GENOTYPE-ENVIRONMENT INTERACTION STUDY ON SESAME (*Sesamum indicum* L.)

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ABSTRACT

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GENOTYPE-ENVIRONMENT INTERACTION STUDY ON SESAME (*Sesamum indicum* L.)

Sesame (*Sesamum indicum* L.) is a tropical oilseed found growing in the mid-altitude (< 1700 m.a.s.l.) regions of Ethiopia. Recently, there has been an attempt by settler farmers from the Ethiopian plateau to expand sesame cultivation in the low altitude areas (< 800 m.a.s.l.). A genotype-environment interaction study on sesame lines developed through progeny selection originating from a bulk of landraces was carried out at six environments in Ethiopia. The environments selected were believed to provide a wide variation in temperature (altitude), moisture and soil. The objective of the study was, therefore, to select a line or lines widely adaptable over these environments for variables seed yield, oil and protein content as well as fatty acid composition. Two statistical methods, namely, the regression model and the procedural approach of superiority measure were used to estimate line adaptability. Several lines were identified which were adapted over the six environments while others were specifically adapted to lo- or high-yielding environments. Lines showing wide adaptation for one variable were not always widely adapted for others. In addition, the two parametric statistics used to analyze the data did not always agree for each variable.

RESUME

ETUDE DE L'INTERACTION GENOTYPE-ENVIRONNEMENT CHEZ LE SESAME (*Sesamum indicum* L.)

Le sésame (*Sesamum indicum* L.) est une plante oléagineuse croissant dans les régions à élévation moyenne (<1700 m.d.n.m.) en Éthiopie. Récemment, la culture du sésame à basse altitude (<800 m.d.n.m.) fut entreprise par des paysans relocalisés. Afin de répondre aux besoins des paysans relocalisés, une étude de l'interaction génotype-environnement a été entreprise dans six environnements différents afin d'évaluer le rendement d'un certain nombre de lignes développées à partir de variétés locales. Les environnements ont été selectionés afin de couvrir une vaste gamme de températures (altitudes), d'humidité et de types de sol. L'objectif était d'évaluer selon des critères de rendement, de teneur en huile, en protéines et acide gras, et de sélectionner les lignées capables de s'adapter aux divers environnements. La méthode de régression linéaire et la méthode d'approche procédurale de supériorité furent employées afin de déterminer la supériorité des lignées. Plusieurs lignées ont bien répondu aux six environnements alors que certaines se sont mieux adaptées à des environnements favorables, et d'autres à des conditions non favorables aux rendements. Les lignées qui ont démontré une grande adaptation pour une variable, n'ont pas toujours bien répondu aux variations des autres paramètres. Malgré le fait que les méthodes utilisées aient été toutes deux paramétriques, les résultats obtenus n'étaient pas en parfaite concordance en ce qui a trait aux variables étudiées.

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1. INTRODUCTION

Sesame (*Sesamum indicum* L.) is found growing in many regions and environments in Ethiopia. The main sesame producing areas are located in the north and northwest of the country adjacent to the republic of the Sudan. A very small amount of this oil seed is also produced in the east and southeast of the country.

Previous sesame improvement work has focused on the identification and development of genotypes adapted to the conditions prevailing in the mid-altitude areas of the country which are generally characterized by low and erratic rainfall distribution. However, since the modest increase in the cropped area was brought about by extending sesame cultivation to the lowland region of the country (rainfed and irrigated), the unsatisfactory performance of the earlier released varieties could be attributed to their inability to adapt to the new environment (Allard and Bradshaw, 1964).

The environmental factors that are expected to be of greater importance in the production of sesame seed oil are temperature as related to altitude difference in the case of Ethiopia (Smilde, 1960), rainfall (Osman and Nour, 1985), soil fertility (Mitchel *et. al.*, 1974), and irrigation management (Rheenen van, 1973, Khandiah and Woldemariam, 1982). Earlier work in the Sudan (Moneim and Mahomud, 1983) also suggested that moisture and edaphic factors play a major role in the genotypic performance of sesame. In addition Henry and Dualy (1987) reported substantial environmental effects on sesame seed yield.

However, in the Ethiopian context, reliable information on the performance of genotypes can only be obtained by evaluating the materials under different environmental conditions of the country.

Moreover, since only limited information is available on genotype-environment interaction on sesame in Ethiopia and elsewhere to date, it is necessary to conduct this study to indicate whether sesame grown under diverse climatic and edaphic conditions will give relatively sustainable economical seed and oil yield. Therefore, it is hypothesized that sesame genotypes grown under different environmental conditions are not relatively affected in their performance with respect to seed yield, oil content, protein percent and fatty acid composition.

Generally, genotypes with relative stability and general adaptability across locations can be more useful to sesame growers in Ethiopia than separate genotypes specifically developed for high and low productivity environments. The reason for this is that peasant agriculture tends to gravitate toward the concept of production stability rather than maximization. In other words, peasants prefer widely adaptable genotypes than those high yielding ones but with restricted adaptability. Obviously, widely adapted genotypes are seen by the farmer as a risk aversion mechanism to climatic and other adverse production conditions such as pest and diseases.

The objectives of the study are to identify the performance of sesame experimental lines at three sites in Ethiopia; to select lines with characteristics of general adaptability over a range of production environments; to study environmental effects on the biochemical constituents of the oil, namely, the fatty acid composition, protein and oil content.

2. LITERATURE REVIEW

2.1 Sesame (*Sesamum indicum L.*)

2.1.1 The Origin of Sesame

Vavilov (1950), put the Ethiopian region to be the center of origin of sesame with basic centers of diversity in the Indian sub-continent and China. Hilterbrandt (1932), also confirmed that the primary center of origin was not Asia but Africa. He based his assertion on morphological, biochemical and physiological differences present in the species. Although, 16 out of the 37 species of the genus *Sesamum* are found scattered throughout Africa, so far there is no historical evidence to suggest that sesame was cultivated south of Ethiopia to any great extent until the 19th century. At this time demand by metropolitan Europe created a market for the crop (Seegeler, 1983). However, Joshi (1961) and Bedigian and Harlan (1986) argued in favor of Indo-Pakistan as the center of origin and domestication. *Sesamum indicum* is the only species cultivated on any scale but occasionally *S.alatum*, *S.angustifolium*, *S.prostratum* and *S.angolense* are cultivated for food, medicinal or ornamental purposes.

2.1.2 Use

Sesame seed is used whole in the confectionery industry or processed for high grade vegetable oil. The seed is a source of many nutritionally important essential amino acids such as methionine. The cake or meal obtained after the oil is extracted constitutes an excellent source of animal feed. In some countries, the cake is processed to produce protein rich flour that can be mixed with soybean flour,corn flour and chickpea to provide very nutritious human foods.

Sesame oil is also used for many industrial purposes. In the pharmaceutical industries the oil is used as a vehicle for various substances to be injected in the body or as an ingredient in cosmetic products. The seed also contains a special enzyme called sesamir, not available in many commercial oil crops, that is believed to act as synergist with pyrethrum insecticide to enhance its efficacy (Ashri a. 1989).

The most outstanding characteristics of the oil is its stability (extended shelf life) which is due to the anti-oxidant properties of small proportions of sesamol liberated from the glycoside sesamolin which occurs in the unsaponifiable fraction of the oil. The amount of the anti oxidant present in sesame oil seeds range between 0.5 to 1% (Nayar and Mehra, 1970).

2.1.3 Botany

The botanical classification of sesame has been revised by Rheenen van (1973). The genus Sesamum is of Magnoliapsida class and Scrophulariales order . It belongs to a small family Pedaliaceae which contains 60 species organized into 16 genera.

The leaf morphology of the Pedaliaceae family is opposite or alternate. Flowers are zygomorphic, calyx 5-cleft; corolla 5 lobed, 2 lipped; stamens 4, anthers connivent in pairs, 2 celled; ovary usually superior, 1-celled with 2 intrusive parietal placentas. Seeds are with a thin fleshy endosperm and the embryo is straight with flattened cotyledons.

Kobayashi (1982), classified sesame into twenty four types varying from the wild type to various differentiated types based on the divergence of their morphological and phenotypic characteristics. The classification is based on number of carpels per capsule, type of leaves, phyllotaxis (arrangement of leaves) and the presence or absence of nectaries.

Sesame is an annual herbaceous plant reaching a maximum height of 200 cm (2 meters) if conditions are favorable and less than 50 cm whenever environmental factors are not conducive for normal growth. Some genotypes indigenous to China are naturally dwarf. With few exceptions, tropical genotypes have broad and serrated leaves. The width and density of leaves change from broad to narrow and become sparse as they progress toward the apex suggesting why most of the densely foliated Ethiopian cultivars bear their pods in the upper 1/3 of the plant due to poor light interception below (Mazzani, 1964 and Moursi and Abdel Gawad, 1965).

There are three types of phyllotaxis arrangements in sesame. According to Kobayashi (1982) genotypes with the opposite leaf arrangement produce a greater number of pods per plant than those with the alternate leaf type. He based his assertion in the efficient light interception facilitated by this kind of leaf arrangement. All leaves have an upper and lower palisade layer.

The stem is erect, normally square, with longitudinal groves. Some circular type stems are present. The stem diameter ranges from 1 to 2 cm and sometimes 3 depending on variety and environmental conditions under which the crop grows.

