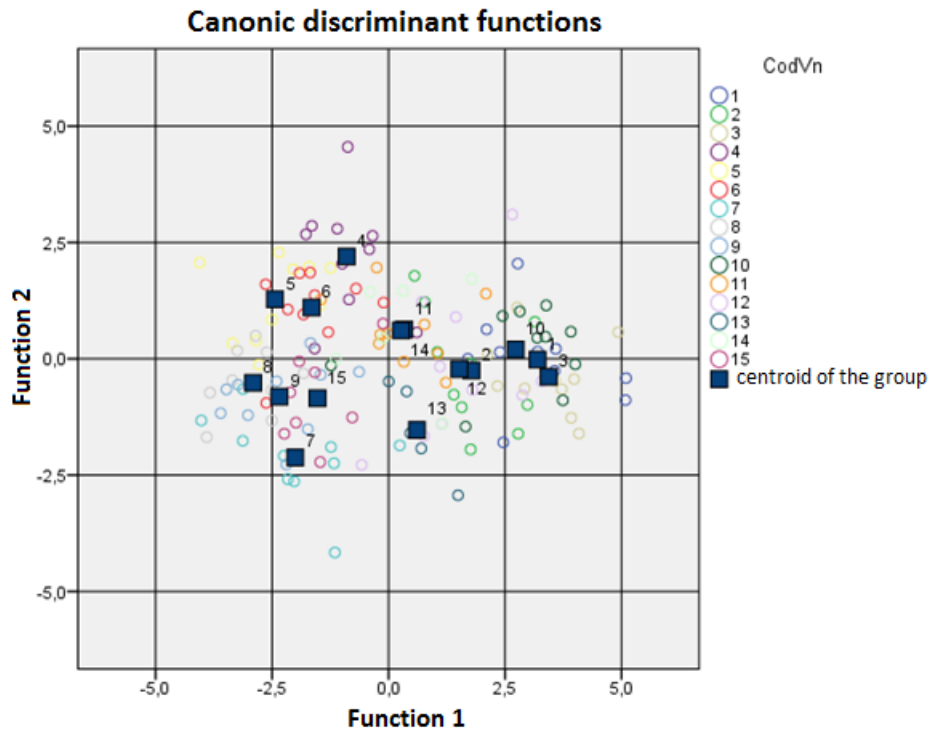


Figure 56: bi-dimensional centroid's diagram of the 15 groups in Kilifi

In Busia the discriminant analysis gave the following eigenvalues table (Tab. 39) whose first three functions explains only 77.6 of the total variability, a bi-dimensional diagram of the centroids of the 15 groups, resulting from the combination of the 5 varieties examined and the 3 levels of Nitrogen fertilization adopted, has been drafted (Fig. 57). In this case the distribution of the centroids and of the single observation shows an overlapping of the 15 groups, indicating a reduction of the variation in this locality if compared to Kilifi.

Table 39: Eigenvalues Busia

Function	Eigenvalues	% of variance	% cumulated	Canonical Correlation
1	,693 ^a	52,4	52,4	,640
2	,199 ^a	15,1	67,5	,408
3	,133 ^a	10,1	77,6	,343
4	,114 ^a	8,6	86,2	,320
5	,091 ^a	6,9	93,1	,289
6	,036 ^a	2,7	95,8	,187
7	,025 ^a	1,9	97,7	,156
8	,013 ^a	1,0	98,7	,114
9	,011 ^a	,9	99,6	,106
10	,006 ^a	,4	100,0	,075

In table 40 the matrix of structure in Busia shows the association between variables and discriminant functions.

Table 40: Matrix of association between original variables and the discriminant functions for Busia data

Matrix of structure										
Discriminant Functions										
Variables	1	2	3	4	5	6	7	8	9	10
Plheig	,659*	,199	,334	,267	-,033	,225	-,168	-,419	-,183	,234
InterL	,641*	,065	,258	-,088	,161	,078	-,362	-,200	,548	-,083
CapLeng	-,278	,711*	,389	,476	-,005	,135	-,086	-,100	,046	-,035
H50Fl	-,014	-,125	,732*	,077	,225	,291	-,296	-,398	-,049	,243
CapThickn	,159	-,044	,527*	,220	,235	-,377	,429	,453	-,129	,208
StThickn	,460	-,257	,303	,603*	-,316	,101	-,310	-,247	-,026	,018
Wcap	,216	,153	,518	,078	-,671*	,122	,012	-,031	-,021	,434
NSXCap	,157	,288	,056	,321	-,070	,620*	-,020	,274	,144	,548
Ncap	,121	-,059	,346	,239	-,451	,259	,529*	-,395	,245	,196
Pyieldg	,110	,082	,034	,255	-,277	-,375	-,110	-,230	,264	,751*

Plant height and intermodal length are associated with the first discriminant function, length of the capsule with the second and height at 50% flowering and thickness of the capsule with the third discriminant function.

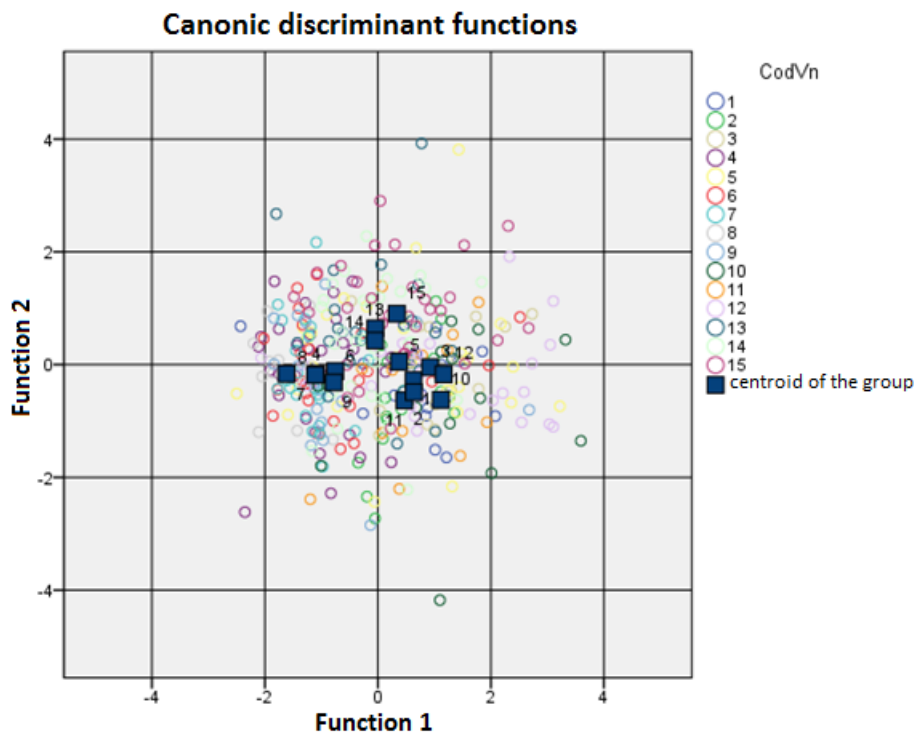


Figure 57: bi-dimensional centroid's diagram of the 15 groups in Busia

The variations observed in the African sesame accessions examined include differences in plant height, capsule length, capsule thickness and capsule weight per plant, number of capsules per plant, number of seeds per capsule, and yield per plant. These findings support previous observations about the large variability in these traits among sesame genotypes (Bedigian, 2010, Bedigian 2011c; Bedigian and Harlan, 1986; Ercan et al., 2002).

In Kilifi the dendrogram based on morpho-physiological traits consisted of five main clusters (Fig. 58). It is worth to notice that N levels of fertilization in some way create phenotypic variability in particular for the varieties Tanzania and Humera that grouped separately, for the others the nitrogen levels do not modified so much the phenotypic structure of the plants.

In Busia the dendrogram based on morpho-physiological traits consisted of four main clusters (Fig. 59) Tanzania cluster again in one single group while it is Ethiopian D2 with Ethiopian D2 and Humera at 50 kg of N per ha, separating from their respective groups at N0 and N100. Dunyar in both sites has the same behaviour.

The main difference between the behaviours of the 15 groups in Kilifi and Busia is the similarity among groups belonging to the same accession. It seems that Busia's environment relatively less warm and with higher levels of water availability has a homogenizing effect and different accessions have reduced distances. Dunyar, Humera, Tanzania forms homogeneous groups. The same applies, with a small exception, to Ethiopian IS while Ethiopian D2 shows certain variability. In Busia the different levels of Nitrogen fertilization do not seem to generate a significant variability for the reasons explained before.

In Kilifi the scenario changes considerably. Dunyar groups in one homogeneous cluster and this behaviour is similar to the one in Busia. Ethiopian IS and Ethiopian D2 cluster in a perfectly similar way: with N50 and 100 they cluster together with a small distance from N0. Humera with N0 and N100 cluster together while relatively distant is Humera N50. Finally Tanzania is the one showing the highest level of variability not clustering with any other phenotype in N0, and clustering with Humera at N50 and Ethiopian IS at N100.

These conclusions are coherent with the practical information of cropping sesame: high sensitivity to temperature (the highest the better for crop development), high susceptibility to water logging, and limited response to fertilization.

Figure 58: Dendrogram of combination of varieties with N in Kilifi

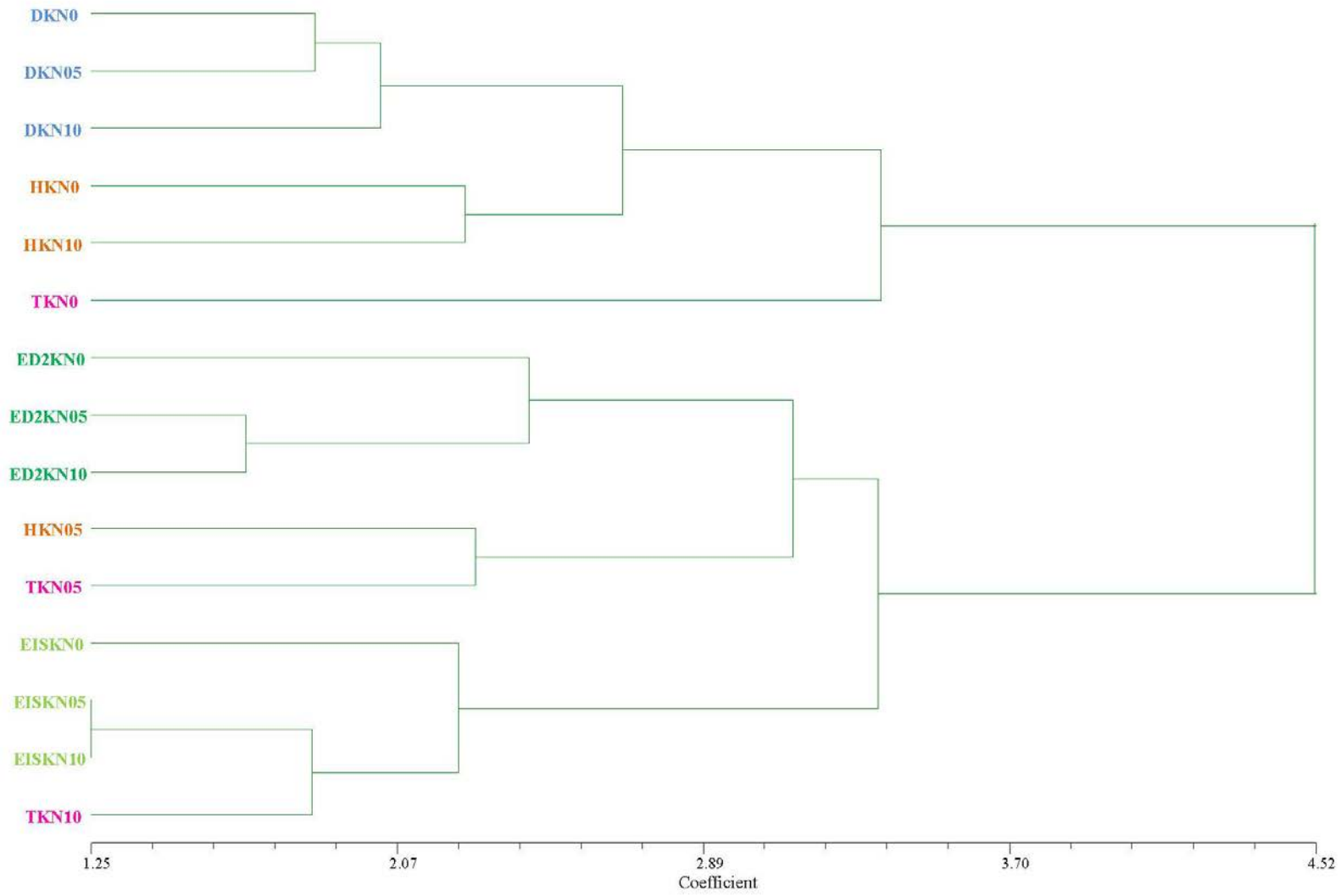
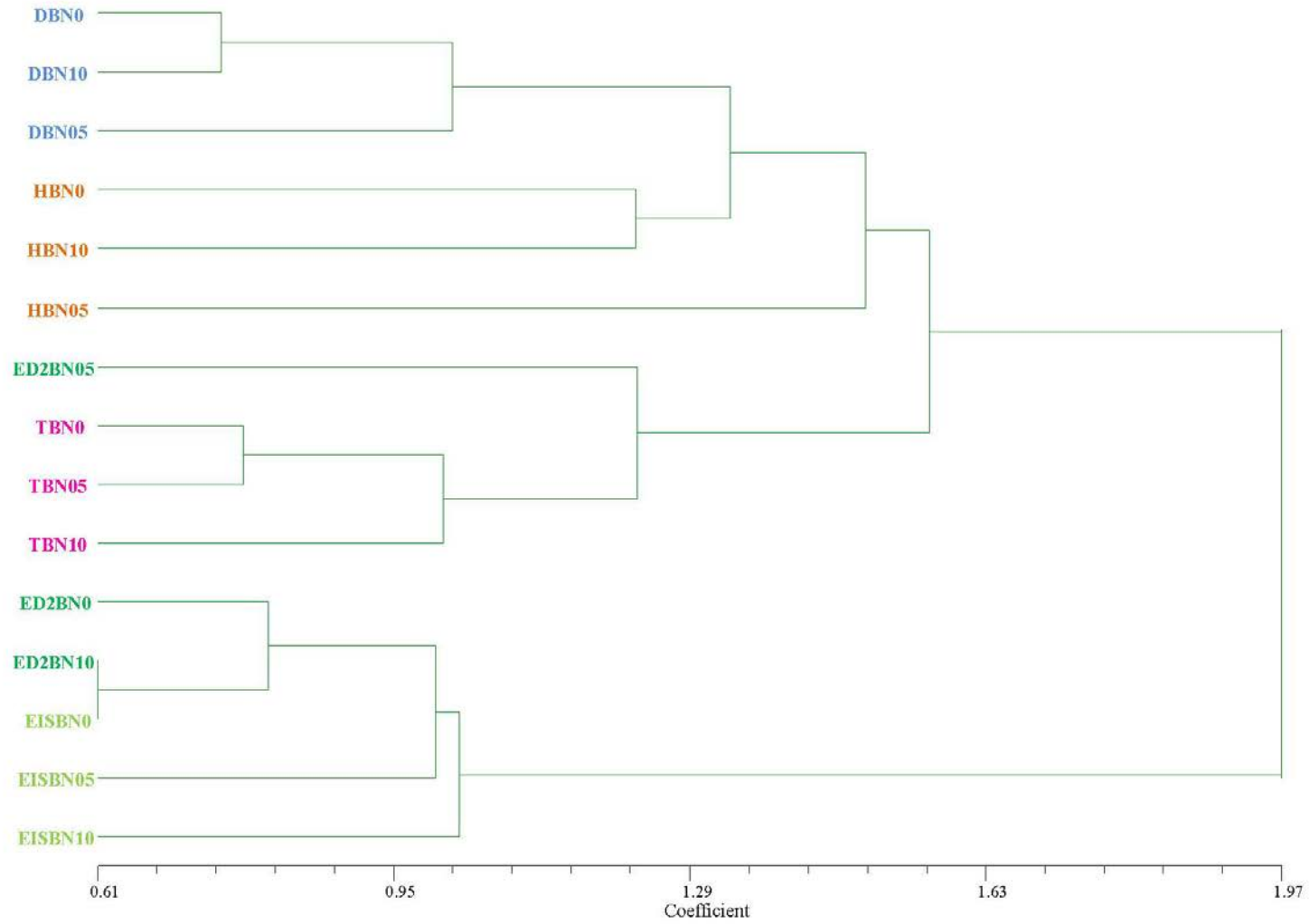