The plant under optimum conditions produces an extensive much branched fibrous root system. While there is a well developed tap root it is not conspicuously elongated as in other crops. The relative root growth is governed to a great extent by the soil type and amount of soil moisture available. Roots develop more profusely in sandy than in clay soils. Furthermore, drier climate tends to restrict the growth of tap and fibrous roots simultaneously (Weiss, 1971).

The flowers are axillary and normally occur singly. In some cases 3 or more flowers per leaf axil are possible. The pod bearing flower is flanked on both sides by two cup shaped extra floral nectaries that may or may not develop into functional flowers. Sesame is a self- pollinated monocieous type plant.

2.1.4 <u>Genetics</u>

Detailed studies on the genetics of sesame have been carried out by a number of workers in India, Venezuela and the U.S.A. The chromosome number in the somatic cell first established as 2n=26 has been confirmed by Yermanos (1980). The chromosome number of 10 out of the 37 species listed in the Index Kewensis has been reported as <u>S.alatum</u>, <u>S.capense</u>, <u>S.malabaricum</u>, <u>S.schenkii</u> 2n = 26; <u>S.angustifolium</u> 2n = 32; <u>S.radiatum</u>, <u>S.anglonese</u>, <u>S.laciniatum</u>, <u>S.prostratum</u>, 2n =64. The chromosome length of <u>Sesamum indicum</u> ranges from 1.6_u to 3.0_u with most of the chromosome being close to 3.0_u (Mukerjee, 1958).

Attempts to recombine different species within the <u>Sesamum</u> genera into an economically desirable cultivated species have not always been successful. The main reason being that different species carry different chromosome numbers. But species with similar chromosomes numbers did not produce viable seeds either (<u>S.indicum</u> <u>x</u> <u>S.alatum</u>). When crosses between species having unequal numbers of chromosomes were attempted no seed was set at all or the seeds were not viable (Nayar and Mehar, 1970). The crosses of <u>S.indicum</u> x <u>S.laciniatum</u> and <u>S.indicum</u> x <u>S.prostratum</u> produced a few viable seeds, but the F_1 plants were almost without exception sterile (Ramanujam, 1942). Weiss (1971) reports that no viable seed was produced in Venezuela from mutual crosses between S.radiatum and S.indicum..

Two species can hybridize and produce viable hybrid progeny only, if barrier capacity (bc) of one species is fully matching with penetration capacity (pc) of the other. Incomplete matching may act as an isolating mechanism and is brought about by evolutionary divergence of populations. However, inspite of the similarity in shape and number of two species, as in the case of S.indicum and S.alatum, there are important but small molecular structural differences, that deprive gametes of some genic materials necessary for viability. Stebbins (1950) termed this situation as cryptic structural hybridity.

As in many other crops, the magnitude of heterosis in sesame was related to the degree of genetic divergence of the parents. Riccelli and Mazzani (1964) noticed that heterosis in sesame was more conspicuous in hybrids of cultivars from distant localities. Similarly, Murty (1975), in India reported that heterosis in Indian x exotic crosses was higher than in Indian x Indian and exotic x exotic crosses. Uzo and Ojiake (1981) also reported heterosis in crosses between temperate x tropical, shattering x non-shattering and branched x non-branched cultivars of diverse origin. It is pointed out, however, that geographic criterion need not to be the genetic base of diversity as some genotypes with the same geographical origin can have a different genetic background with widely divergent features (Trehan et al., 1974).

Varying degrees of heterosis in yield and its components have been observed by previous workers. Pal (1945), working with inter-varietial hybrids, indicated that a few of his hybrids expressed a conspicuous hybrid vigor for plant height, number of branches per plant, days to maturity, number of capsules per plant and seed yield per plant. Later, considerable heterosis for various characters in sesame was reported by several workers, Dixit (1976), and Dora and Kamala (1986). Furthermore, hybrid vigor was found to be less marked for oil content than for any other characters observed (Tyagi and Singh, 1981 and Chaudhari et al., 1984).

Genetic male sterility has been reported by two workers in the U.S.A. Brar (1982a), reported 3 genetically diverse single plants exhibiting male sterility and poor female fertility in the field, but good male and female fertility in the greenhouse. However, a stable male sterile trait under both greenhouse and field condition was reported by Osman and Yermanos (1982).

Yermanos et al. (1967) studying the genes controlling the fatty acid composition of safflower (Carthamus tinctorius L.) arrived at the conclusion that maternal effects were not involved in the inheritance of oil composition and that oil content is controlled by several genes without any apparent dominant gene action. Earlier findings by Knowles and Hill (1964) suggests that the chemical composition of safflower seed is determined by its genotype and not by the genotype of the maternal plant.

In sesame cytoplasmic inheritance of oleic and linoleic contents of oil does not appear to be important in reciprocal crosses and reciprocal backcrosses. Similarly, no maternal effect was discernible with regard to oleic and linoleic inheritance (Mosjidis and Yermanos, 1984). Heritability estimates, on 14 single plant selections, 1 from each of the 14 diverse introductions of sesame were 81% for oleic, 83% for linoleic, 81% for palmitic and 94% for iodine value (Brar, 1982b).

Culp (1959) studied the variation of oil and protein content in a cross of two varieties of sesame and concluded that there was no evidence of dominance in these two characters and that most of the variation was due to additive and environmental effects. The heritability estimates based on these varieties were 50 and 60% for oil and protein respectively. On the other hand Murty and Hashim (1973) found that both oil and protein content are governed by additive as well as dominant gene action. Heritabilities estimated as the portion of the additive and additive x additive components of variance were 23 and 30%.

Asthna and Pandey (1977) working with Indian mustard (*Brassica juncea*) on the genetics and inheritance of oil content reported that oil content was controlled by non additive gene action. However, Singh and Sinha (1967) and Swamy (1970) working with *Brassica campestris* reported both additive and non additive gene action controlling oil content. Their findings on the genetics of mustard oil content appear to be closer to those of sesame.

2.2 Genotype-Environment Interaction.

In the past, information based on Genotype-Environment interaction study has been somewhat helpful to breeders and agronomists in developing new improved cultivars for use by farmers. However, it has not been easy for scientists to understand fully the phenotypic expression of genotypes in relation to environment. The underlying reason for this is simply, no climatic variable is believed to exactly repeat itself every year. Under these circumstances, as one expects, selection of cultivars is less than efficient due to failures of genotypes to have the same relative performance in different environments (Knight, 1970).

Crop performance variation is mainly due to predictable and unpredictable factors or changeable and unchangeable production factors. The unpredictable or unchangeable environmental factors include the integrated influence of all non genetic variables affecting phenotypic expression of various genotypes. These types of environmental variables can be represented by important weather factors such as temperature and precipitation as well as edaphic conditions. Other predictable environmental factors that may have similar influence on crop performance but can be modified by human interference are management factors such as planting date, fertilizer rate and plant spacing (Allard and Bradshaw, 1964).

Oil and protein are the two most important constituents of sesame seed, and their synthesis and deposition in the seed occurs over a long period during seed filling. According to Khidir and Khattab (1972), Saha and Bhargava (1984) and Soler et al. (1988), protein deposition is a steady but gradual process from the time of fertilization to 30 days after. In the case of oil deposition very little (< 2%) is accumulated in the first one-third of seed development. The maximum accumulation (40 - 60%) occurs from 20 to 30 days after flower fertilization. At this crucial stage of seed development, environmental factors such as day length and temperature play a major role in the accumulation of lipids and protein (Canvin, 1965 Kluijver and Smilde, 1960). The levels of fatty acids are also closely but inversely related with temperature (Howell et al., 1957).

2.2.1 **Environmental Factors Affecting Sesame Performance**

There are numerous environmental factors that affect the growth and performance of sesame. There is also considerable evidence to show that environment affects oil quantity and quality (McNair, 1945). Among them temperature , photoperiod, soil fertility and soil moisture are particularly important.

2.2.2 **Temperature Effect**.

2.2.2.1 Seed Yield

Sesame is warm climate crop adapted to a tropical environment. A constant temperature of 24°C to 27°C is optimal for growth and development, however, continuous high day temperature of 33°C and low night temperature of 15°C retard growth (Smilde, 1960). The optimum photoperiod required for flower induction is 10 hours. Low temperature at flowering can result in sterile pollen, or premature flower fall. Conversely, periods of high temperature near 40°C at flowering will seriously affect fertilization and reduce the number of capsules produced (Weiss, 1983).

For successful crop performance and profitable seed yield, sesame requires a total of 2700°C heat accumulation unit during growth (Kostriasky, 1955). According to Ding (1983) the heat accumulation unit required for sesame production need not be above 2300°C. The heat unit is calculated by adding, during the days of the growing season, the daily mean temperature degrees above a certain established base temperature. The base temperature to be used is the temperature below which the specific crop does not make any appreciable growth. The base temperature for sesame is around 15° C.

In the southern U.S.A., sesame planted after July 15 usually performs poorly because of cool temperature coinciding with the reproductive stage of the plant (Langham, 1985). Seegeler (1983) observed differences in cultivar performance due to temperature differences in that increasing altitude (lower temperature) always lowered seed and oil yield.

Yield per se is the function of the yield components or traits inherent in the crop species and the environment under which it grows (Eriskine et al., 1977). In sesame, seed yield is a complex character contributed by a number of morphological traits and yield components such as seed per capsule, plant height, number of branches, pods per plant, root depth and seed weight (Weiss, 1983).

Research in India, showed different response of some yield characters grown under different environmental conditions, namely rainfed, irrigated, cool and warm climate. Kandaswamy (1985) studying the response of yield components to the environment found that plant height, number of seeds per capsule and length of capsule were negatively affected by very low moisture and cool temperature conditions. On the other hand, he reported little effect of environment on number of branches and pods per plant. A similar study by Godwat and Gupta (1986) showed a non significant effect of environment on branches per plant, number of capsule per plant, capsule length and number of seeds per capsule.

Thus, information based on the extent of genetic variation for yield attributes expressed under different environment is of considerable importance when selecting for high yielding and stable genotypes.

2.2.2.2 Oil Quantity

The effects of environment on the quantity of oil produced by sesame was reported by Tribe (1967). He observed a continual decrease of the oil content of sesame seeds the further the crop was grown eastward from the Mediterranean and middle east region to Japan. Similar observation was made by workers in Korea (Lee et al. 1980).

Earlier in this century, Ivanov (1926) working with 12 flaxseed genotypes at 20 sites in the U.S.S.R, however, suggested that the influence of geographical factors on oil content is not large. In another study, Yermanos et.al. (1972) were unable to establish any geographical pattern in the distribution of seed oil content and composition of some 721 sesame introductions examined in California, U.S.A.

Sesame produced under cooler environment in Ethiopia may yield lower oil content than those raised in warmer climate (Seegeler 1983). Similarly, soybean grown under cold climate tend to yield less oil content per seed (Howell and Cartter, 1953 and Whigham and Minor , 1978).

In contrast, low temperatures influenced the synthesis of high oil content and also high unsaturated fatty acids in flaxseed (Sosulski and Gore, 1964; Dybing and Zimmerman, 1965). Likewise, safflower grown in cooler regions of California, produced seed with about 2% higher oil content and 5 units higher iodine value than that produced under warmer and drier conditions (Yermanos et al., 1967).

2.2.2.3 Oil Quality

Evidence of temperature effect on the chemical constituents of soybean (Glycine max), peanut (Arachids hypogea) and safflower were reported by numerous workers (Howell and Collins, 1957, Worthington et al., 1972 , Dhwan *et al.*, 1981). Generally speaking, oil plant species capable of thriving at different agro climatic zones of the world, produce more unsaturated fatty acids in their seeds when grown in colder climate (Hilditch and Williams, 1964 and Hazel and Prossor, 1974).

Several theories have been advanced to explain this phenomenon. Harris and James (1969) proposed that increased desaturase activity is the result of increased solubility of oxygen at low temperature. Low temperature may cause the induction of desaturase enzymes and this mechanism has been demonstrated in some microorganisms (Fuji and Fulco, 1977). It was also suggested that differential temperature may bring about changes in the fluidity of the membranes, which results in altering the activity of the desaturase enzymes responsible for the conversion of fatty acids from one stage to the other (Kates *et al.*, 1984). Others (Browse *et al.*,1983) found evidence which suggests that the apparent increased lipid desaturation at lower temperature in developing safflower cotyledons is actually the consequence of greater increases in fatty acid synthesis than oleate desaturation at higher temperatures which therefore decreases the ratio of polyunsaturated to monosaturated fatty acids at higher temperatures.

There is a conflicting report on the rate at which temperature fluctuation brings about the shift of balance within the fatty acid composition. William *et al.* (1988) working with *Brassica napus* leaves concluded that plants are preconditioned by the temperature of growth and do not respond to sudden changes in environmental temperatures. However, Harwood (1989) argued that one type of lipid pattern (saturated vs unsaturated) can be altered by sudden exposure of plants to temperature outside their normal range.

It has been demonstrated by many research workers that the majority of oil crops behave similarly to temperature regimes in so far as fatty acid synthesis is concerned. Thompson et al. (1973) reported a sharp increase of unsaturation of corn seed oil with decreased temperature during seed maturation. However, different genotypes showed different response to the same temperature regime. Likewise, elevated temperatures caused marked reduction in the percentage of unsaturated fatty acid and in particular the percentage of linoleic acid (Harris et al., 1978). Similar trends were observed with safflower (Knowles, 1972).

In line with the previous findings on the majority of oil crops studied, sesame seeds produced in the cooler north central region of Korea gave higher content of linoleic acid than those grown in the southern part of the country (Lee et al., 1981). Kinman and Earle (1964) had a similar observation when working with sunflower introductions from the U.S.S.R and North American hybrids planted across diverse locations and seasons in the U.S.A. In sunflower, temperatures higher than 16^{o}C during seed development resulted in lower linoleic percent (Harris et al., 1978).

Although some generalization can be made regarding temperature effects on the synthesis of oil in oil seed crops, it is equally important to recognize the genetic difference that exist among crop species and varieties. Canvin (1965) investigating the chemical constituents of rapeseed, sunflower, safflower, flax and castorbean in relation to temperature found that the fatty acid composition of castor seed oil was not affected over a range of 10^{o}C. This species would appear to be largely unaffected by changes in temperature.

Contrary to the earlier findings on chemical composition of oilseeds that seem to suggest that lower temperature activates the desaturase enzymes which are responsible for the conversion of higher saturated fatty acids to unsaturated fatty acids, Brar (1980) in California, found that with increasing temperature , the unsaturated component of the fatty acids in sesame also increased to some extent. However, the increase of the unsaturated fatty acids with increasing temperature occur only in those genotypes identified to be of high linoleate background.

2.2.2.4 Protein Content

Temperature does not appear to be strongly associated with protein content. Whigham and Minor (1978) noted that in soybean temperature has little effect on the amount of protein synthesized in the seed. Similarly, in India nine groundnut genotypes tested at different locations having variable mean temperatures showed no marked difference in their protein content (Dahwan *et al.*, 1981). However, temperature may have an effect on the quality of protein produced. In a greenhouse experiment Krober (1956) found that soybean genotypes grown under a 32^{o}C temperature regime produced seed with a higher methionine value 1.4% higher than those raised at 21^{o}C.

2.2.3 **Moisture Effect.**

2.2.3.1 Seed Yield

The effect of moisture on the performance of sesame has been dealt with by many workers. Osman and Nour (1985) reported that sesame grown under different rainfall patterns showed different response. However, this should not negate the fact that sesame is one of the crops known to respond to water deficit more efficiently than to excessive moisture. This is mainly due to the physiological characteristics special to the species to respond to water deficit by partial stomatal closure (Hall and Kaufmann, and Hall and Yermanos, 1975 a & b).

Generally, excessive rainfall or unlimited irrigation water, limits sesame production (Rheenen 1979). The adverse effect of excessive moisture is reflected in lack of aeration for the plant caused by water logging condition, flower reduction and disease promotion. In the Sudan a yield reduction of 32 - 37% was reported as a result of deliberate flooding prior to seeding and with no surface drainage confounded with premature irrigation practices after seeding. In comparison, seed yield increased by 43% with low rainfall supplemented with only one irrigation at flowering stage (Hack, 1980).

The effect of moisture on plant growth is also reflected by way of nutrient uptake. Under water stress conditions the effective use of nutrients especially nitrogen is reduced by 50% (Hooda and Kalra, 1981).

2.2.3.2 Oil and Protein Quantity

Shaw and Liang (1966) found that maximum protein content in soybean occurred when plants were under water stress late in the pod filling stage i.e. when seeds are not yet fully developed. The same study also showed the positive relationship that exists between early stress and oil content. Stone and Tucker (1969) had arrived to similar conclusions with soybean. But severe moisture stress during pod filling stage adversely affect both the oil and protein content of soybean. However, the degree to which these economically important characteristics of soybean are affected by water stress depends on the type of genotypes evaluated, namely, early or late flowering (Rose, 1988). Huck and Davis (1975) reported that water stress had no apparent effect on percent oil or protein in soybean seeds. Sionit and Kramer (1977) also, claimed that moisture stress applied at various growth stages of sesame crop did not appreciably affect oil or protein content.

In flaxseed, oil percentage and iodine value (unsaturated fatty acids) were seriously reduced with low rainfall and high temperature combined together (Dillman, 1943).

2.2.4 **Soil Effect.**

2.2.4.1 Seed Yield

Soil variation does not seem to affect the performance of sesame seriously (Weiss, 1971). The crop is adapted to many soil types, but it thrives best on well drained, moderately fertile soils of medium texture and neutral reaction pH. However, shallow soil with an impervious sub-soil or those which are saline, are not suitable. The crop is extremely sensitive to salinity and salt concentration (Yousif et.al., 1972). Salinity was reported to decrease yield of sesame especially when the phenomenon occurs in the later stage of the growth cycle (Cerda et al, 1977).

There are conflicting reports in the literature, regarding the nutrient requirements of sesame. Mitchel et al. (1974) reported substantial increase in most of the yield components due to fertilization with nitrogen, phosphorus and potassium. Similar results were reported by Chakraborty et al. (1984) and Taylor (1986). A few workers also reported marginal increase of seed yield as the result of nitrogen and phosphorus application (Arunachalam and Venkatesan, 1984 and Metwally et. al., 1984).

On the other hand the depressing effect of fertilization, especially nitrogen was also reported by Bonsu (1977) and Aranchlan (1981). One possible reason for the negative association of nitrogen with yield is mentioned to be the shading effect as well as massive vegetative growth at the expense of the economically important part of the plant promoted by high dosage of nitrogen.

The translocation of nitrogen, phosphorus and potassium from the leaves, stems and roots of the plant to the seed bearing pods during the active vegetative stage did not substantially increase seed yield (Balkrishna and Narayanan, 1983). An examination of pod dry matter percentage reveals that the seed dry matter portion constitutes 30% of the total while the remaining 70% is made up of the economically unimportant seed bearing pod walls (Saha and Bhargava 1980). This, may explain partly the marginal response of sesame to fertilization.