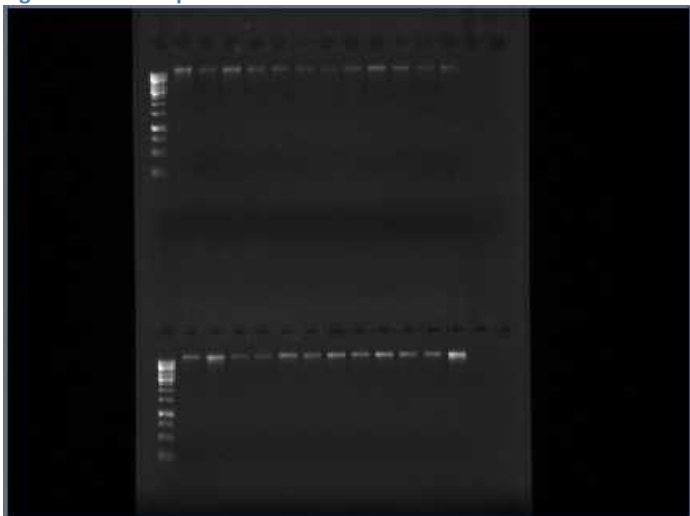
Figure 59: Dendrogram of combination of varieties with N in Busia



6.2. Genomic analysis findings

11 varieties of African sesame have been screened in the genomic analysis following the methodology described in the relevant chapter of materials and methods. Among these 11 genotypes were included the 5 accessions tested on field for morphological and productive traits. 6 genotypes per each accession have been analysed with 7 primers. DNA has been extracted, evaluated, amplified and finally sized. Below are figures reporting samples of the steps of the genomic analysis. In figure 60 it is reported the evaluation of DNA extraction by the Agarose gel electrophoresis.

Figure 60: Electrophoresis DNA evaluation



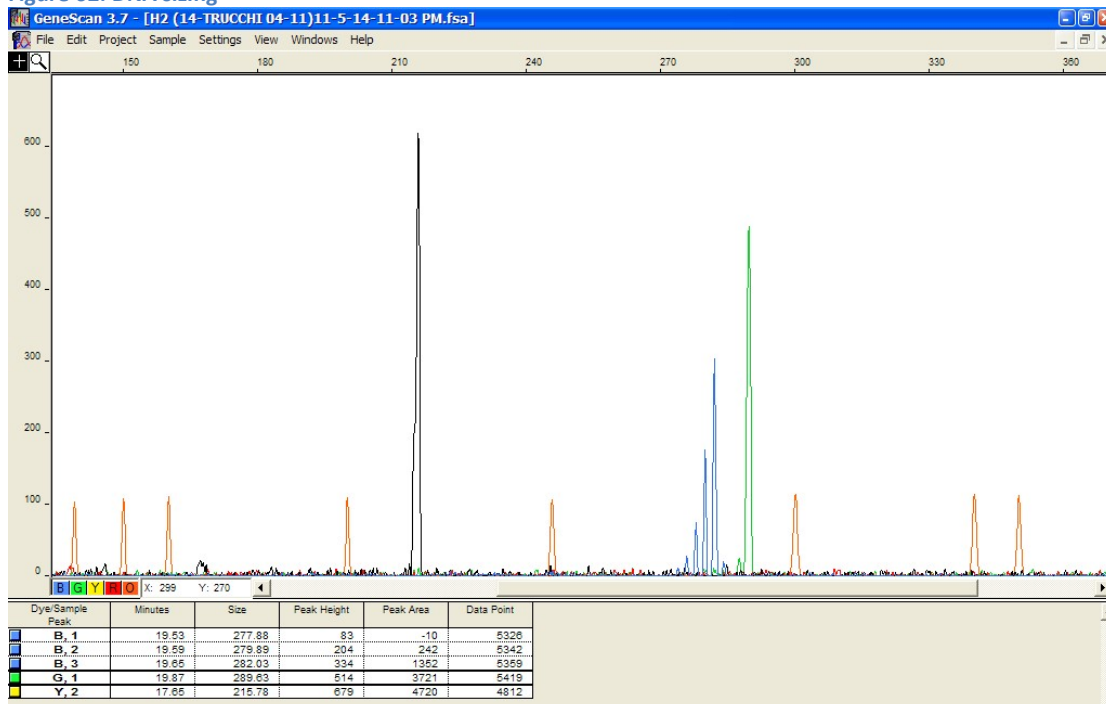
The figure 61 shows the amplification products obtained by the utilized primers.

Figure 61: DNA amplification



After the evaluation of the amplified fragments, the DNA sizing (Fig. 62) was performed as described in materials and methods chapter.

Figure 62: DNA sizing



Based on the sizing of the amplified products obtained by 7 primers used, the number of alleles per each primer and their frequencies have been utilised to calculate the number of alleles per locus, effective number of alleles, the expected heterozygosity, the number of polymorphic loci and the average heterozygosity (Tab. 41).

Table 41: Table of allelic frequency

Accessions	8			9			72			108		
	Na	Ne	hExp	Na	Ne	hExp	Na	Ne	hExp	Na	Ne	hExp
Uganda	1	1.000	0.000	1	1.000	0.000	1	1.000	0.000	2	1.180	0.153
Uganda C	1	1.000	0.000	1	1.000	0.000	1	1.000	0.000	3	2.323	0.569
Uganda L	1	1.000	0.000	1	1.000	0.000	1	1.000	0.000	4	3.429	0.708
Sudan	1	1.000	0.000	1	1.000	0.000	1	1.000	0.000	3	2.571	0.611
Tanzania	2	1.385	0.278	4	2.057	0.514	1	1.000	0.000	3	2.571	0.611
Icease	1	1.000	0.000	2	1.385	0.278	1	1.000	0.000	3	2.182	0.542
Humera	1	1.000	0.000	3	2.571	0.611	1	1.000	0.000	2	1.385	0.278
Somaliland	1	1.000	0.000	4	3.429	0.708	2	1.385	0.278	3	2.571	0.611
Dunyar	1	1.000	0.000	4	3.600	0.722	1	1.000	0.000	4	3.000	0.667
Etiopie D	1	1.000	0.000	4	3.600	0.722	3	2.880	0.653	2	1.800	0.444
Etiopie IS	3	2.909	0.656	3	2.667	0.625	2	1.600	0.375	3	2.667	0.625
	2	1.209	0.085	7	2.119	0.380	3	1.260	0.119	10	2.334	0.529

Accessions	123			182			184			Accessions	P	Hav
	Na	Ne	hExp	Na	Ne	hExp	Na	Ne	hExp			
Uganda	2	1.800	0.444	2	1.800	0.444	1	1.000	0.000	Uganda	3	0.149
Uganda C	3	2.000	0.500	2	1.385	0.278	1	1.000	0.000	Uganda C	3	0.192
Uganda L	3	2.571	0.611	1	1.000	0.000	1	1.000	0.000	Uganda L	2	0.188
Sudan	3	2.571	0.611	2	1.800	0.444	1	1.000	0.000	Sudan	3	0.238
Tanzania	4	3.000	0.667	3	2.571	0.611	3	2.571	0.611	Tanzania	6	0.470
Icease	2	2.000	0.500	1	1.000	0.000	2	1.180	0.153	Icease	4	0.210
Humera	1	1.000	0.000	2	1.800	0.444	3	2.000	0.500	Humera	4	0.262
Somaliland	2	1.385	0.278	2	1.385	0.278	3	2.000	0.500	Somaliland	6	0.379
Dunyar	4	3.429	0.708	2	1.800	0.444	2	2.000	0.500	Dunyar	5	0.435
Etiopie D	4	2.483	0.597	1	1.000	0.000	2	1.800	0.444	Etiopie D	5	0.409
Etiopie IS	3	2.909	0.656	1	1.000	0.000	2	1.600	0.375	Etiopie IS	6	0.473
	10	2.286	0.507	2	1.504	0.268	4	1.559	0.280			

Na=number of di alleles observed per each locus and each accession

Ne= effective number of the alleles based on the frequency they appear

Hexp= expected heterozygosity (1-summatory of squared frequencies)

Hav= average heterozygosity

P= polymorphic alleles per each accession

The number of alleles per primer ranged from 2 to 10 (the allele nulli is considered) with the primers 8 and 182 showing the lowest variability (only two loci) and 108 and 123 the highest (10 loci).

The value reported per each accession in the last column of the table is the average of allelic frequency (an indicator of the genetic variability) of all loci. The accessions showing the highest variability are the red ones, those with an intermediate grade of variability in black while in blue are reported those with low variability (Tab.41).

EthiopianIS and Tanzanian are the most variable with highest levels of genetic polymorphism while Ugandan accessions the lowest.

Is a bit surprising finding high variability in Ethiopian IS and Ethiopian D2. Probably these accessions have been collected in field visits or on the local market in Ethiopia and not from some research station as assumed initially. They cluster together and are relatively close to Tanzania, which confirms the phenotypic behaviour in Kilifi.

Is as well surprising to find low variability in the Ugandan accessions: are they the results of the selection work of a research station and distributed to farmers country wide?

In the varieties Icease and Humera there is reason to believe that characters have been fixed through a breeding programme: Icease has been provided by ICRISAT and Humera is originated in Ethiopia where has been likely produced in a research station of the Ministry of Agriculture. In both cases characters have been fixed and variability limited.

The high variability of Tanzania and Dunyar is expected as both varieties come from local markets.

Based on the allelic frequencies, the Nei distance between the 11 accessions has been calculated¹⁰ (Tab. 42).