2.2.4.2 Oil quantity

The effect of soil per se on the production of oil seeds and in turn on oil quantity in the seed is better understood in the way soils facilitate the availability of nutrients and moisture to the growing plant. McNair (1945) described the effect of soil types on oil formation to be dependent on seasonal conditions. He observed that in some seasons clay soil produced a higher percentage of oil than loam and vice versa. However, climate and mineral nutrients are more important factors than soil taken by itself in modifying oil quality and quantity in the seed.

In general, the oil content of crops was adversely affected by nitrogen (Loof, 1960, Bunting 1969, Wankhede et al., 1970 and Sawan et al., 1988). Kinman and Stark (1954) made an observation to the effect that sesame genotypes grown in one area of Texas where the fertility status of the soil was poor gave a higher oil percentage than those grown in nine other states where the nitrogen level was from medium to high. In India, heavy nitrogen application (up to 120 kg/ha) was observed to reduce sesame seed oil content from 41.07 to 36.14% (Chakraborty et.al., 1984). Mitchel et.al. (1976) also reported that sesame seed oil content was significantly depressed by increasing nitrogen but remained relatively unaffected by phosphorus and potassium.

Like sesame, the oil content of rapeseed was relatively unaffected by nitrogen and phosphate fertilizer (Appelqvist, 1968 and Cooke, 1967). Earlier Bahatty (1964) confirmed the negative effect of nitrogen fertilization on oil content of 3 oil bearing species. With the application of 40 kg and above nitrogen per hectare to rapeseed and safflower, the oil content of the seed was reduced from 40.3% to 39.7% (Rafey et al., 1988) and 28.4% to 24.7% (Kalole and Meena, 1988) respectively. Nitrogen fertilization at the rate of 0, 30, or 60 kg per Feddan (0.4 ha) showed no visible effect on safflower seed oil content (El-Ahmer, 1987).

In rare cases the application of nitrogen to sesame appears to increase oil content (Taylor, 1986). It is however speculated that the confounding effect of other environmental variables might have played a role in raising the oil percent in the seed as the nitrogen rate increased.

2.2.4.3 Oil Quality

The ratio of the saturated to unsaturated fatty acid groups as well as the amount of individual fatty acids within the two groups of lipids are also affected by nutrients in the soil. Thus, in rapeseed while nitrogen reduced the percentage of oleic acid it increased linoleic and linolenic. In contrast with the increase of phosphate fertilizer oleic acid content was increased and linolenic decreased while the effect on linoleic was variable (Appelqvist, 1968).

Information on how elements individually or in conjunction with each other alter the proportion of fatty acids in plant tissue or seeds is scarce. Meyer and Bloch (1963) have described a system which clearly showed that in the presence of phosphorus bearing molecules, NADPH and oxygen as a catalytic agent, the conversion of Oleyl-CoA to linoleic acid proceeds steadily. Although not clearly understood nitrogen and phosphorus as well as other elements play a significant role in the bio-synthesis and proportion of fatty acids in plant tissue. The nutrient effect on fatty acid proportion is also assumed to be a partially indirect one, that is, through changes in the proportion of subcellular organelles with different but rather constant lipid pattern (Newman, 1966). Fowler and Downey (1970) made a similar observation working with Brassica napus, where disproportionate changes in the testa, nucleate endosperm and embryo during seed development can bring about a variation in fatty acid composition.

Despite the depressing effect of salt on sesame seed yield, there is evidence to suggest that the oil chemical constituents and content were relatively unaffected by excessive presence of salt in the soil (Yousif et al., 1972). In safflower the effect of salt on fatty acid composition is negligible (Yermanos et al., 1964). However, the total oil percent produced in the seed decreases proportionally with increasing salinity without affecting fatty acid composition (Irving et al., 1988).

2.2.4.4 Protein Content

Nitrogen increased crude protein (N x 6.25) concentration of sesame seed from 21.5 to 25.0% (Weiss 1983). The effect of phosphorus and potassium was not noticeable on protein (Mitchel et al., 1976). Bahatty (1964) working with flax and rape seed, Singh et al. (1987) with sesame, and Sharma and Guar (1988) with sunflower, reached similar conclusions in that nitrogen had a significant influence on protein content.

2.3 **Methods of Measuring Genotype-Environment Interaction**

There are several methods used to estimate the relative adaptability of genotype performance across environments. Some of these methods were briefly reviewed by Westcot (1986). Basically there are two approaches used for the estimation of genotype - environment interaction.

According to Lin et. al. (1986) the parametric approach bases its model on deviation from the average genotype effects ($X_{ij} - \bar{X}_{i.}$) or on genotype-environment interaction ($X_{ij} - \bar{X}_{i.} - \bar{X}_{.j} + \bar{X}_{..}$). Some genotype adaptability statistics do not rely on linear regression to estimate genotype-environment interaction effect. Instead, the sum of squares is used as a measure of estimation. Plaisted and Peterson's (1959) pairwise variance estimate, Wricke's (1962) ecovalence stability parameter and Shukla's (1972) stability variance are a few examples. The coefficient of determination R^2 (Pinthus 1973) and R_1 and R_2 production indices of Langer et al. (1979) are also classified as non regression parametric stability measures.

The parametric approaches of linear regression are the Finlay and Wilkinson (1963) and the Eberhart and Russell (1966) deviation from regression stability parameter. The other statistic worth mentioning is the procedural approach of superiority measure developed by Lin et al. 1988.

The adaptability parameters so far mentioned are parametric, having quantitative mathematical characteristics. Thus, three basic concepts of adaptability can be derived from them (Lin et. al., 1986). A genotype can be considered generally adaptable if:

1) its among-environment variance is small.
2) its response to environment is parallel to the mean response of all genotypes in the trial.
3) the residual mean square (EMS) from the regression model in the environmental index is small.

While almost all the non regression adaptability parameters fall under type 1, the Finlay and Wilkinson and, Eberhart and Russell adaptability statistics correspond to type 2 and type 3 respectively. The procedural approach of superiority measure falls under type 2 category.

An alternative approach to the parametric method of estimating relative adaptability is the non parametric approach of clustering genotypes or locations according to their similarity (or dissimilarity) of response to a range of environments. Several methods for clustering genotypes (or environments) based on similarity of response characteristics are available. The Euclidean distance based on genotype by environment interaction of Aboul Fittouh et al. (1969) and genotype effect, and genotype - environment interaction of Mungomery et al. (1974) fall under this category. Furthermore the dissimilarity index of Lin and Thompson (1975) and Lin (1982) are considered as basically qualitative more than quantitative and fall under the clustering category.

The parametric approaches of linear regression first developed by Yates and Cochran (1938) and greatly modified by Finlay and Wilkinson (1963), and further extended by Eberhart and Russell (1966) to include the scatter points along the regression line as a measure of genotype adaptability are by far the most widely used estimation parameters. The first parameter attempts to explain the genotype by environment interaction by comparing the difference between the slopes of the genotypes' linear response and the second by measuring the deviation of residual mean squares (MS) from regression. The procedural approach method is based first on screening out the genotypes with low mean squares (closer to the maximum response values). Thereafter, a pairwise genotype-environment mean square between the the maximum and those with low superiority measure values are calculated to determine if the differences from the maximum response are about the same for all locations.

To examine genotype performance across sites, Finlay and Wilkinson used the mean yield of the trial at each site in each season as a measure of the environment in which the trial has been conducted. This measuring unit is generally known as Environmental Index. Ideally an index, independent of the experimental genotypes and obtained from environmental factors such as rainfall, temperature, photoperiod and soil fertility would have been desirable. However, this has not been possible because of the complexities involved in accounting for all environmental variable encountered in the field.

Finlay and Wilkinson regressed the yield of each genotype against the environmental index and were able to draw the attention of the adaptation features embodied in the regression line. They then concluded that genotypes with a slope near 1.0 and high mean yield are generally adaptable. A genotype with slope > 1, they suggested was below average and adaptable to favorable environments only. While a genotype with < 1 and high mean yield has an above average adaptability and is suited to unfavorable environment.

The regression equation modified by Finlay and Wilkinson is as follows:-

$$b = \sum_{j=1}^{q} (X_{ij} - \bar{X}_{i.})(\bar{X}_{.j} - \bar{X}_{..}) / \sum_{j=1}^{q} (\bar{X}_{.j} - \bar{X}_{..})^2$$

Where

X_{ij} is the mean of the i^{th} genotype ($i = 1,2, \ldots p$) in the j^{th} environment ($j = 1,2,\ldots,q$),

$\bar{X}_{i.}$ is the mean of the i^{th} genotype,

$\bar{X}_{.j}$ is the mean of the j^{th} environment, and

$\bar{X}_{..}$ is the overall mean

Eberhart and Russell (1966) added a new adaptability (stability) parameter called deviation from regression in the model to describe measurements of unpredictable irregularities in the response to envircnment. According to them, a stable genotype is characterized by a regression coefficient which is not different from unity (b=1) and deviation from regression close to zero. In other words, a genotype that differs from the majority of genotypes under consideration, either below or above their optimum will show marked deviation around its regression line. This has been termed as stability.

The stability model that Eberhart and Russell (1966) used to detect genetic differences in maize breeding lines in a given set of environmental conditions is as follows :

$$Y_{ij} = U_i + B_i I_j + S_{ij}$$

Where Y_{ij} = the mean of the i^{th} genotype and the the j^{th} environment

U_i = mean of the i^{th} genotype overall environment

B_i = regression coefficient of i^{th} genotype

I_j = the environment index of the j^{th} environment

S_{ij} = deviation from regression

Testing the significant proportion of the variation of genotypes over environments is accounted for by fitting a regression line. Since the genotype-environment interaction sum of squares is a linear function of the environmental values this portion is partitioned into an item measuring differences between the slopes of each regression (heterogeneity b) and a residual item. However, in order to arrive at a point that the regression mean square (linear) accounts for a significant larger proportion of the total variation, it should be compared with the residual mean square (Perkins and Jinks, 1968). The degree of genotype stability or general adaptability can therefore be accounted for by measuring the heterogeneity of the regression lines more than by the deviation of regression as strongly argued by Breese (1969).

Unpredictable irregularities may be evident in the genotypic response to environment. This irregularities described to be as deviation from regression, however, is not independent of the slope and cannot explain the phenomenon independent of the slope (Hardwick and Wood, 1972). Thus, a genotype can have marked deviation from linear regression, not because it was inherently irregular, but because it showed different response pattern from the majority of groups with which it was being compared (Westcott, 1986). Lin *et al.* (1986), doubted the usefulness of the deviation from regression advocated by Breese (1968) as an additional parameter of stability because of its descriptive nature based on the data being analyzed and not a predictive model which includes into the model pre-measured environmental variables. The inconsistency of Eberhart and Russell model when dealing with different numbers of genotypes and environments was reported by Witcombe and Whittington (1971).

The use of regression coefficient 'b' as an adaptability parameter was useful, because it measures genotypes' yield as a linear response to environment not as a specific property of a genotype (Knight, 1970 and Freeman and Perkins, 1971). The interpretation of data using the 'b' value from the response curve is, therefore, more appropriate as being indicative of yield response to environmental variations.

The procedural approach measure of adaptability proposed by Lin and Binns (1988) relies on fixed standards as a reference point to identify genotypes of general superiority and adaptability as well as those with specific adaptability. The standard is the maximum response of each genotype at each location and the superiority of a genotype is then measured against the maximum response across all locations.

The equation used is as follows:

$$Pi = [n(\bar{X}_{i.} - \bar{M})^2 + \sum_{j=1}^{n} (X_{ij} - \bar{X}_{i.} - M_j + \bar{M})^2]/(2n)$$

Where X_{ij} = yield of the i^{th} genotype in the j^{th} location

M_j = maximum response among all cultivars in the j^{th} location

$\bar{X}_{i.}$ = mean of genotype i across locations

$\bar{M}$ = mean of maximum response

n = number of environments

The first term of the equation is the sum of squares for genotype effect while the second term represents genotype environment effect when two cultivars are compared.

Although genotype selection was based on Pi values which are the measure of superiority, this parameter alone cannot safeguard the unintentional rejection of genotypes poor in general adaptability but otherwise good in specific adaptability. To avoid this, a pairwise comparison of genotype-environment mean squares between each test genotype and the maximum response (the maximum response among all genotypes in the j^{th} location) was calculated. Also the genotype-environment mean square [MS(GE)] of each test genotypes was computed and the boundaries or 'cut off' points for genotype-environment determined. In all cases, an empirical 'cut off' point using the F value multiplied by the pooled mean square divided by the number of observations is used as the stopping criterion. The main reason for using the test statistics from the ANOVA is that the distiributional properties of the two parameters, that is, the Pi and [MS(GE)] are not known.

Within the cluster approach of qualitative classification, the similarity (or dissimilarity) of genotype response used by Lin and Thompson (1975) combines the concept of a common regression line and the technique of cluster analysis. The objective is to group the genotypes with similar intercepts and regression coefficients by a clustering method. The smaller the dissimilarity index computed the closer the relationship. Large values indicate increasingly dissimilar ones. This method of analysis provides a broad picture of genotype response to environment but is less specific.

The dissimilarity or similarity index computed by the cluster method can only provide an overall picture on the similarity of genotypes based on their response to environment. It is therefore important to realize that the cluster analysis proposed by Lin and Thompson (1975) should not be taken as a tool for identifying the response of genotypes to the environment in a narrow sense. Rather, it should be used as an adjunct to other methods of evaluating genotypes' response to the environment (Ghaderi et al., 1980).

The procedural method of statistics has one notable advantage, in that, by using the maximum response as a standard, it provides a broader and more stable inferential base for comparison. In addition, the difference between the maximum response and the highest yielding genotypes can provide an important clue for formulating a strategy of genotype recommendation.

The linear regression model measures the response of genotypes to the environment. The response is assumed to be a linear function of the environment. In this regard, stability is understood to be a relative measure depending on the set of genotypes included in the test. Therefore, proper inference on the results obtained is possible.

It is felt that by combining the linear regression method of Finlay and Wilkinsons' (1963) model of adaptability and the procedural approach of superiority measure of Lin and Binns (1988) as well as the dissimilarity index of Lin and Thompson (1975), proper decision with regard to genotype selection can be made.

3. MATERIAL AND METHODS

In the summer of 1987 and 1988, experiments were carried out at three sites in Ethiopia. The sites were chosen to provide differences in seasonal rainfall and temperatures. One of the sites had facilities for irrigation. Appendix 1 Table a, shows a summary of the climatic data of the three sites for the 1987 and 1988 seasons. The difference in planting dates between the two years ranged between 7 and 14 days. Table 1 shows a brief description of the three sites.

Table 1.

Description of the tnree sites in Ethiopia where sesame performance was evaluated

Site number	1	2	3
Site Name	Bisidimo	Abobo	Melka Werer
Geographical Position	42^{o} 10′ E 9^{o} 11′ N	34^{o} 41′ E 8o 19′ N	40^{o} 9′ E 9^{o} 15′ N
Soil Type	Sandy Loam	Clay Loam	Alluvial
Sowing Date	7.vii.'87 12.vii.'88	6.vi.'87 17.vi.'88	6.vi.'87 22.vi.'88
Altitude^{x} (m.a.s.l.)	1450	500	750

x meter above sea level

A randomized complete block design with three replications was used at each location. The plot size was 4 x 2.4 m and the inter and intra row spacing was 0.4 and 0.1 m respectively. Such spacing is believed to give a theoretical population of 250,000 plants per hectare. Plots were hand planted with more than one seed being placed per hill to ensure proper stand. Thinning was done 25 days after emergence or when seedlings attained 10-15 cm in height. Weeding and other field operations such as earth banding and surface drainage were performed by hand while basic land preparation was done by tractor power. The center 4 rows were harvested by hand to determine seed yield.

All plot areas were essentially free of economic pests but bacterial blight disease infestation was severe at Abobo in both years. In order to simulate standard farm practices no measure, either chemical or otherwise, was taken to control the disease.

This experiments were designed to study the effect of environment on seed yield and chemical constituents of eight genotypes of diverse origin.

3.1 **Line Origin**

Initially 25 experimental lines were used in the study. However, due to heavy bacterial blight (*Xanthomonas sesami*) infection, 17 lines were excluded and the study was concentrated on the relatively tolerant lines alone.

Six of the eight lines included in the study (Harrar, Fincha, 207958, 7B, 111518 and 111519) are landraces collected from the high and low rainfall regions of the country. All the indigenous lines are characterized by late maturity, profuse branching and little pod setting in the main branches on approximately 1/3 of the plant height. The lines 111518 and 111519 are relatively early maturing and believed to be more tolerant to diseases. The lines were developed by single progeny selection method from a bulk of populations collected from farmers' lots across the sesame growing regions of the country. Selection for lines with best agronomic characters continued for four generation before being included in preliminary yield trials in the 1982/83 cropping season. During the process of the preliminary testing, those single plants selected from Harar, 111518 and 111519 gave seed yield ranging from 1833 kg to 1917 kg per hectare (Anno 1986).

The line 76/48R is an introduction from Venezuela. It is relatively short and bears more pod in its main branches. The other one, namely 5E is an introduction from East Africa and reported to be tolerant to bacterial blight disease. Like the indigenous, it is bushy with wider leaves and relatively better pod bearing type.

3.2 Data Collection and Sampling

Soil samples were obtained by augering samples at 15, 30 and 45 centimeter depth,to determine the physical and chemical properties of the soil. The samples were sun dried and ground before sample analysis was done. Disease score was taken two times, once at the flowering stage and then at maturity. Data for part of the agronomic study, number of pods per plant and number of seeds per pod, were based on five randomly selected plants. The following variables were measured:

3.2.1 Flowering: The date of flowering was recorded when 50% of the plants in the plot were believed to be at full bloom.

3.2.2 Plant height: Measurement of the distance from the base to the stem tip was taken a short while before maturity.

3.2.3 Number of branches per plant: The number of branches per plant was taken after pod setting.

3.2.4 Number of pods per plant: Because of the indeterminate habit of flowering , it is common to find in sesame well formed pods starting from the bottom. Only well formed pods that contribute or were likely to contribute to the total seed and oil yield were counted.

3.2.5 Number of seeds per pod: Pods were sun dried and the seeds were counted by a seed counter equipment.

3.2.6 Lodging: This measurement was based on visual observation. Plots that had all the plants standing were assigned a figure (100%), while those on the ground or tilting 45^{o} or more were given 0.

3.2.7 Root depth: Sesame has a deep tap root with most of the secondary root system distributed 5 to 10 centimeter from the soil surface. Plant samples for root measurements were taken by wetting the soil to approximately one meter depth to facilitate plant uprooting. The uprooted plants were then immersed in a half barrel full of water to remove soil and the length of cleaned tap roots were measured.