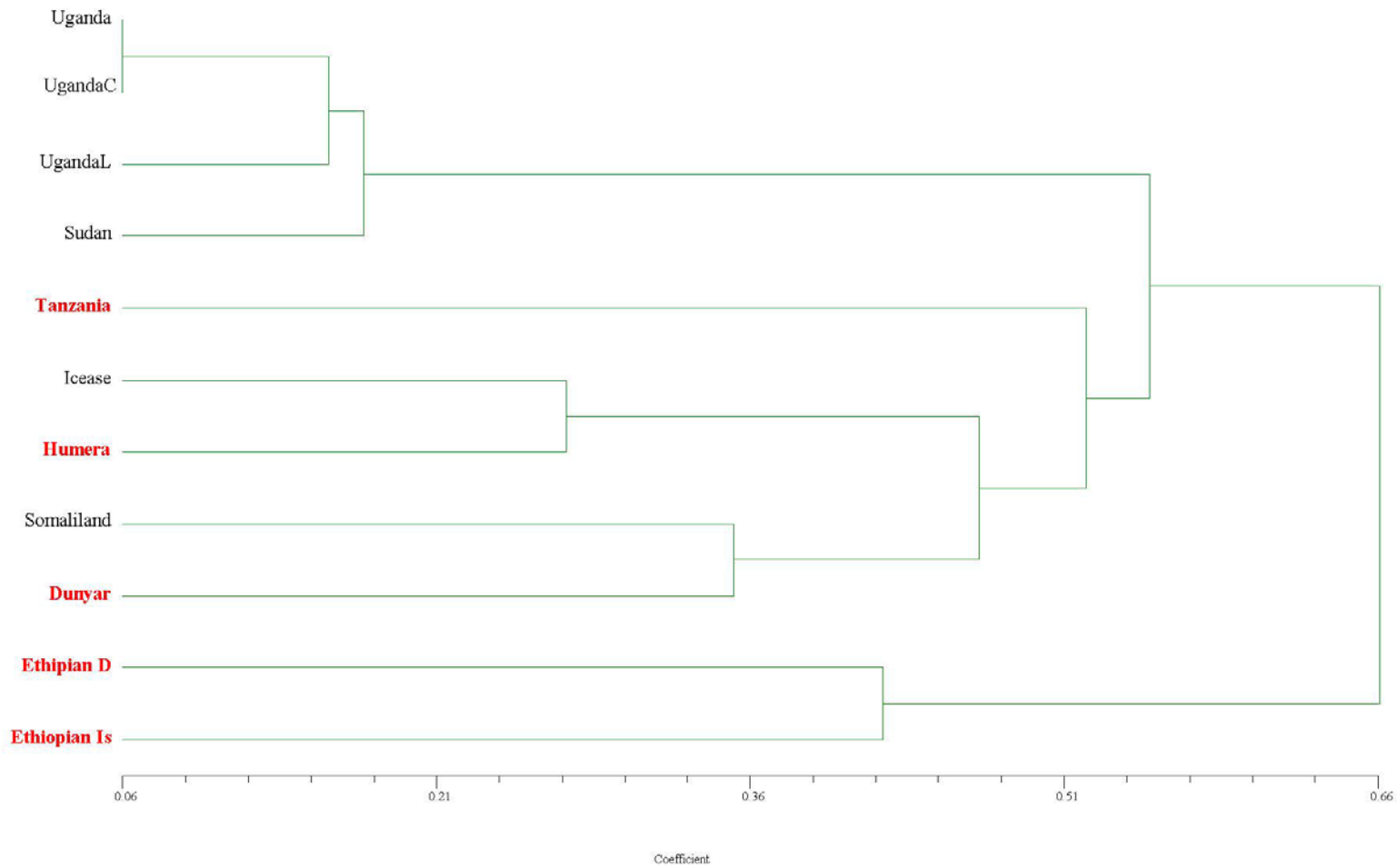
With Sahn algorithm (in NTSYS pc2.2) Nei distances have been elaborated to draft the dendrogram visualizing the genetic distances between all the accessions shown in figure 63.

¹⁰ Nei index = $1 - \sum \sqrt{\text{products of the allelic frequencies between two accessions compared per each locus}}$.

Table 42: Matrix of Nei distances between 11 African accessions

	Uganda	Uganda C	Uganda L	Sudan	Tanzania	Icease	Humera	Somaliland	Dunyar	Ethiopian D2	EthiopianI S
Uganda	0.000										
Uganda C	0.056	0.000									
Uganda L	0.169	0.141	0.000								
Sudan	0.209	0.102	0.204	0.000							
Tanzania	0.563	0.587	0.527	0.587	0.000						
Icease	0.515	0.543	0.500	0.598	0.468	0.000					
Humera	0.455	0.457	0.356	0.431	0.505	0.269	0.000				
Somaliland	0.705	0.692	0.547	0.664	0.526	0.426	0.395	0.000			
Dunyar	0.597	0.566	0.444	0.629	0.573	0.534	0.510	0.348	0.000		
Ethiopian D2	0.720	0.723	0.727	0.712	0.763	0.555	0.567	0.431	0.495	0.000	
EthiopianI S	0.699	0.668	0.644	0.658	0.858	0.739	0.683	0.561	0.630	0.420	0

Figure 63: Nei genetic distance between the 11 African considered accessions based on allelic frequencies of the examined genes



Some interesting indications are drawn from Figure 63:

1. the three accessions from Uganda cluster together and with Sudan accession probably do to the same origin.
2. Dunyar and Somaliland cluster together this confirming that farmers in Somaliland use the same accession used in South and called Mombasa (see Ahmed Yakub Sidow, 2011) possibly originating from Kenya and Mombasa and Dunyar are different names attributed to the same genetic material.
3. Tanzania is completely isolated and does not cluster with any other accession.
4. Ethiopian D2 and IS cluster together confirming the common origin.

The genic pool constituted by the 11 African accessions examined showed a relatively wide variability encouraging using them in further sesame breeding programs.

From a theoretical point of view it is expected that morpho-physiological and molecular data may complement and confirm each other. The former providing information on plant characteristics while the latter providing the information on genetic basis of these characteristics. It is remarkable that Tanzania, in both analysis the morphological and the genetic behaved in the same high variable way as well as Humera confirmed its medium variability, while Dunyar, from the analysis of morphological and productive traits, showed a limited variability, but from the genetic analysis showed one of the highest.

In our study, the comparison of different accessions based on the morpho-productive traits and the genomic SSR markers showed that there was only a partial correlation among the two classifications this is in line with literature as Ercan et al (2004) and Bhat et al (1999) observed the same poor correlation between molecular and morphological markers.

Nevertheless other studies (Tabatabaei et al. 2011) reports that among the traits evaluated, seed yield per plant, height to the first capsule, flowering period, and number of capsules showed high correlation with molecular data, providing encouraging evidence that for traits with less complex genetic background, molecular markers can be effective in sesame breeding.

The information so far collected provides interesting guidelines for breeding programmes:

Considering the:

1. Plasticity of the sesame gene pool capable to adapt to different ecosystems;
2. The different response to fertilization and the extreme rusticity of sesame accessions;
3. The variability showed by several accessions among those examined.

The following crossing scheme may be considered for sites like Kilifi where high temperatures and light soils are available.

	Ethiopian IS	Humera
Tanzania	X	X
Ethiopian D	X	-

While in sites where temperature is lower and moisture in the soil is higher like it happens in Busia, crossing like the below may be explored.

	Tanzania	Ethiopian D2	Dunyar
Tanzania	X	-	-
Ethiopian IS	-	X	-
Dunyar	-	-	X

6.3. Market and Financial analyses findings

6.3.1. The sesame market

Before analyzing the findings related to market is worth examine the structure of sesame value chain in Somalia and the market for this commodity, at international as well as national level.

6.3.1.1. The sesame value chain

Sesame is grown in Somalia without application of any other input than seeds, generally stored from the previous season, labour, generally provided by the family members and, in the riverine cropping systems, water for irrigation. No fertilizer, no herbicides and no pesticides are used. Should exist the possibility for organic certification, sesame produced in Somalia would be traded as organic fetching even higher prices on the international market.

Sesame seeds are normally the grains produced the previous year and their genetic quality is generally quite poor. No sesame varieties exist in Somalia, but landraces and populations. Should some international agency provide good quality seed farmers would use them and store part of the harvest for the next year. The latter happened several times in the past but after few years the improved varieties have been mixed with the local ones and improved germplasm characteristics have been lost. The lack of the essential characters of seed explains why there is no difference in market price between seeds and grains (all are grains, used for both food and sowing).

Farmers use to sell their harvest at farm gate to the middlemen (0.9-1.0 USD/kg) (Figure 68). Normally they have to sell the grains immediately after the harvest, when the price is at lowest level, to face the debts contracted during the cropping season. It is not infrequent that the middlemen also contribute to the production process as lending money to the farmers. Therefore, sesame production may be considered a sort of contract farming where the farmer has no too many degrees of freedom to decide who to sell the produce. In some cases farmers bring their produce to the grain store of the farmer organization where the middlemen or the exporters go and buy at whole sale price. Paradoxically in this wholesale market farmers fetch better prices (1.2-1.4 USD/kg) because the quantity sold are larger and thus they have a stronger bargaining power (before each sale information is gathered at Bakara market) as the farmer organization is not a merely price taker and finally the trader is willing to pay a bit more as he has not to go around buying small quantities at each farm. The storing fee paid by the farmers to the farmer organization is largely compensated by the better price they get.

Middlemen and farmer organizations may sell to the workshops (1.2-1.4 USD/kg) that process the sesame and produce oil or to retailers at village or town level or eventually to Bakara. Some of them have consolidated links in UAE and may export directly to Dubai (no custom controls exist and no export or import permits are required/provided in regional market) at 1.8-2.4 USD/kg.

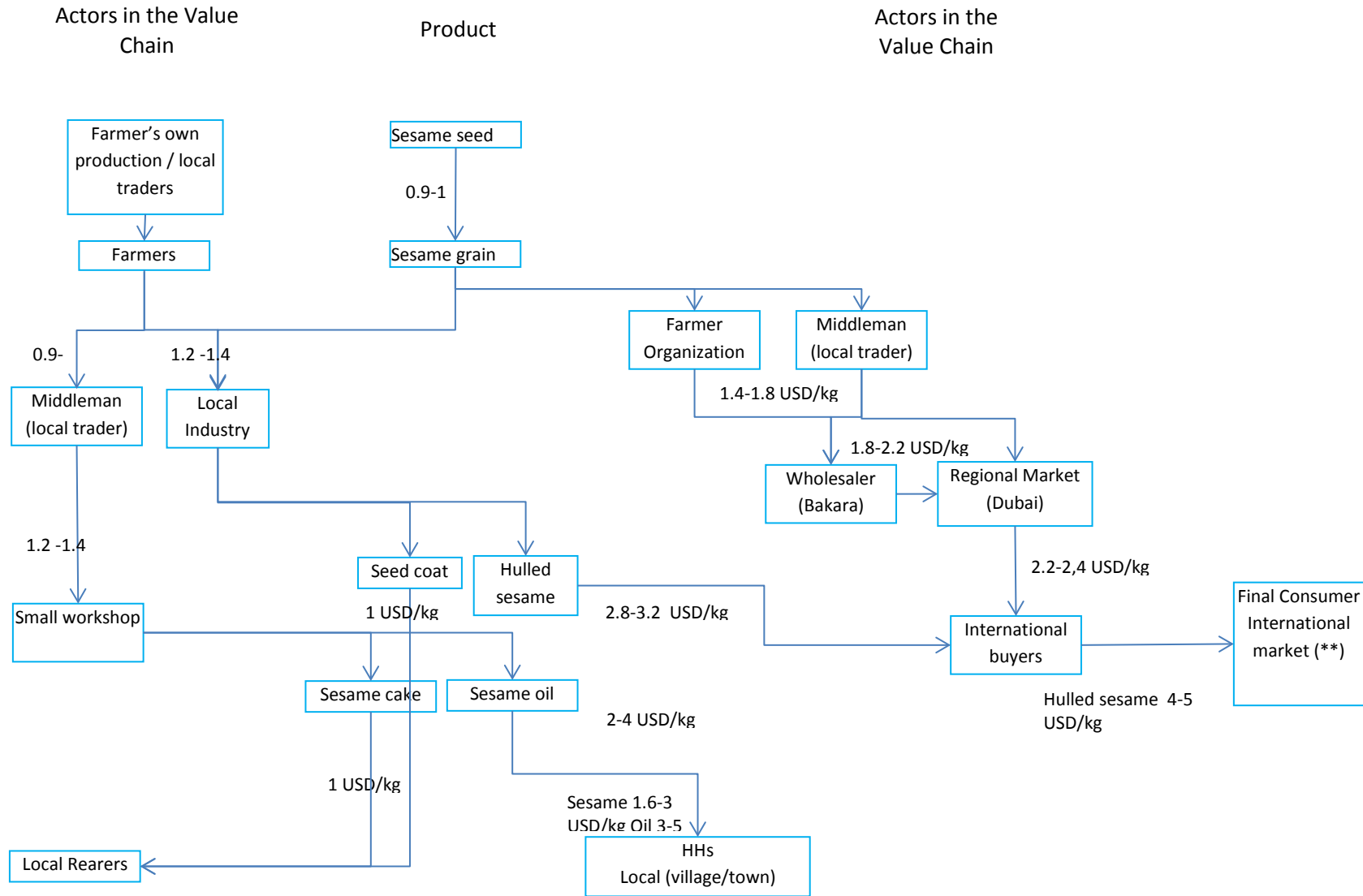
Workshops sell their oil to retailers (2-4 USD/kg) and the cake residual of the seed pressing (1 USD/kg) to animal rearers who use it as animal feed integrator.