3.2.8 Disease: Disease score was measured on a 0-9 point scale at plant development stage and pod formation. Plots with healthy plants with no symptoms of bacterial blight disease were designated 0 value in the point scale while the heavily damaged plots were given 9 points.

3.2.9 Maturity: In sesame the crop is believed to be physiologically mature when two thirds of the leaves turn yellow and the first formed basal pods start shattering. Thus, this sign was taken to record the dates of maturity.

3.2.10 Seed yield: The center four rows were harvested for seed yield. Except for the two guard rows on both sides (lengthwise) of the plot, entire plants in the plot were cut by sickle, stalked, and dried for 1-2 weeks before being thrashed on polyethylene or cotton cloth sheets.

3.2.11 Thousand seed weight: Composite seed samples were obtained from each plot, counted by seed counter equipment and weighed.

3.2.12 Harvest Index: Plant samples were cut a few centimeters above the ground. The biological mass excluding the seed pods were placed in paper bags and sun dried (except at Melka Werer). After one week, seeds were carefully sieved and weighed separately while the remaining pod and other biological mass were mixed together and weighed separately. Harvest index was determined in the second year of the experiment at all sites.

The Harvest index formula: $\frac{\text{Economic yield}}{\text{Biological yield}} \times 100$

3.3 Method of Agronomic Data and Seed chemical analysis

3.3.1 Agronomic data analysis

A separate analysis of variance was performed with data from each site-year combination. Hereafter, site-year combinations will be referred to as environments. Furthermore, combined analysis of variance was carried out with environments, experimental line and replicates as fixed effects.

Regression analysis proposed by Finlay and Wilkinson (1963) was used to establish linear response of lines to the environments with respect to seed yield, yield components and chemical composition. In this analysis 'b' measures the linear response of lines to environmental effects. A joint regression analysis was also carried out to determine the heterogeneity of slopes.

In the joint regression analysis, the sum of squares due to line-environment interaction was partitioned into line-environment (linear) and deviation from linear regression. Significance of the line-environment interaction (linear) mean squares was tested against the corresponding deviation mean square. The significance of deviation from regression was tested using the pooled error mean square from the combined analysis of variance as denominator in the F-ratio. In all cases the pooled mean squares were divided by the number of replications,since the adaptability analysis was based on means of the number of observations.

The data were also analyzed by the procedural approach of superiority measure modified by Lin and Binns (1988). In the parametric analysis of procedural approach of superiority measure , selection of genotypes for general adaptability was based on Pi values. Pi is a measure of distance mean squares of a test genotype and the maximum response in a given environment.

Lines were also clustered into groups for seed yield and oil content according to their similarity of response (dissimilarity index) first suggested by Lin and Thompson (1975).

Simple correlation coefficient for each year in all possible combinations of pairs of characters or variables were determined. However, since a change in one character is often accompanied by changes in several others, conclusive practical applications can not be drawn solely from simple correlation and regression coefficients. Thus, partial correlation coefficient were computed for pairs adjusted for variables.

3.3.2 Seed chemical analysis

The total oil content in the seed was determined using the nuclear magnetic resonance (NMR) method. Protein and fatty acid composition were determined using the standard Kjeldhal method and gas liquid chromatography (GLC) respectively.

3.3.2.1 Oil Content: The oil content of the seed was determined by the non destructive method using nuclear magnetic resonance (NMR). The NMR technique quantifies total hydrogen associated with oil in seeds independent of the hydrogen associated with non oil matrix (Conway 1963). A glass test tube holding a whole sesame seed sample of exactly 2.5 g was placed in the magnetic unit of the instrument, Newport Analyzer Mark III. A steady field value of 635 x 10^{-4}T and a radio frequency of 2.7 MHz was used for all analyses. The integration period was at 8.0_s and a radio frequency (RF) value 30.0^o u^a. The instrument was installed in a room where the temperature was maintained at 25°C. As a result of resonance created in the magnetic housing a derivative curve i.e. mobile hydrogen signals associated with the fat only are picked up by the integrator. The curve produced is proportional to the total energy absorbed by the seed and therefore, to the amount of mobile hydrogen or oil.

3.3.2.2 Fatty acid composition: The major fatty acids that constitute sesame oil are palmitic, stearic, oleic and linoleic. The most reliable methods to recover the lipid constituents of oil seeds are based on the cold extraction method of Bligh and Dyer (1965).

A sample of 250 mg of hand cleaned sesame seed was thoroughly homogenized in a chilled mortar and pestle in a homogenization medium consisting of chloroform/methanol/acetic acid (1:2:0.1 v/v). The homogeneities and later the pellets were centrifuged at 500g for three minutes in an IEC desk top centrifuge to remove insoluble debris. To insure complete extraction of lipid from the seed samples, more extraction solvent was added to the sample and centrifuged. The supernatant was siphoned by pipette and mixed with boron trifloride (BF3) in methanol and benzine for esterification. The sample was dried under nitrogen, on aliquot dispensed, then again dried under nitrogen then transesterified (Morrison and Smith 1964).

The sample was analyzed by GLC using a Varian model 3400 gas chromatography equipped with a flame ionization detector 1.8 m x 4 mm glass column packed with 10% CSP-509 on chromosorb W operated isothermally at 185^{o}C. The injector and detector temperatures were 275^{o}C and 300^{o}C respectively. Helium was used as a carrier gas with a flow rate of 50 ml/min with 0.5 uL of sample injected. Fatty acids were identified by comparison of their retention times with that of a known standard.

The samples were prepared in triplicate for each of the 48 samples.

3.3.2.3 Protein analysis: Crude protein concentration was determined with a Tecator Kjeltec designed to quantify the amount of nitrogen in ammonium form.

Sesame seed (250 mg) which had been hand cleaned and oven dried at 70°C for 24 hr. was ground using mortar and pestle before being placed in a digestion flask containing sulfuric acid, selenium and potassium sulfate. The digestion time required for the sample tissue to disintegrate and release ammonium was between one hour and one hour and half. Preliminary tests done on digestion time gave no significant differences between the two digestion times.

The sample was analyzed according to the modified kjeldhal boric acid method of the the American Approved Committee of Cereal chemists (1976). The sample, after being cooled and diluted with 75 ml of de-ionized water was steamed and distilled in a flask containing sodium hydroxide. The ammonium was collected in 1% boric acid and then titrated against 0.1 N hydrochloric acid. Percent crude protein was calculated using a conversion factor of 6.25 (Panford et al., 1988).

4.0 Results and Discussion

4.1 Agronomic Characters.

4.1.1 Seed Yield

Adaptability of lines for seed yield was evaluated for 6 environments (i.e combinations of two years and three sites) which represented a wide range of growing conditions. Environment mean yield ranged from 969 to 128 g 6.4 m^{-2} (Table 2). Mean seed yield over environment for the eight lines ranged from 270 to 493 g 6.4 m^{-2}. The highest yielding line was 7B, a selection from Northern Ethiopia, followed by 111519 a selection from the Blue Nile Gorge. The line Harar gave the lowest yield of 270 g 6.4 m^{-2} (Table 2).

Pooled analysis of variance showed significant effects for sites and years ($p < 0.001$). (Appendix 2 Table a). This result indicates that there were variations in the environmental conditions throughout the experimention period. There was also differences among the experimental lines ($p=0.005$). The differences among the lines were possibly influenced by environmental variations associated with rainfall, temperature and soil conditions. As shown in Appendix 1, Table a and b, precipitation and temperatures for the six environments differed markedly especially during the active plant development stage of June and July. Appendix 1 Table c also shows the extent of difference in soil conditions.

Line-site, and line-year-site interaction mean squares were also significant ($p < 0.001$ and $p = 0.002$, respectively). The significant first order interaction indicated that there were changes in the relative rankings or magnitudes of differences among lines over sites. The second

Table 2

Mean seed yield (g 6.4 m^{-2}) of eight sesame lines grown at three sites in Ethiopia over two year

Lines	1987 Bisidimo	1987 Abobo	1987 Melka W.	1988 Bisidimo	1988 Abobo	1988 Melka W.	Line means
7B	358 a	151 a	1493 a	105 a	195 a	654 ab	493
Harar	293 a	31 a	568 d	185 a	67 a	476 b	270
111518	275 a	107 a	1372 a	108 a	154 a	577 b	432
Fincha	468 a	269 a	892 bc	396 a	138 a	387 c	425
76/48R	383 a	211 a	884 bc	112 a	253 a	665 ab	418
5E	385 a	250 a	673 c	193 a	49 a	641 ab	365
207958	373 a	214 a	894 bc	382 a	34 a	752 ab	442
111519	553 a	138 a	978 b	177 a	133 a	892 a	479
Means	386	171	969	207	128	631	

Environment

Standard error = 97.820

'Within each environment, line means followed by the same letter are not significantly different at the 0.05 level by Duncan's multiple range test.'

order interactions implies that there were different in the relative ranking of lines over year-site combinations. The line-year interaction was not significant, indicating that relative performance of the lines, averaged over sites, did not differ from year to year. It further alludes to the fact that testing over years may not be important. On the other hand, significant line-site interaction signifies that testing at several sites may be necessary. Furthermore the results suggest that a line or lines adapted to specific conditions may be developed. These significant interactions, although indicative of the the effect of environment on the behavior of lines, cannot provide a basis for the formulation of broad biological concept and interpretation of values. The reason is that, line-environment interactions have not proved to be tractable in biometric analysis except partially by regression technique which depends on the average response of lines, at each site, to provide an overall inclusive measure of that environment. Therefore, two adaptability parameters were used to estimate the general performance of the experimental lines.