Since last year one industry hulls sesame in Mogadishu. It exports hulled sesame directly to Europe (3.2 USD/KG CIF). The seed coat residual of the process is sold (1 USD/kg) as animal feed. The same industry also cleans the seed to be exported to Europe, China or India (2.4 USD/kg CIF) after a treatment with aluminium phosphide and produces also some small quantity of oil to be sold in the

local market. The cleaning process has two dimensions: cleaning the impurity (stones, leaves, branches) and colour sorting that is separating white sesame, which is exported, from brown or black sesame, which is processed to oil or sold in the local market where it has a big demand.

The actors in the value chain, the produce and the average price for each transaction are reported in the following scheme.

Figure 64: value chain of sesame



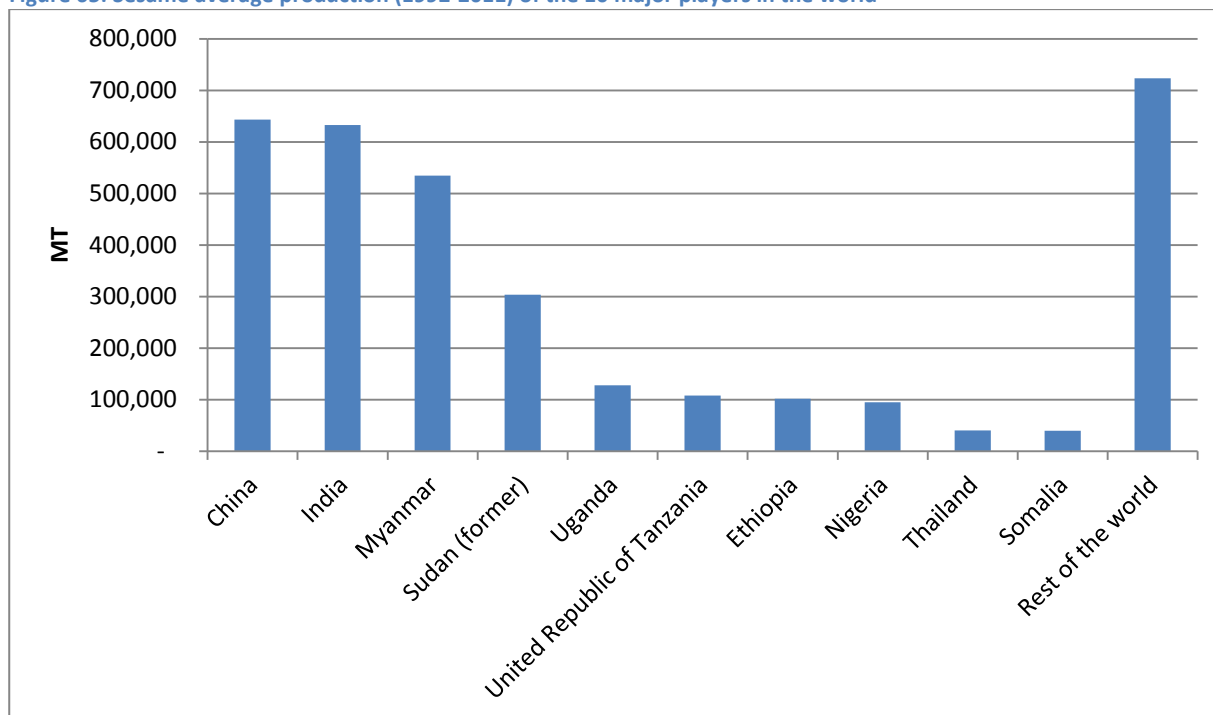
(*) When hulled sesame loses 12-15% in weight and increase market value by 25-30%

(**) it is intended the first buyer in the international market (bakery, supermarkets, ect.). Retailer price in International market for sesame grains ranges from 7-10 USD/kg and 8 to 15 USD/kg for sesame oil.

6.3.1.2. International market

In this section we briefly summarize the most recent trends at international level using FAOSTAT data¹¹. Almost 80% of the sesame world production is produced by six top countries (Figure 65), with the three major producers in the world (China, India and Myanmar) totalling 54% of the entire global production.

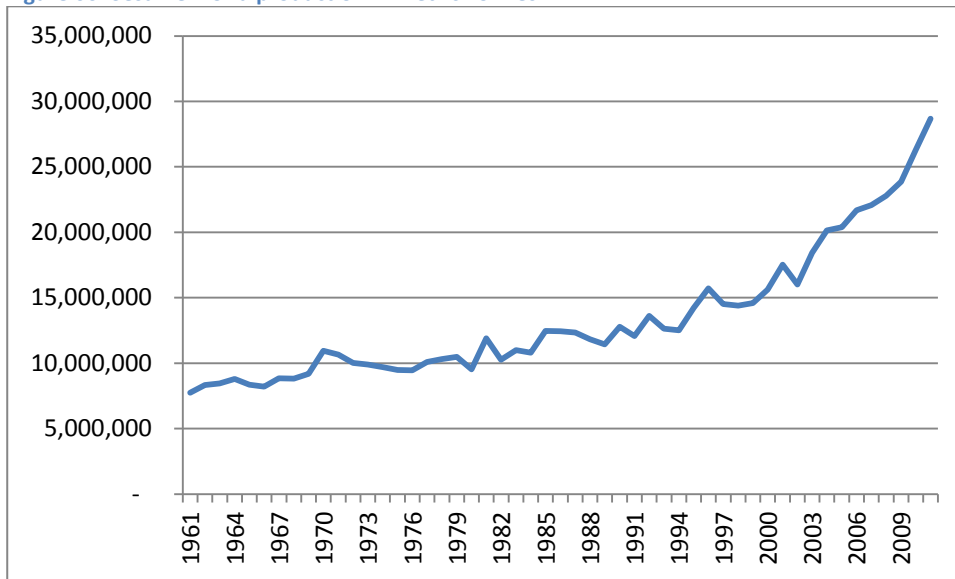
Figure 65: Sesame average production (1992-2011) of the 10 major players in the world



Despite the limitations mentioned earlier in this work, the world sesame production (Figure 66) has increased over the last two decades. This was largely due to Myanmar and some African countries that, pulled by the high market demand and high market prices (see below), significantly increased their production from 2005 onward (Figures 67 and 68).

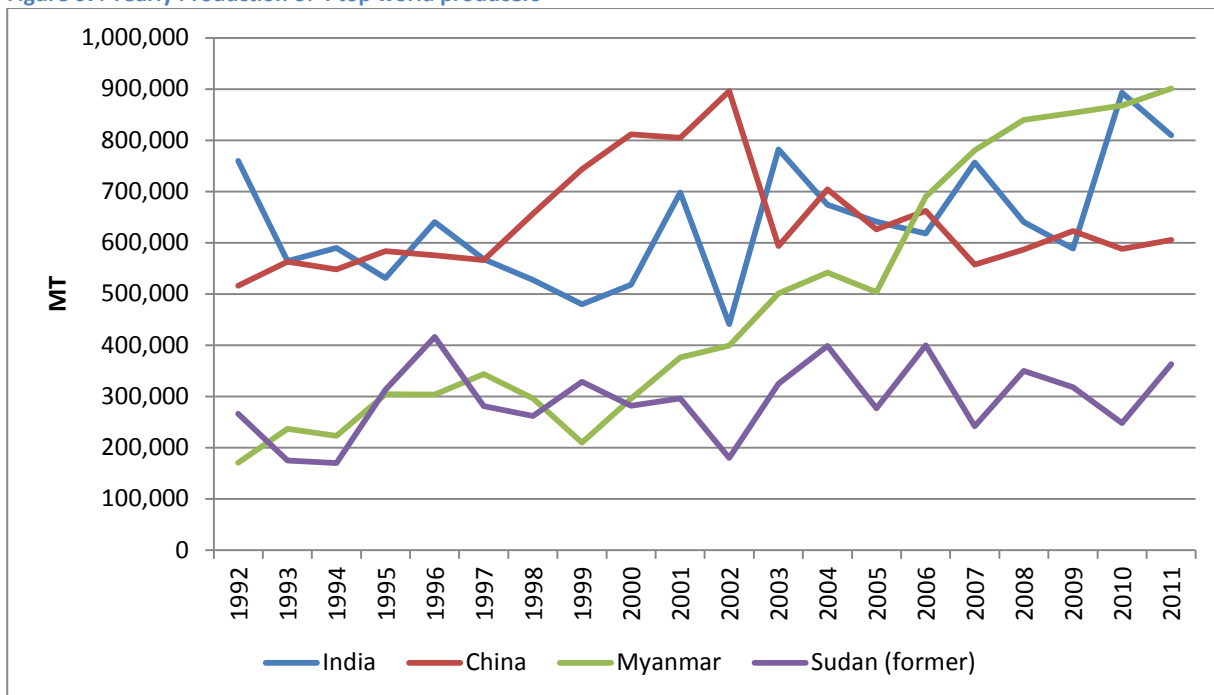
¹¹ FAOSTAT provides data from 1991 onwards for 134 countries, representing over 93% of the world's value of production at 2004-2006 International Dollar Prices. In all data series totals are shown for continents and the world. They include the total imports or exports of each of the respective countries, regardless of destination or origin. Thus continental totals also include goods imported from, or exported to, other countries belonging to the same continent. Consequently, these totals are by no means to be taken as the continents' net trade. Furthermore, import and export may not necessarily match because of some accounting inconsistencies (e.g., exports are normally expressed in FOB while imports in CIF prices; some countries import and re-export the same items; the reporting period may be different; etc.). Nevertheless, FAOSTAT is the best available source of data and makes possible to sketch an overall picture of international trade of a given commodity.

Figure 66: Sesame world production in metric Tonnes



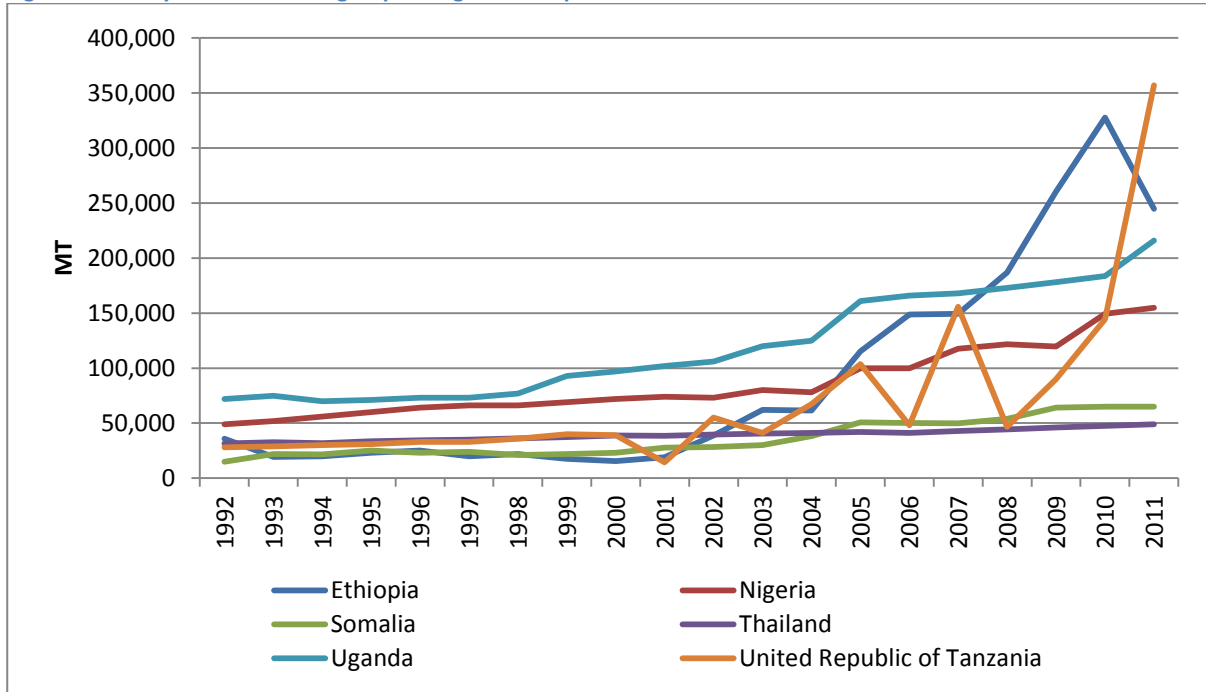
Nevertheless sesame production, particularly in the top ranking producers¹², appears to be erratic. This is due to the fact that sesame almost everywhere is produced in rainfed cropping systems: as a result, the production is significantly influenced by rainfalls.

Figure 67: Yearly Production of 4 top world producers



¹² The production graphs are split in two, one with the four major producers and one with the following six producers (the rest of the world is neglected), due to large difference between the total production of the former group vis-à-vis the latter group.

Figure 68: Yearly Production 2nd group of largest world producers



The countries featuring a production increase got this outcome largely because of an increase of the area invested in sesame production (Figures 69 and 70).

Figure 69: Area Harvested per year (ha) top 4 countries

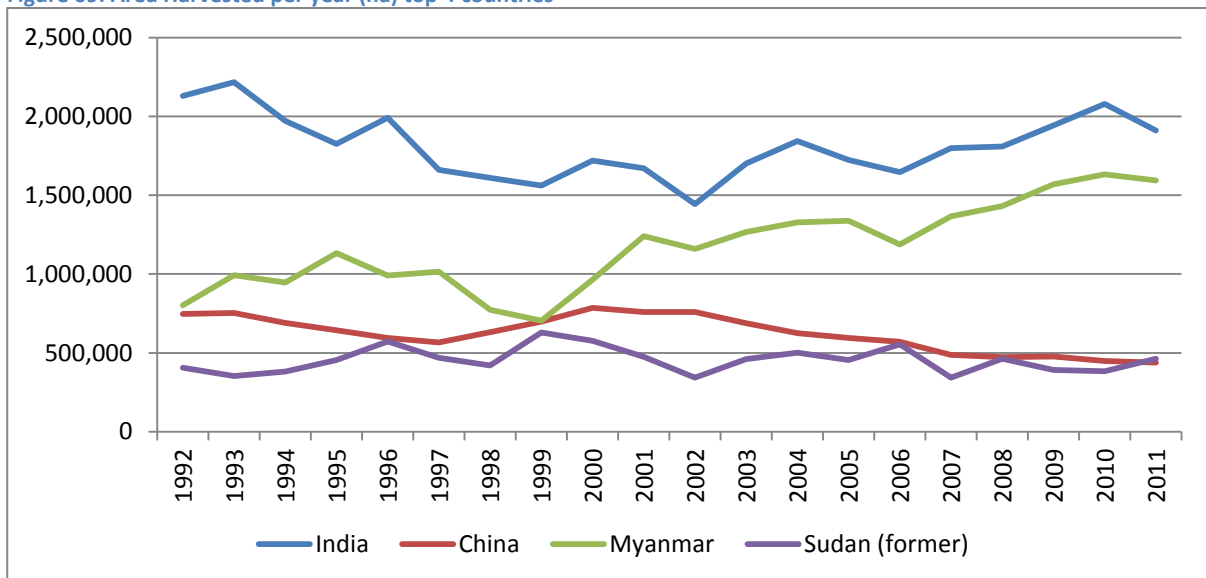
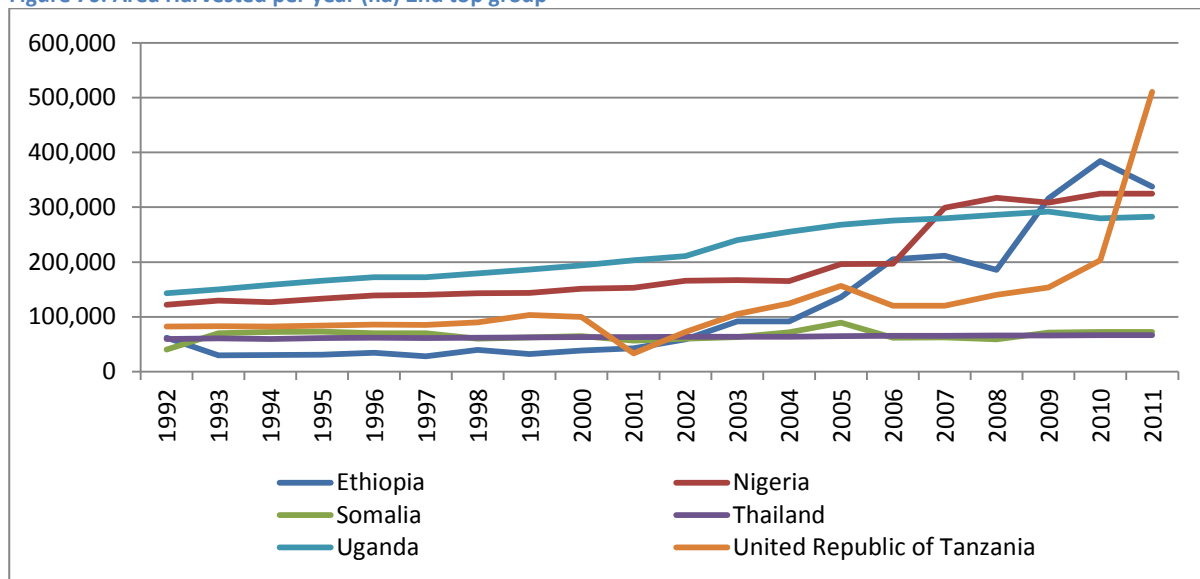
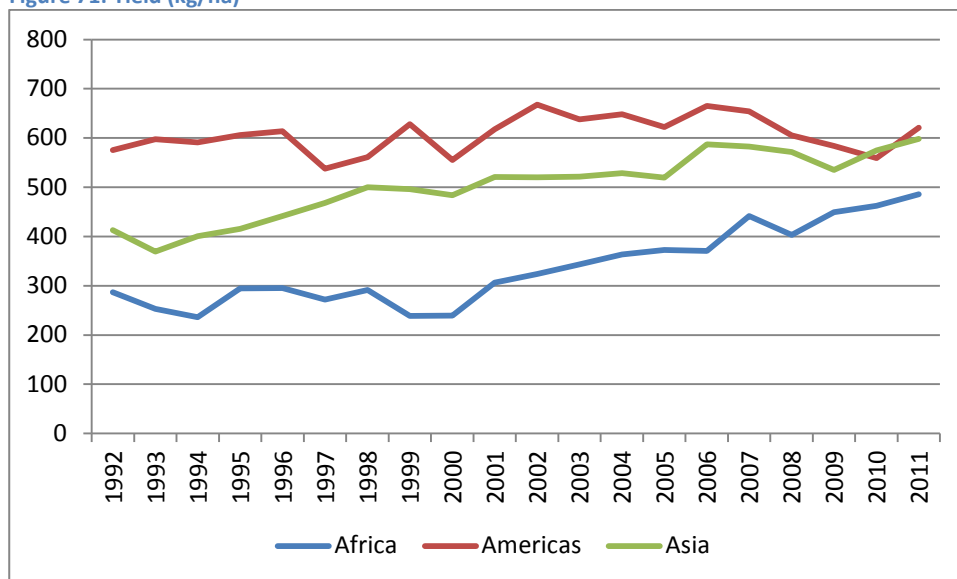


Figure 70: Area Harvested per year (ha) 2nd top group



Yields did not change significantly over the whole period, remaining very low especially among African countries (Figure 71).

Figure 71: Yield (kg/ha)



Prices have been fairly constant since early nineties until 2006 when they start growing as other agricultural commodities did. However, differently from other commodities, sesame prices have been steadily increasing since then (Figure 72)¹³. This is striking considering the substantial production increase over the same years. The most immediate explanation for this phenomenon is that supply was not able to meet an ever increasing demand.

¹³ Today, November 2014, in Amsterdam the CIF price for white sesame is 2,400 USD per ton and in Asia it is 1,800-2,000 USD FOB (depending on the quality) up to 2,400 USD/ton for the black sesame.

Figure 72: Sesame Producer Prices

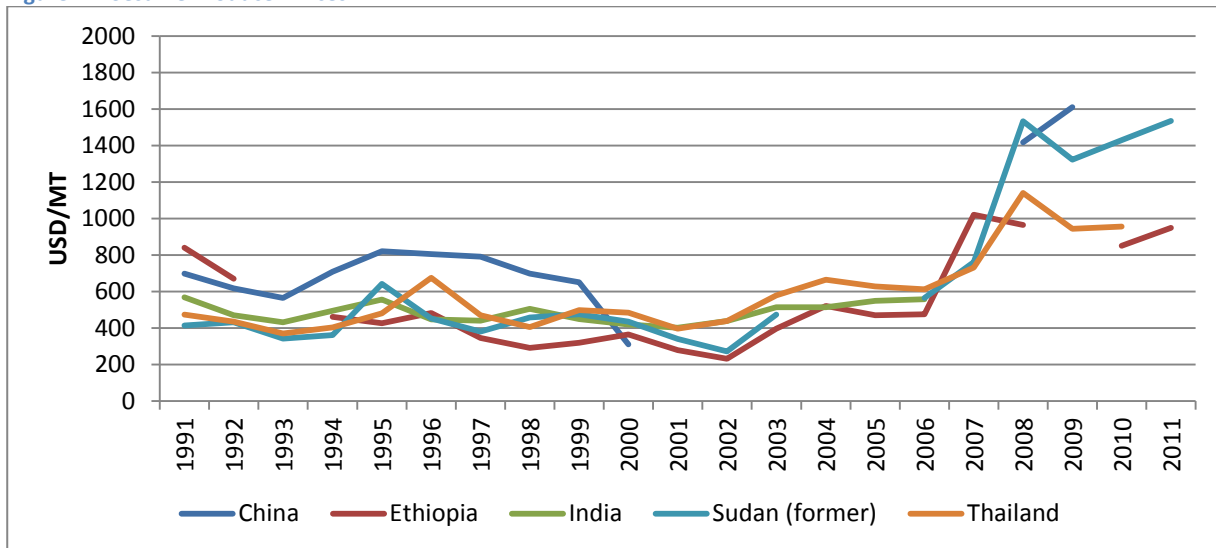
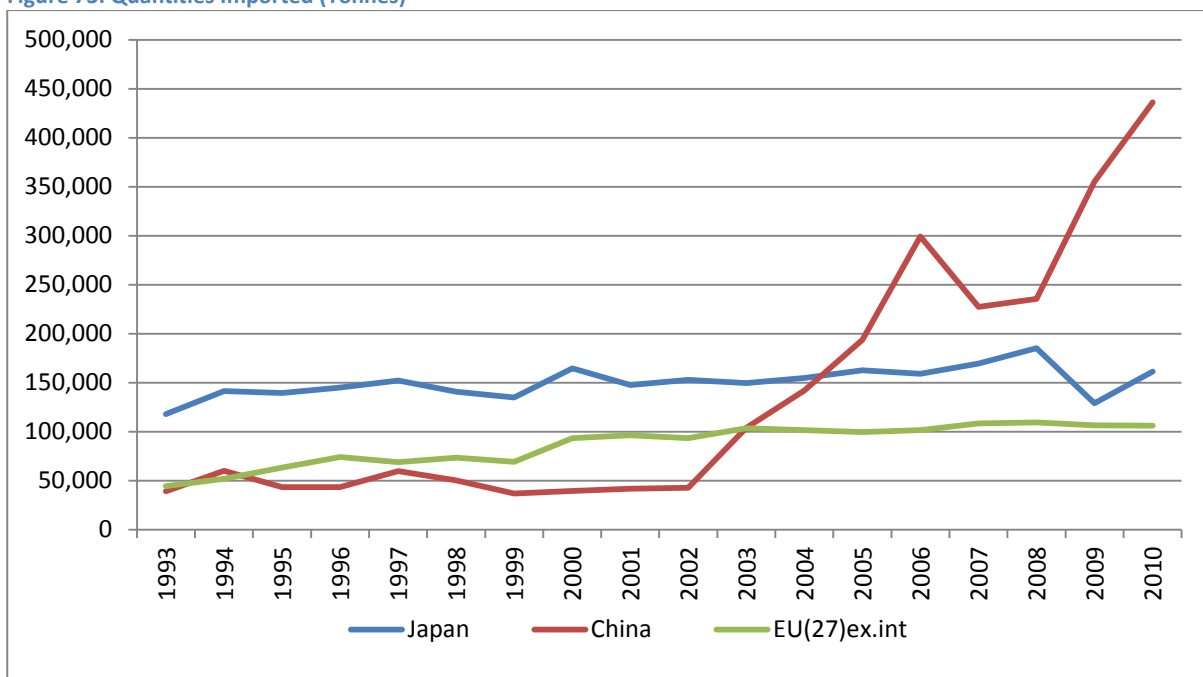


Figure 73 showing major importing countries clearly emphasizes the role played by China whose fast growing demand¹⁴ was key in determining the international market dynamics. The most important importing countries besides China are the EU 27 and Japan.

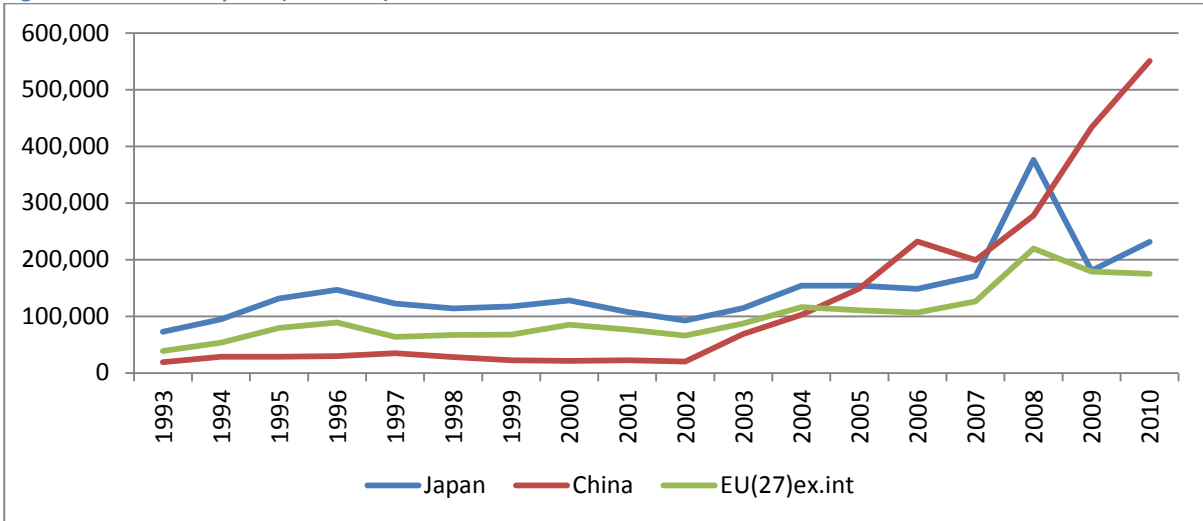
Figure 73: Quantities Imported (Tonnes)



In 2011 the value of imports of the three most important importing countries was 2,104,500,000 USD, which is 21% of world imports in the same year.