The joint regression analysis is given in Appendix 2, Table b. In this analysis most of the sources of variation were found to be highly significant ($p < 0.001$). Line effect was significant ($p = 0.005$). The partitioning of line-environment interactions further reveals that the greater portion of the interaction was due to linear response. Significant slope heterogeneity ($p=0.001$) implies that there is some detectable differences among lines in each of the environment where they were grown.

If the heterogeneity mean square is not significant when tested against the regression's residual mean square, it still does not rule out the possibility that the regression of some lines or all taken separately may be highly significant when tested against their remainder mean square (Perkins and Jinks 1968).

According to the results of the regression analysis of individual lines shown in Table 3, 111518 and 7B are typical of the lines which are very sensitive to changes of environment. A small change in the environment could trigger large changes in yields. Both lines can be described as being specifically adapted to high yielding environments. These lines have less than average adaptability with regression coefficient of b = 1.45 for 111518, and b= 1.56 for 7B. The mean seed yield across environment for 111518 and 7B is above average with 7B giving the highest seed mean yield close to 500 g 6.4 m^{-2}. Another experimental line with below average adaptability and mean seed yield of 479 g 6.4 m^{-2} is 111519. The regression coefficient of this line is 1.14.

On the other hand, Fincha with a regression coefficient of 0.70 but with average mean seed yield of 425 g 6.4 m^{-2} could be well suited to less favorable environments. Its response to changing environment is low at best. In contrast, Harar, with regression coefficient of 0.64 and mean seed yield of 270 g 6.4 m^{-2} is poorly adaptable to all production environments. The same is true for 5E with regression coefficient of 0.72 but with low mean seed yield of 365 g 6.4 m^{-2} (Table 3).

The line 207958 with above average seed yield of 442 g 6.4 m^{-2} and regression coefficient of b = 0.94, responded to changing environment modestly. Its performance is regarded as average and can be considered as generally adaptable to all environments. Furthermore, it has a high

Table 3

Various measure of adaptability determined for seed yield (g 6.4 m^{-2}) of eight sesame lines grown at three sites in Ethiopia 1987 and 1988.

Environment (loc.&Year)	Max. Response(g)	Line	Min. Response(g)	Line	Response Range
Bisidimo '87	553	111519	275	111518	278
Abobo '87	269	Fincha	31	Harar	238
Melka. W.'87	1493	7B	568	Harar	925
Bisidimo '88	396	207958	105	76/48R	291
Abobo '88	253	76/48R	67	Harar	186
Melka. W.'88	892	111519	387	Fincha	505

Lines	Mean (gm/plot)	Pi	MS(GE)	b	p	R^2
Max.response	643	0	-	1.29		
7B	493	16386 ns	5359 ns	1.56 **	0.001	0.94
Harar	270	102670 *	33246 *	0.64 **	0.002	0.92
111518	432	25844 *	3707 ns	1.45 **	0.001	0.93
Fincha	425	53056 *	29383 *	0.70 *	0.017	0.79
76/48R	418	44610 *	13990 ns	0.88 **	0.001	0.94
5E	365	70567 *	32079 *	0.72 **	0.006	0.89
207958	442	38498 *	18278 ns	0.94 **	0.004	0.90
111519	479	31745 *	16358 ns	1.14 **	0.003	0.90

*, ** significant at 0.05 and 0.01 probability level respectively
ns non significant
Pi = superiority measure
MS(GE) = mean squares of genotype-environment
R^2 = determination coefficient
b = regression coefficient
'cut off' point for Pi = 20094
'cut off' point for GE(MS) =20764

determination coefficient (R^2) value of 0.90 indicating that most of the production variables have been taken into account by the regression model. Fig. 1 shows the pattern of linear response of the lines Harar (poorly adapted), 7B (below average adaptability) and 207958 (average adaptability).

Using the procedural approach method of line adaptability analysis, the Pi value of most lines showed significant at the 0.05 level, indicating that the majority are inferior when measured against the maximum response. Those lines having closer values to the Pi and with substantially lower line-environment interaction mean square [GE(MS)] than the estimated error confirms a degree of parallelism with the maximum response (Table 3).

The line 7B with Pi value less than the 'cut off' point (20,094) and R^2 0.94 was found to be closer to the maximum response than any line and by definition superior in performance. Evidently, line 111518 has a higher Pi value than 7B but lower [GE(MS)] than all the test lines. Thus, in order to show the magnitude of its relative closeness to the maximum response figuratively, 7B is plotted with the maximum response against the environmental index. According to Fig. 2 the linear response of 7B is relatively closer and parallel to the maximum response indicating that the difference from the maximum response are about the same for all sites. Thus line 7B could be considered as suitable to poor and productive environment alike.