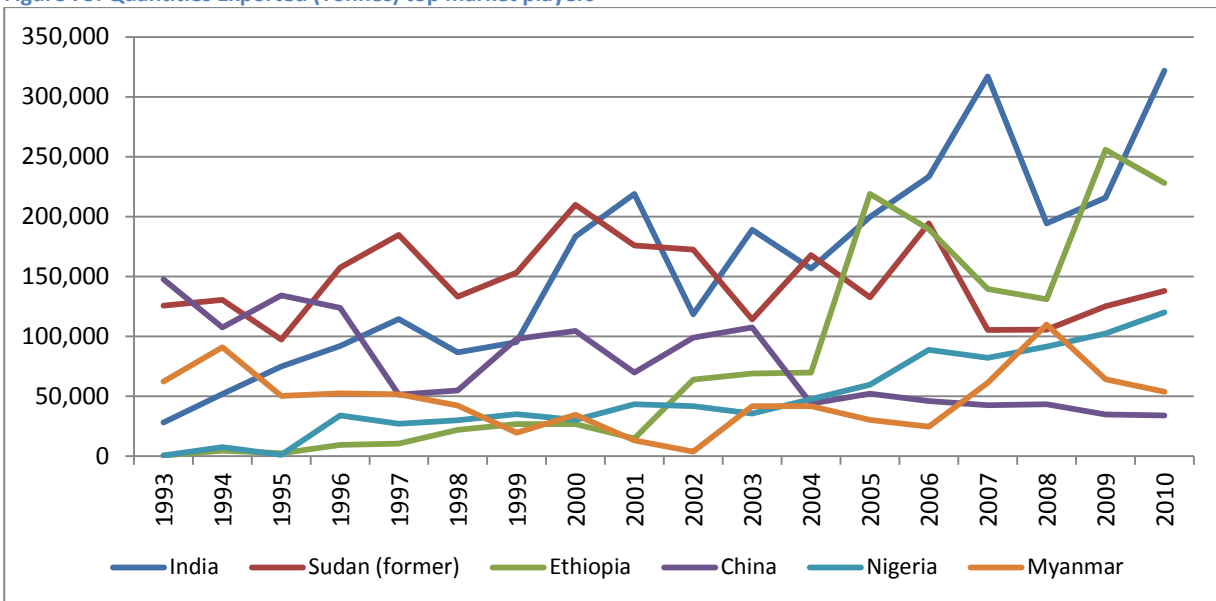
¹⁴ Despite China is the world largest producer it is also the first importing country all over the world.

Figure 74: Value of Imports (1000 USD)



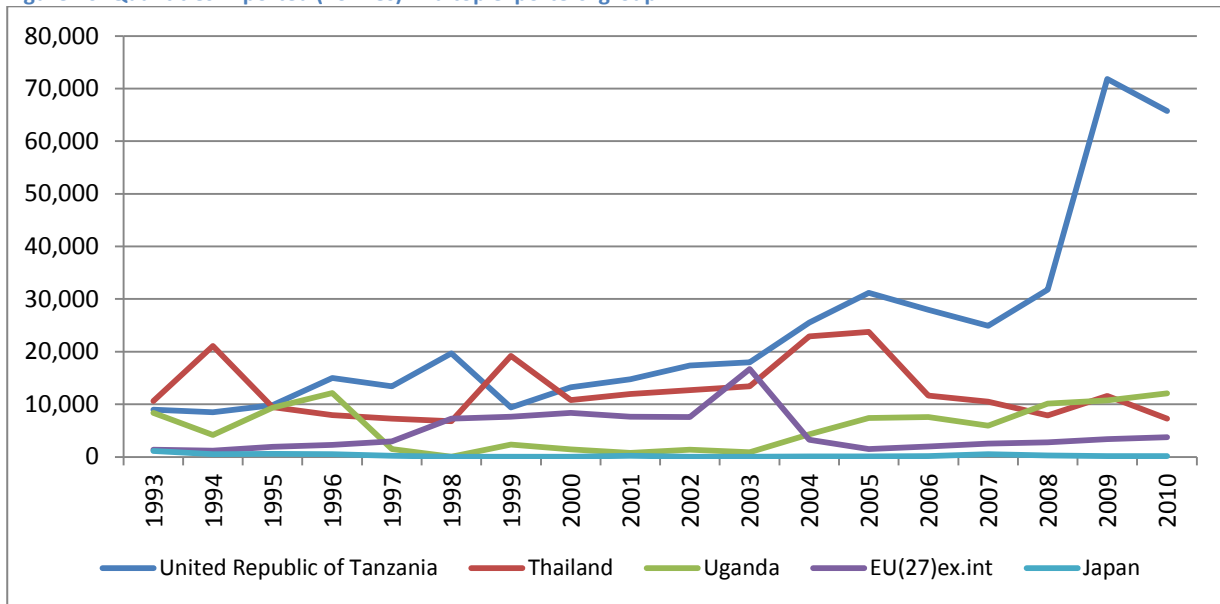
The most important exporting countries are the same as the most important producing countries¹⁵ plus some importing countries such as EU27 and Japan who partially re-export their own imports (Figures 74 and 75).

Figure 75: Quantities Exported (Tonnes) top market players



¹⁵ The exports from these countries share also some features of production, such as their erratic nature.

Figure 76: Quantities Exported (Tonnes) 2nd top exporters' group



Export values follow the same pattern export quantities (Figures 77 and 78). In year 2011 the four most important exporting countries totalled 1,254,870,000 USD, which is 11% of total world exports.

Figure 77: Export Value (1000USD) top 4 countries

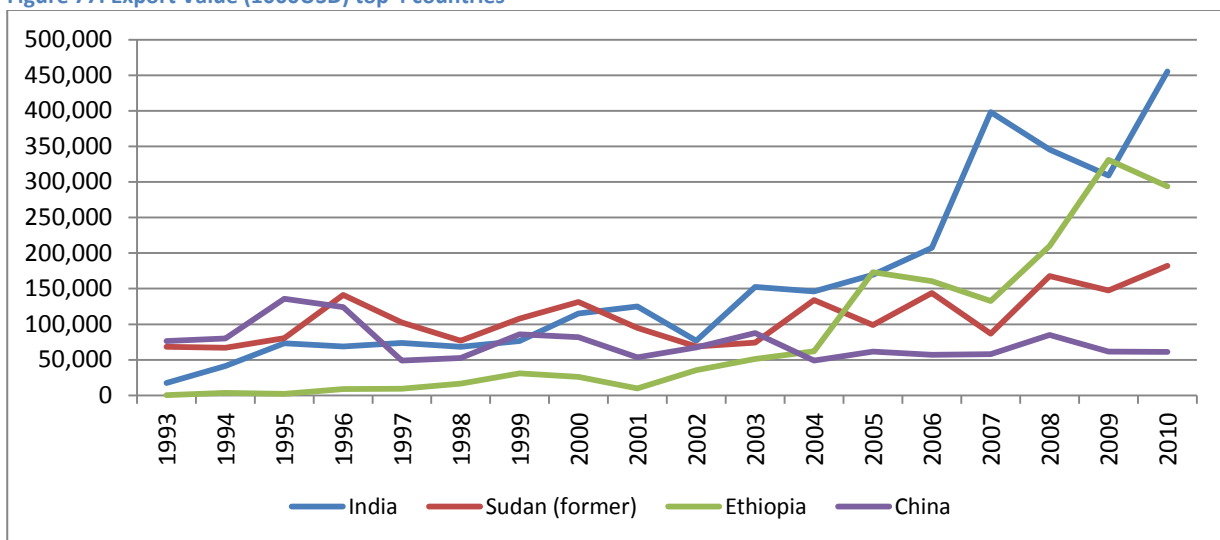
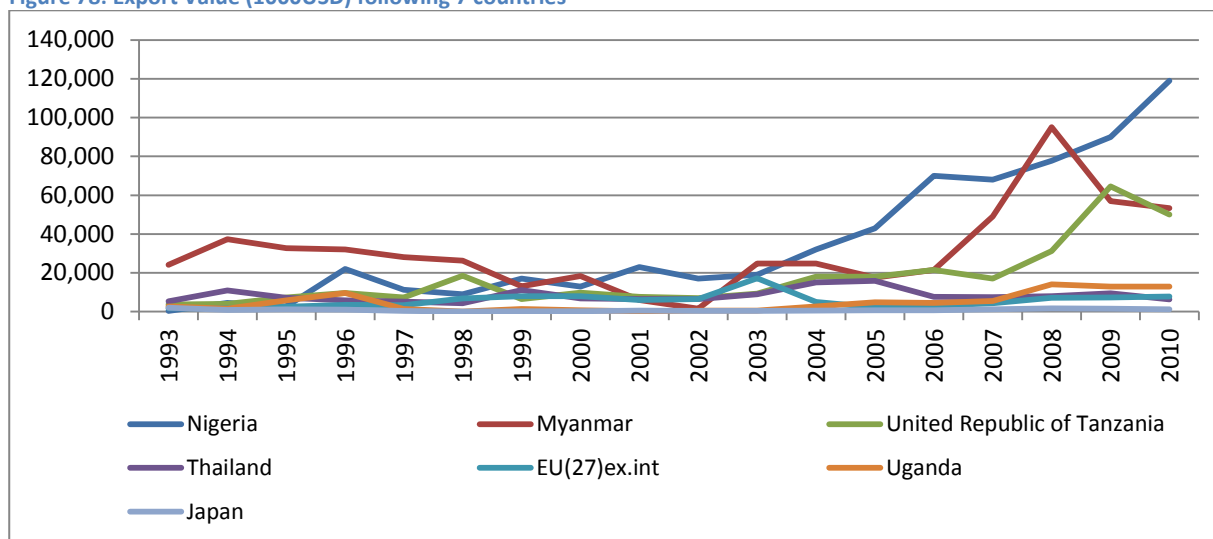


Figure 78: Export Value (1000USD) following 7 countries



In conclusion, the international market has been characterized by growing supply and by an ever more increasing demand, which determined a significant price increase. This situation represents a window of opportunity for any producing/exporting country, including Somalia. Before analysing if this window of opportunity represents a real option for Somali farmers, i.e. if sesame cropping is profitable in the Somali environment, it is worth analyzing the sesame market in Somalia.

6.3.1.3. The sesame market in Somalia

Data on sesame market in Somalia are drawn mainly from not published field reports of local NGOs and personal interviews with farmers and traders.

Notwithstanding the absence of State (or may be due to this) in Somalia private sector is vibrant, it is the backbone of the economy and is strongly protected by clan relations that not even Al Shabab may influence at country level. Traditionally Somali traders maintain strong links within the country and within the world through Diaspora.

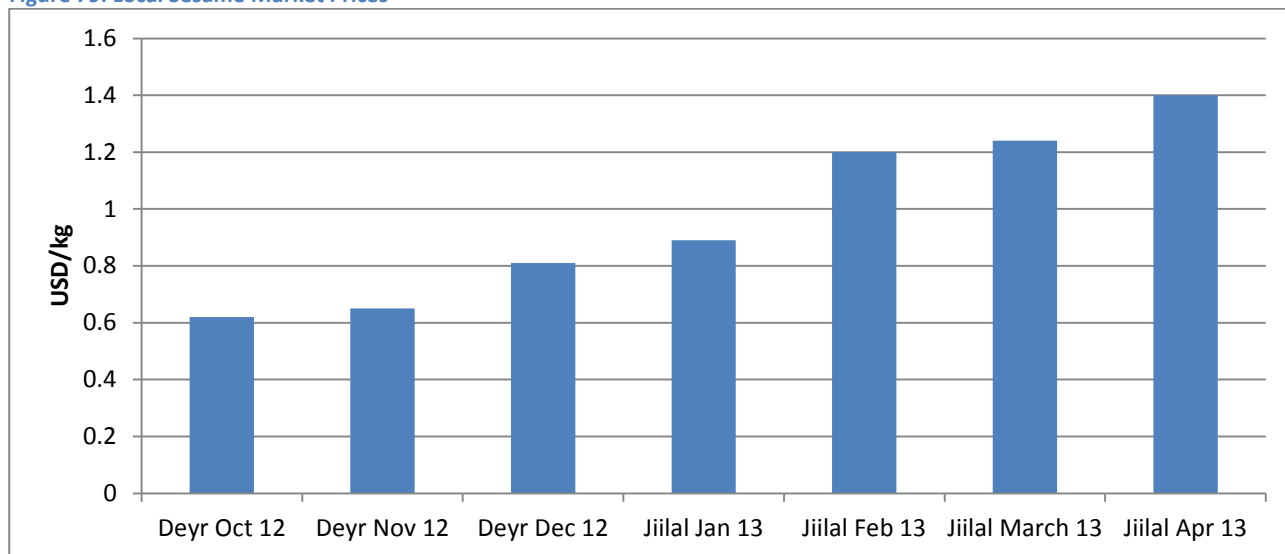
All the above leads to the first consideration which may appear *incredible to the* distant observer: in Somalia markets are almost perfect, with no distortions or market failures affecting market transactions: no presence of State (no custom duties or tariffs, no import or export taxes), no limitation to transport (business is not influenced by the insecurity, even if some transaction cost are incurred at the check points), no limitation to transfer of information (Somalia has a very efficient telecommunication system based on mobile phones and any trader may contact in no time Somali traders in the entire Somalia and in the world through diaspora linkages).

In Somalia sesame is a cash crop partially used for self-consumption, showing scarce competition with staple food due to the different cropping seasons (staple food with longer growing cycle in Gu and sesame with a cropping cycle as short as 75 days in Deyr). It is cultivated as part of risk mitigation strategies adopted by smallholder farmers. Indeed, the most important crops in Somalia are maize and sorghum usually grown during the long-rain season; vice versa, growing maize and sorghum in the short-rain season would be too risky: this is when sesame production is most appropriate. Currently, in Somalia less than 15,000 ha of sesame are grown annually in the irrigated area of Middle and Lower Shabelle while the

potential is close to 100,000 ha. The domestic production of sesame is estimated at 65,000 Tonnes (FAOSTAT, 2011)

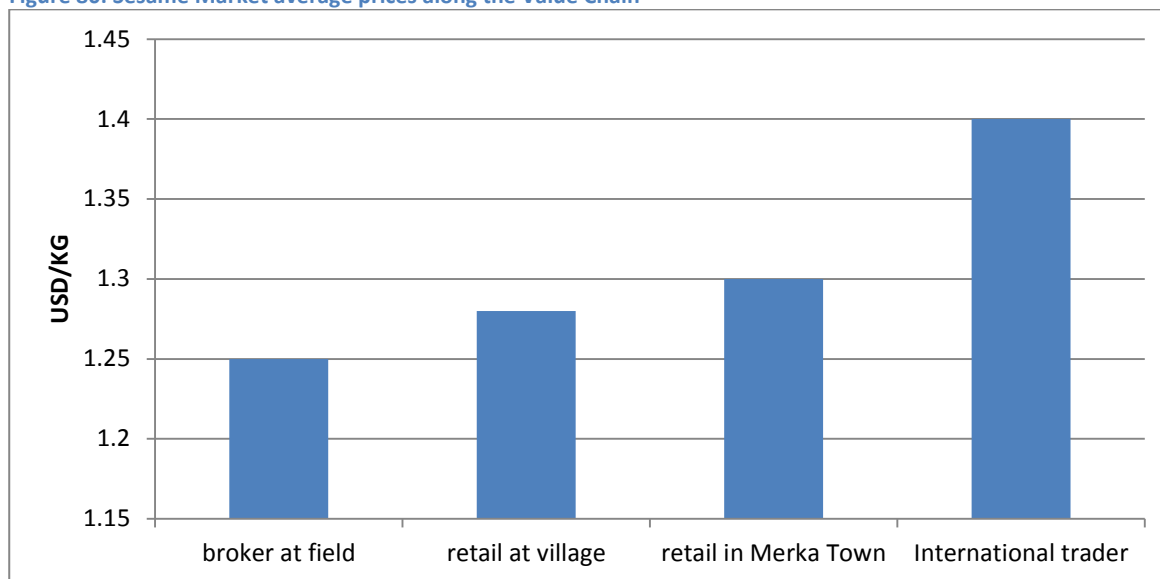
Market opportunities for Somali production are interesting. The demand for sesame has been quite sustained over the last years. As a result, prices are rising pulled by export demand and partly by domestic demand due to some economic development. They fluctuate over the year reaching their maximum one month before the harvest and the minimum immediately after (Fig. 79).

Figure 79: Local Sesame Market Prices



As it is expected the sesame prices are different along the value chain reflecting the cost of transport and the margin of the relevant actor (please refer to the value chain scheme in figure 64 and 80)

Figure 80: Sesame Market average prices along the Value Chain



6.3.2. Assessment of sesame production profitability in Somalia

In order to know if the opportunities offered by the international demand for sesame is real, it is necessary to analyze the financial structure of sesame cropping. This will be done along this paragraph to conduct a profitability analysis.

Data gathered at field level on the costs and benefits of production have been used to establish the sesame cropping profitability. The analysis has been conducted at household level considering the data available from FSNAU (Food Security and Nutrition Analysis Unit in FAO), field reports and personal interviews.

Keeping in mind that a continuum exists among different sesame cropping methods and ecosystems, the profitability analysis of sesame cropping (expected level of production, costs and benefits and break even point) is carried out according to the three most typical possible scenarios of sesame cropping in Somalia:

- d. rainfed traditional: 6 kg of seed per ha, sowing broadcasted and minimum crop caring;
- e. rainfed improved: 8 kg of seed per ha, sown in rows (generally 60 cm x 18 cm), with at least two weedings (riverine traditional is in between the rainfed improved and the other two systems (rainfed improved and riverine traditional) with 6-8 kg of seed per ha, broadcasted and without weeding but with some additional irrigation if gravity irrigation is available or pumped irrigation if affordable by the farmer);
- f. riverine improved: 8 kg of seed per ha, sown in rows (generally 60 cm x 18 cm), with two to three weedings and some irrigation when gravity irrigation is available or pumped irrigation if affordable by the farmer.

All data refer to the unit area of 1 hectare, which is the area usually grown at smallholder farmer level. This figure may be significantly different in riverine and rainfed systems. Nevertheless, the analysis carried out can provide useful information for these systems as well and can be considered representative for the South Central region of Somalia.

6.3.2.1. Production costs

Here below are reported the summary tables (Tab. 43, 44 and 45) computing the actual cost of production in the three different scenarios where sesame is grown in Somalia: rainfed traditional, rainfed improved and riverine improved.

Table 43: SESAME TRADITIONAL in rainfed

No	Item	Unit	Qty/ha	Unit Cost \$	Total Cost \$/ha	Remarks
Production						
1	Ploughing	Hour/Ha	3	27	81	mechanical power
2	Harrowing	Hour/Ha	1	27	27	mechanical power
3	Ridging (by <i>kawaawe</i>)	man day	6	6.25	37.5	self/labour
4	Seeds	Kg	0	0	0	
5	Irrigation	Times	0	12.5	0	self-help/labour
6	Sowing	man day	5	5.3	26.5	self/labour
7	Fertilizer	Kg	0	0	0	
8	Manure	Kg	0	0	0	
9	1 ST Weeding	man day	7	3.12	21.84	self/labour
10	2 nd Weeding	man day	7	2.5	17.5	self/labour
11	Chemicals	Gr/ml/lt	0.5	9	4.5	self/labour
13	Spraying	man day	12	4.7	56.4	self/labour
14	Harvesting	man day	4	3.12	12.48	self/labour
15	Heaping	man day	8	3.12	24.96	self/labour
15	Crop guarding (watchman)	Night/Month	13	3.84	49.92	self/labour
16	Threshing and packaging	man day	5	3.12	15.6	self/labour
17	Post harvest Chemical		0	0	0	
18	bags	pcs	9	0.5	4.5	
19	Transportation cost	sack	7	4	28	vehicle/donkey cart
Total Cost of Production (TCP)					407.7	

Table 44: SESAME RAINFED improved

No	Item	Unit	Qty/ha	Unit Cost \$	Total Cost \$/ha	Remarks
1	Ploughing	Hour/Ha	3	27	81	mechanical power
2	Harrowing	Hour/Ha	1	27	27	mechanical power
3	Ridging (by <i>kawaawe</i>)	man day	6	6.25	37.5	self/labour
4	Seeds	Kg	0	0	0	
5	Irrigation	Times	0	12.5	0	self-help/labour
6	Sowing	man day	5	5.3	26.5	self/labour
7	Fertilizer	Kg	0	0	0	
8	Manure	Kg	0	0	0	
9	1 ST Weeding	man day	7	3.12	21.84	self/labour
10	2 nd Weeding	man day	7	2.5	17.5	self/labour
11	Chemicals	Gr/ml/lt	0.5	9	4.5	self/labour
13	Spraying	man day	12	4.7	56.4	self/labour
14	Harvesting	man day	6	3.12	18.72	self/labour
15	Heaping	man day	8	3.12	24.96	self/labour
15	Crop guarding (watchman)	Night/Month	13	3.84	49.92	self/labour
16	Threshing and packaging	man day	6	3.12	18.72	self/labour
17	Post harvest Chemical		0	0	0	
18	bags	pcs	9	0.5	4.5	
19	Transportation cost	sack	7	4	28	vehicle/donkey cart
Total Cost of Production (TCP)					417.1	

Table 45: SESAME RIVERINE improved

No	Item	Unit	Qty/ha	Unit Cost \$	Total Cost \$/ha	Remarks
1	Ploughing	Hour/Ha	3	27	81	mechanical power
2	Harrowing	Hour/Ha	1	27	27	mechanical power
3	Ridging (by <i>kawaawe</i>)	man day	6	6.25	37.5	self-help/labour
4	Seeds	Kg	0	0	0	
5	Irrigation (gravity)	man day	4	12.5	50	self-help/labour
6	Sowing	man day	5	5.3	26.5	self-help/labour
7	Fertilizer	Kg	0	0	0	
8	Manure	Kg	0	0	0	
9	1 ST Weeding	man day	7	3.12	21.84	self-help/labour
10	2 nd Weeding	man day	7	2.5	17.5	self-help/labour
11	Chemicals	Gr/ml/lit	0.5	9	4.5	self-help/labour
12	Spraying	man day	12	4.7	56.4	self-help/labour
13	Harvesting	man day	8	3.12	24.96	self-help/labour
14	Heaping	man day	10	3.12	31.2	self-help/labour
15	Crop guarding (watchman)	Night/Month	13	3.84	49.92	self-help/labour
16	Threshing and winnowing	man day	10	3.13	31.3	self-help/labour
17	Post harvest chemicals	0	0	0	0	
18	Sacks	pcs	12	0.5	6	
19	Transportation	sack	10	4	40	vehicle/donkey cart
20	Total Cost of Production (TCP)				505.62	

The cost of production has been calculated explicitly including the cost of labour as this is the usual approach. However, in standard operational situation in Somalia, labour is normally provided by the household; as a result, the cost of labour should not be considered as a financial cost, considering that the household labour opportunity cost is close to zero for lack of real working opportunities. In addition considering real situation in Somalia, not all the labour activities listed above are *real* (e.g.: spraying). Actual labour costs really sustained are those related to mechanical power for ploughing and harrowing and some other costs during peak time ¹⁶. This implies that the actual financial cost of labour for cropping sesame is about 33%, 40% and 41%¹⁷ of the total labour cost computed respectively for sesame riverine improved, sesame rainfed improved and sesame rainfed traditional) of what is reported above with a consequent positive impact on the profitability of the cropping.

However, it should be noticed that his assumption in the last years may be challenged because of the ongoing urbanization process, internal migration related to lack of security or search for better life opportunities and to the fact that during the labour peaks in the cropping season (sowing, weeding, harvesting) there may be a labour shortage.

Another important consideration refers to the allocation of workload by gender (Tab.**Error! Reference source not found.** 46) (Sidow, 2011) shows the relevance of the role of the women in the sesame cropping. In Somalia the share of women work contribution to household total workload in sesame production activities is second only to that of vegetables. This is extremely important because in principle any increased income from sesame production can be in principle conducive to women empowerment, due to existing customary income sharing rules in rural areas.

¹⁶ Smallholder farmers supply in a form of mutual support with no money transaction, i.e. groups of 10-15 neighbouring farmers works in one of the member's farm one day and receive food and so on during the next 15 days where all the farm have received the support of all the others.

¹⁷ Considering the cost for food provided during the peak time to guest the neighbouring farmers about 20 USD/day for three days (sowing, weeding and harvesting) along the cropping season and the cost of labour as computed.

Table 46: Tasks required for sesame cultivation in Somalia

Operation	Hours	Men	Women
Bund formation	54	54	
Irrigation	51	51	
Planting and seed cost	24	14	10
spraying	10	10	
Weeding	36		36
Basal dressing	5	5	
Harvesting	90	36	54
Threshing	50	25	25
Carting	2	2	
Cleaning	12		12
Subtotal	334	197	137
Miscellaneous (10%)	33.4	19.7	13.7
Total	367.4	216.7	150.7
Percent		59%	41%

6.3.2.2. Profitability of sesame production in Somalia

A recent field data collection in Lower and middle Shabelle (riverine area) referring to 4,500 farmers belonging to two different agrosystems (riverine and rainfed) who received 8 kg of Humera seeds showed the following.

Table 47: Basic data on sesame production

		Area	Yield obtained Kg/Ha		
Sowing date	Harvesting date		Low	High	Average
<i>Nov-Dec</i>	<i>Feb-March</i>	Riverine	650	900	775
		Rain-fed	400	600	500

The value of the production is, in the case of sesame, clearly defined by the level of production and by the quality of the production. The quality of the production identified by the traders is based on size, taste and colour. The sesame traditionally grown in Somalia is called Dunyar and is mixed in colour (black 35% cream and white 65%), level of production are between 300 and 350 kg/ha. Humera, the tested variety in Somalia, produced between 600 and 900 kg/ha and it is white with an excellent taste.

Dunyar has a high domestic demand and is used also to produce oil. Market price of sesame in towns may reach, in retailers' shops 3 USD/kg and the oil at about 5 USD/l while the cake resulting from the oil extraction is sold at 1 USD/kg as animal feed integrator. Very seldom this variety only rarely may have access to foreign markets.

Table 48 shows that the sesame production in a traditional cropping system wouldn't be profitable to smallholder farmers should they pay for labour, i.e. hiring casual workers.

Table 48: Scenario 1: Sesame traditional cropping system

	Income	Unit	Qty	Unit price (USD)	Total (USD)
1	Yield per ha (average)	kg	350		
2	Gross revenue at farm/village gate	USD	350	0.85	297.5
3	Gross revenue at market level	USD	350	1	350
4	Gross revenue at international trader level	USD	350	0	0
5	Cost of production	USD			407.7
6	Net revenue at farm gate level (Output-Input)				-110.2
7	Net revenue at market level (Output-Input)				-57.7
8	Net revenue at international trader level (Output-Input)				-407.7
	Man day/ha		54		

Table 49 shows that the sesame production in a rainfed improved cropping system would be profitable to smallholder farmers even if they should they pay for labour, i.e. hiring casual workers.

Table 49: Scenario 2: Sesame good quality in rainfed

	Income	Unit	Qty	Unit price (USD)	Total (USD)
1	Yield per ha (average)	kg	500		
2	Gross revenue at farm/village gate	USD	500	1	500
3	Gross revenue at market level	USD	500	1.2	600
4	Gross revenue at international trader level	USD	500	1.4	700
5	Cost of production	USD			417.1
6	Net revenue at farm gate level (Output-Input)				82.94
7	Net revenue at market level (Output-Input)				182.94
8	Net revenue at international trader level (Output-Input)				282.94
	Man day/ha		57		

Table 50 shows that the sesame production in a riverine improved cropping system would be very profitable to smallholder farmers even if they should they pay for labour, i.e. hiring casual workers.

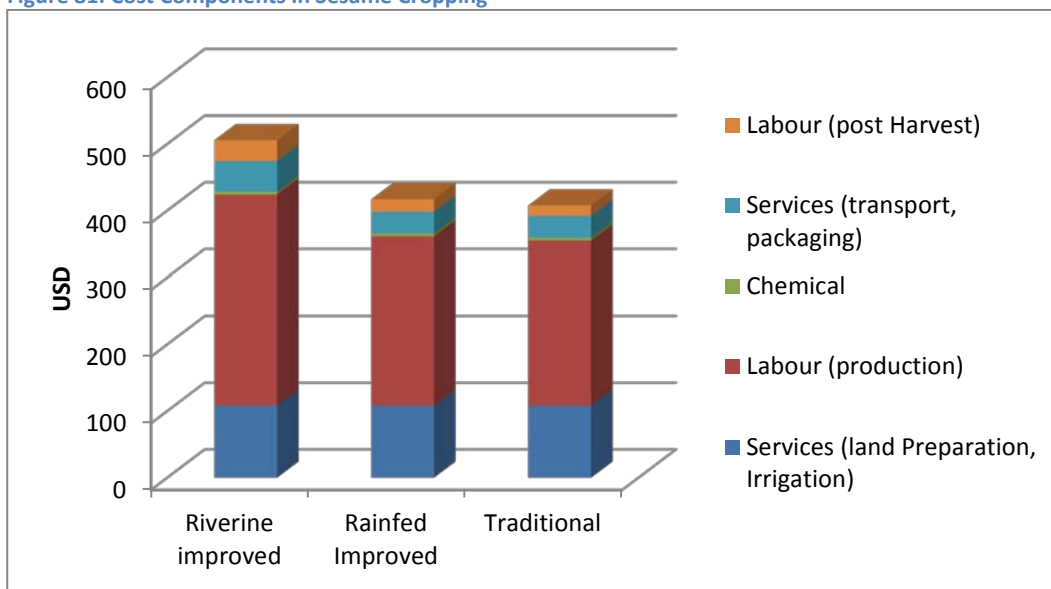
Table 50 Scenario 3: Sesame good quality in riverine

	Income	Unit	Qty	Unit price (USD)	Total (USD)
1	Yield per ha (average)	kg	775	0	0
2	Gross revenue at farm/village gate	USD	775	1	775
3	Gross revenue at market level	USD	775	1.2	930
4	Gross revenue at international trader level	USD	775	1.4	1085
5	Cost of production	USD			505.62
6	Net revenue at farm gate level (Output-Input)				269.38
7	Net revenue at market level (Output-Input)				424.38
8	Net revenue at international trader level (Output-Input)				579.38
	man day/ha		69		

6.3.2.3. Overall assessment

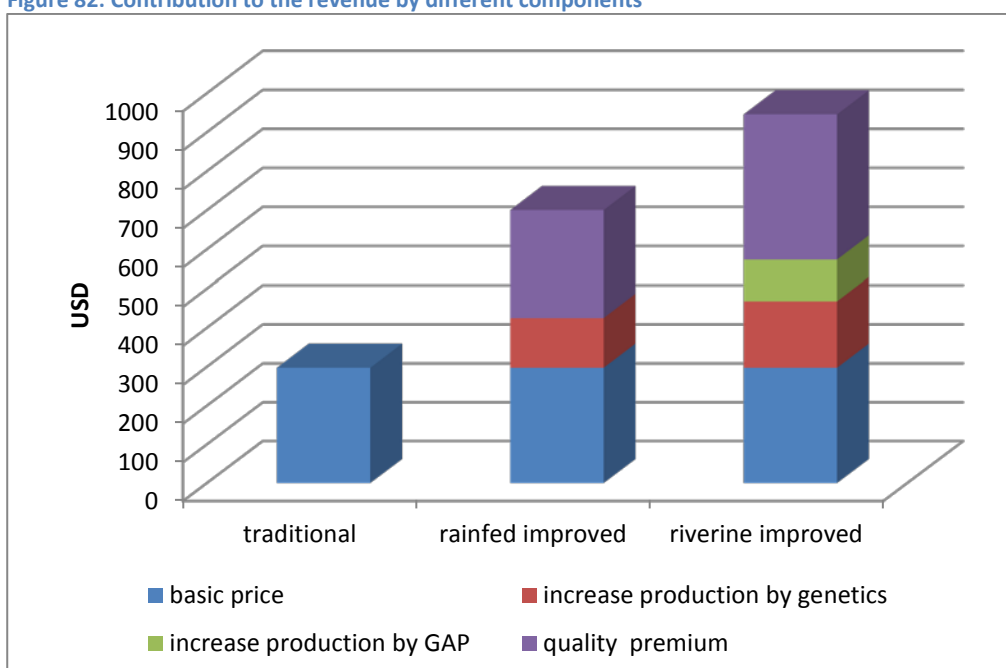
Figure 81 summarizes the costs components per each cropping system. Comparing these components it emerges that the production cost slightly increases with the level of production while the post harvest cost increases significantly with the production.

Figure 81: Cost Components in Sesame Cropping



Considering the basic price of 0.85-0.9 USD/kg and the positive impact on production due to the use of improved genetic material and of adequate GAPs, and finally considering the quality premium paid by the international trader ($(1.4 \text{ USD/kg} - 0.85 \text{ USD/kg}) / 1.4 \text{ USD/kg} = 39\%$), the total revenue for the smallholder farmers in the three different scenarios is depicted in Figure 82.

Figure 82: Contribution to the revenue by different components



The key success element is the link created among farmer organizations (receiving and stocking the production) and an international trader guaranteeing the purchase of the entire production by the end of the season paying a quality premium.

Based on the production costs summarized for the three cropping methods described so far in table 51, to conclude this analysis it is worth to assess the break even of production for the different scenarios with and without the cost of labour (Tab. 52 and 53).

Table 51: Sesame summary of production costs

Production items	Riverine improved	Rainfed improved	Traditional
Services (land preparation, irrigation)	108	108	108
Labour	315.82	253.34	247.1
Chemical	4.5	4.5	4.5
Post Harvest			
Services (transport, packaging)	46	32.5	32.5
Labour	31.3	18.72	15.6
Total	505.62	417.06	407.7

Table 52: Break even (kg/ha) considering labour cost

Break Even with labour costs	Riverine improved	Rainfed improved	Traditional
Quantity produced (kg/ha)	775	500	350
Total cost of production	505.62	417.06	407.7
Unit cost (USD/kg)	0.65	0.83	1.16
Price of sale (USD/kg)	1.4	1.2	0.9
Break even (kg/ha)	361.16	347.55	453

Table 53: Break even (kg/ha) without considering labour cost

Break Even without labour cost	Riverine improved	Rainfed improved	Traditional
Quantity produced (kg/ha)	775	500	350
Total cost of production	189.8	163.72	160.6
Unit cost (USD/kg)	0.24	0.33	0.46
Price of sale (USD/kg)	1.4	1.2	0.9
Break even (kg/ha)	135.57	136.43	178.44

In order to break even the production costs in the traditional cropping system (when the cost of labour is considered) at least 453 kg/ha of sesame should be produced. However, as in the traditional system no more than 350 kg/ha are produced, the only reason why sesame is still cropped in this agricultural system is that labour is not paid (accounted) for. Vice versa, sesame production is highly profitable in the two other production systems, with a break even well below the standard operating conditions.

Furthermore, the financial analysis shows that in Somalia it is more convenient to produce sesame than maize in riverine improved conditions. In the case of maize, a similar work conducted in the past three years testing the income growth related to germplasm improvement and GAP adoption in riverine irrigated

areas led to the following outcome: the gross revenue per ha computed adopting the same methodology is 1,200 USD with a production cost of 770 USD and a net revenue of 430 USD per ha. In riverine a small holder farmer growing maize in Gu and sesame in deyr will have an income of about 2,285 USD corresponding to 1.04 USD/person/day¹⁸.

However, the alternative is purely academic in Somalia where Gu, the long rain season, is used for producing maize, and Deyr the short rainy season to produce sesame and would not be politically correct in a food insecure country like Somalia to grow sesame also in Gu. Luckily the latter matches with the technically more appropriate solution as the crop rotation with maize is in any case an ideal solution in terms of agronomic practice and in addition growing sesame in Gu also does not seem compatible with temperature and light requirements of sesame.

Another important aspect to analyse is the efficiency in the use of water, the scarcest resource in Somalia. Table 54 summarizes the most important parameters in the use of water comparing the sesame cropping systems with the other major crops in the region, namely sorghum and maize.

Table 54: Value the water in term of different production

Crop	Water needs (min) mm	Water needs (max) mm	yield grain MT/Ha	efficiency in water use kg grain/mm	mm of water per Ton of green matter	value of grain/ha (US\$)	value of fodder US\$/ha	total value of production (US\$)	US\$ value of each mm of water
Sesame	304.8	406.4	0.6	1.18	-	840	0	840	2.36
Sorghum	449.58	482.6	1.2	1.74	31.08	360	150	510	1.09
Maize	558.8	609.6	3	3.47	41.01	960	250	1210	2.07

In terms of technical efficiency, growing maize is the most efficient system of using water. However, in terms of economic efficiency (i.e. considering the net revenue of each crop) the most efficient crop is sesame, for which 1 mm of water produces 2.36 USD.

¹⁸ Household average composition is of 6 persons (FSNAU Data). Average sesame production 775 kg/ha average sesame price 1.4 USD/kg.

7. Conclusions

For a Somali farmer, daily engaged in surviving, dwelling with drought and floods occurring regularly one season after the other when not during the same season, the existential problem is how to survive. Social networks are almost non-existing (with exclusion of the clan support and the zaqat¹⁹), the state is almost absent and in the market he is the weakest ring of the chain He is alone and shall cope with the hardship of natural and social environment alone. No surprise if along the centuries he has developed some coping mechanisms perfectly adapted to the environment. One of these is the rotation sesame maize during Deyr and Gu respectively. In this context two consecutive genetic improvement works, one on Maize and the present on sesame have created the conditions for improving his/her quality of life through income growth.

The present study concludes the following:

1. The 11 accession of Sesame African germplasm examined showed high genetic variability and are suitable to begin new breeding programs to improve the production and the quality;
2. Sesame is sensitive to the ecosystem and high environmental impact on phenotypic expression is demonstrated in all the accessions/varieties tested on field, for this reason it is relevant to develop local breeding programs involving local farmer;
3. Several gene pools identified are promising to improve sesame cultivation in different sites with different cropping systems;
4. Sesame, under the experimental conditions adopted in this study, demonstrated a relatively limited response to N and P fertilization, in other words its requirements for these nutrients are limited. The crop rotation adopted in Somalia by small holder farmers is in line with this conclusion as fertilizer, if used, is distributed during Gu to maize and sesame in Deyr will take advantage of the residual fertility of the nutrients distributed during the previous season.
5. Due to the previous, sesame showed to be an environmental friendly crop with reduced input costs thus requesting a limited financial investment the latter providing an additional motivation for smallholder farmers to continue and expand its cultivation.
6. The question if sesame cropping would reduce food security in Somalia is purely academic; farmers will continue growing maize in Gu and sesame in Deyr. However, global sesame demand represent an opportunity at household level for income growth thus cropping sesame might reduce food sovereignty but would increase food security.
7. It has been demonstrated along this study that the adoption of improved GAPs (without the adoption of extra input –fertilizer and extra labour- but following the on-going cropping practices thus without extra costs) and improved germplasm in sesame cropping translates in an income growth exceeding 1,000 USD per year. The final result for a small holder farmer household adopting improved GAPs and germplasm in growing maize and sesame along the year is 1.04 USD/day per person (significantly higher than the 0.26-0.53 US\$/person/day estimated in rural areas of Somalia). An economic analysis not considering the cost of labour provided by the farmer in his own farm would bring a more positive result.

¹⁹ Charity, one of the five pillars of Islam.

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