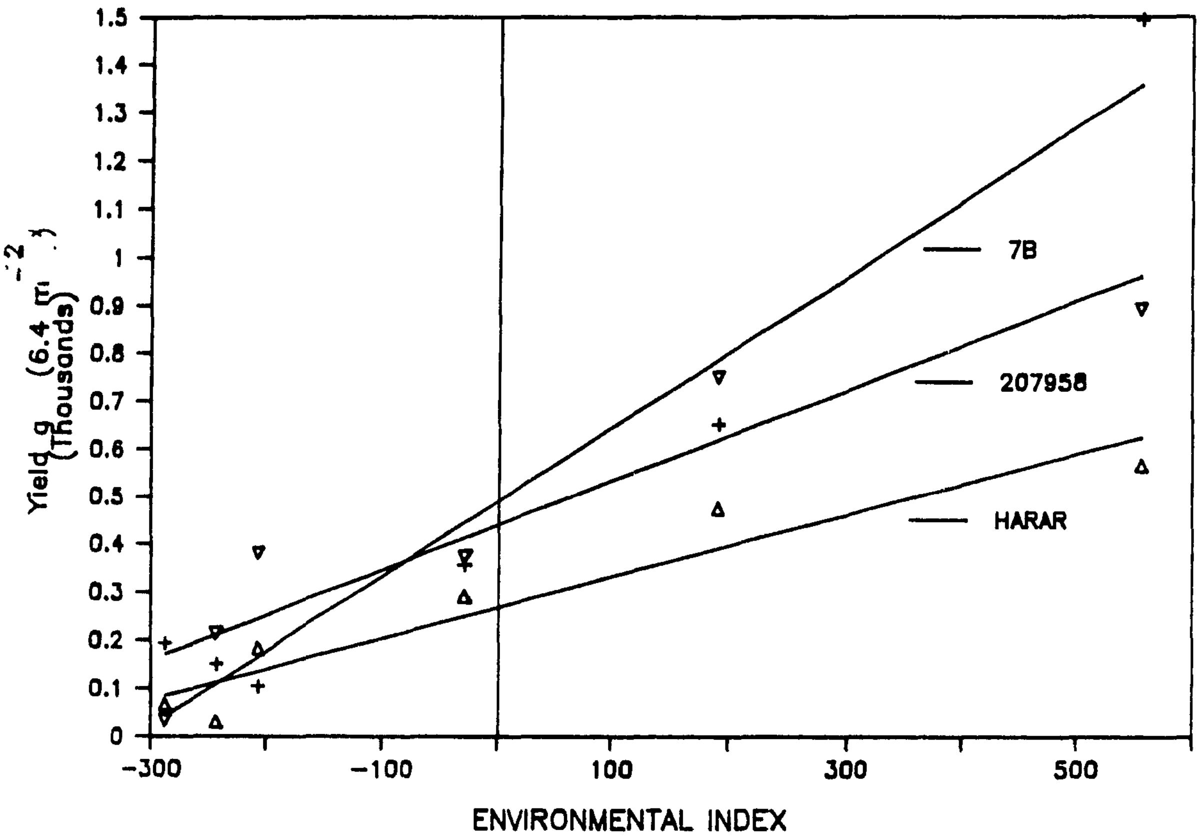

Fig. 1

Seed yield response of three lines of sesame evaluated over several environments

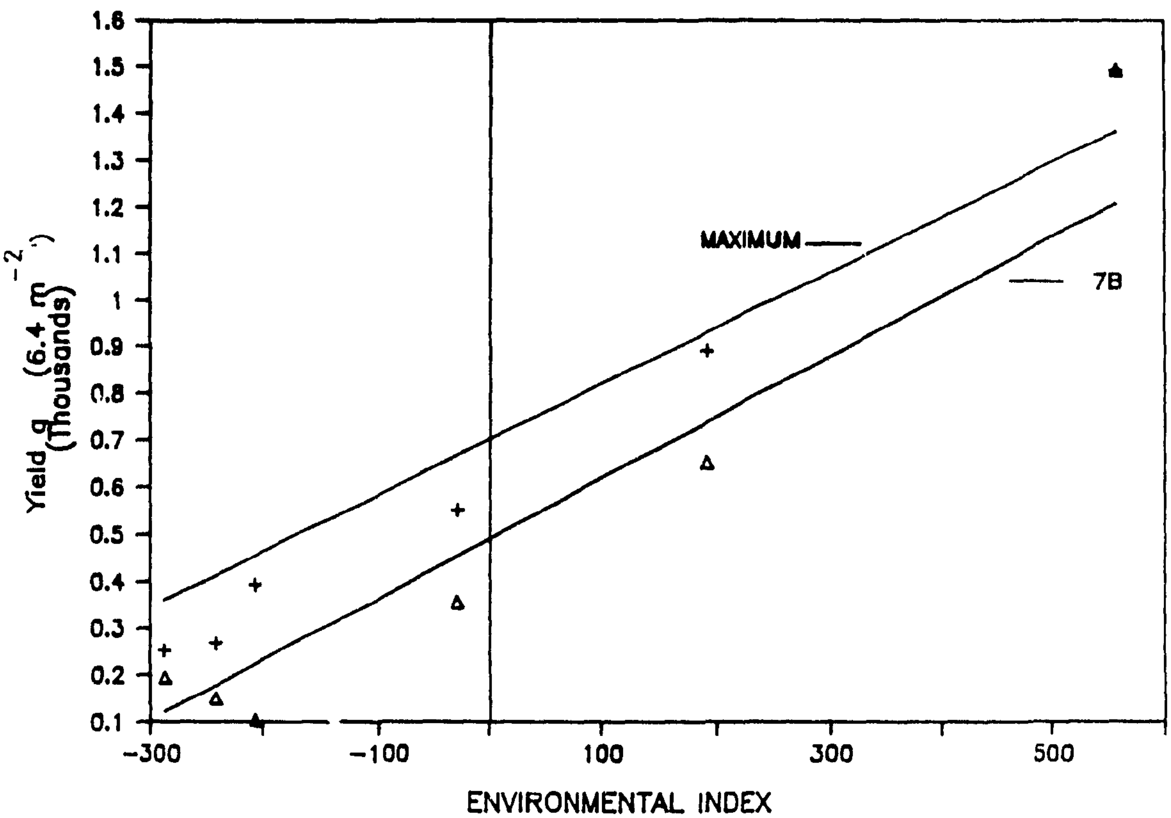

Fig. 2
Comparison of the superior line of sesame with the standard, maximum response

According to the clustering method of non parametric statistics, the dissimilarity index between Fincha, 76/48R together with 207958 and the rest is 100%. The dissimilarity index between 5E and 7B on one hand and 111519 and 111518 on the other is 30%. According to Fig 3, Fincha and 207958, Harar and 7B, 5E and 7B as well as 111519 and 111518 are classified as similar in response by as much as 90%. These results reflect more the genetic background of each line than an individual response of the lines to the environment.

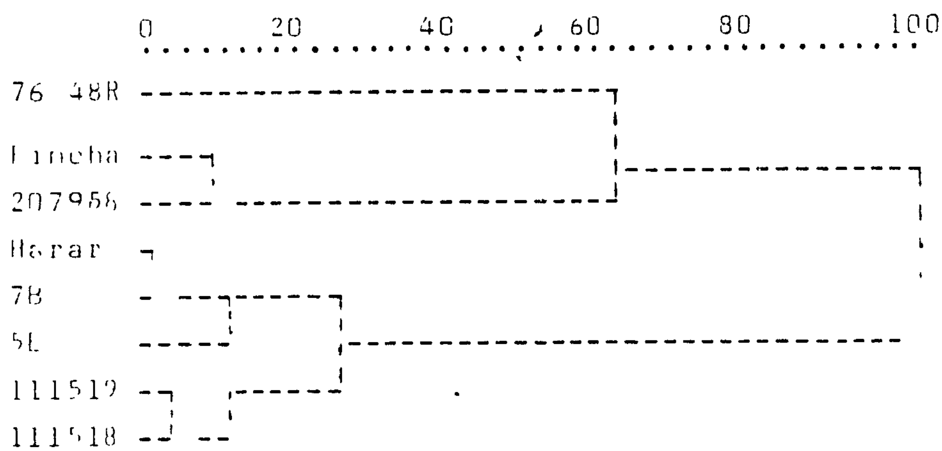

Fig. 3

Dendrogram of all test lines showing the degree of their relationship for seed yield

4.1.2 Yield Components

The seed yield components of sesame were subjected to statistical analysis to determine trait or traits that are likely to contribute to seed yield.

Pooled ANOVA on days to flowering showed that year, site and line effects were highly significant ($p < 0.001$). Similarly line-year interaction gave highly significant ($p = 0.001$) results. On the other hand year-site, and line-site-year interaction effects showed no significance difference (Appendix 3 a).

The joint regression analysis on days to flowering gave similar results as those pooled ANOVA in which the response of lines to environmental effects were significant. There was also significant line-environment interaction. However, the slopes were found to be homogeneous (Appendix 3 b).

Regression of individual lines are shown in Table 4 a. The lines Fincha and 207958 took more days to flower, and flowering appeared to be influenced by favourable environmental conditions. The average days to 50% flowering was about 55 and 56 days respectively. In contrast, none of the lines tested showed the tendency of general adaptability across all the environments for days to flower. However, 7B with regression coefficient of 0.87 and significantly different from zero ($p = 0.043$) is the the earliest to flower and may be considered as adaptable to unfavorable conditions.

The pooled ANOVA and the joint regression for days to maturity is given in Appendix 4 a and b. All sources showed highly significant

Table 4

Various measures of adaptability determined for days to flowering (a) and maturity (b) of eight sesame lines grown at three sites in Ethiopia 1987 and 1988

(a)

days to flowering

Line	b		p	$\bar{x}$	R^2
7B	0.87	*	0.043	52	0.68
Harar	0.60	ns	0.135	60	0.47
111518	0.89	ns	0.079	50	0.59
Fincha	1.42	*	0.027	55	0.74
76/48R	1.03	ns	0.233	57	0.33
5E	0.77	ns	0.056	53	0.64
207958	1.20	**	0.005	56	0.88
111519	1.19	**	0.010	54	0.84

(b)

days to maturity

Line	b		p	$\bar{x}$	R^2
7B	0.79	**	< 0.001	91	0.96
Harar	1.55	**	< 0.001	103	0.99
111518	0.84	**	0.001	88	0.95
Fincha	1.06	**	0.001	93	0.95
76/48R	1.13	**	0.001	94	0.95
5E	0.97	**	< 0.001	91	0.99
207958	0.72	**	0.002	93	0.91
111519	0.91	**	< 0.001	91	0.97

*,** significant at 0.05 and 0.01 probability level respectively

ns non significant

b = regression coefficient

R^2 = determination coefficient

$\bar{x}$ = mean

differences except for line-year interaction in the biometric analysis of the data, while the residual was insignificant in the joint regression analysis. The highly significant differences obtained for line slopes ($p < 0.001$) indicate that lines responded differently to environmental variations.

Thus, the line Fincha with regression coefficient 1.06 and an average of 93 days to mature showed a degree of general adaptability. Similarly, 5E with slightly less days to maturity than Fincha has a regression coefficient of 0.97 which is not far from the average adaptability value of 1.00 (Table 4 b). Since the determination coefficient (R^2) value amounts to 0.95 and 0.99 for Fincha and 5E, respectively, it can be safely assumed that the production variation is accounted for by the regression slopes. None of the lines tested seem to mature moderately earlier than 5E, 111519 and 7B at all production environments.

The line Harar matured later than most lines tested (Table 4 b). Whi e, line 111518 matured earlier than Harar by at least two weeks. As can be seen in Table 4 a, those lines with above average adaptability and early to flower are also early to mature and suitable to unfavourable environment.

According to the pooled ANOVA for number of branches per plant, no significant difference was observed for line, line-year and line-site interactions (Appendix 5 a). Similarly, the joint regression on number of branches showed no differences among lines and slopes (Appendix 5 b). Regression on individual lines reveals that Fincha with regression coefficient 1.00 is generally adaptable to all the production environments under study (Table 4 c). This line has an average of 5 branches per plant.

Table 4

Various measures of adaptability determined for number of branches (c) and pods plant (d) of eight sesame lines grown at three sites in Ethiopia 1987 and 1988.

(c)

number of Branches/plant					
Line	b		p	$\bar{x}$	R^2
7B	1.30	**	0.003	4.66	0.90
Harar	1.07	**	0.001	5.33	0.93
111518	0.49	ns	0.350	4.66	0.22
Fincha	1.00	*	0.018	5.00	0.78
76/48R	1.27	*	0.014	5.17	0.81
5E	1.18	**	0.001	5.17	0.95
207958	0.72	*	0.016	5.00	0.80
111519	0.96	**	< 0.001	5.17	0.96

(d)

number of pods/plant					
Line	b		p	$\bar{x}$	R^2
7B	0.95	**	0.003	50.00	0.90
Harar	1.03	*	0.011	42.11	0.83
111518	0.92	**	< 0.001	50.00	0.98
Fincha	1.22	**	0.004	55.50	0.88
76/48R	0.93	**	0.008	45.33	0.85
5E	1.05	**	0.001	50.83	0.94
207958	1.02	*	0.013	54.33	0.81
111519	0.85	*	0.013	44.83	0.81

*, ** significant at 0.05 and 0.01 probability level respectively
ns non significant
b_2 = regression coefficient
R^2 = determination coefficient

$\bar{x}$ = mean

It is also important to note here that the determination coefficient (R^2) of Fincha is lower than the statistically acceptable value of 0.80. The line Harar, with regression coefficient of 1.07 and determination coefficient (R^2) of 0.93 can also be be regarded as generally adaptable for number of branches per plant. Its mean number of branches is the highest of all the experimental lines. This line is also significantly different than the rest ($p = 0.001$) (Table 4 c). The line 76/48R with regression coefficient of 1.27 and the determination coefficient (R^2) of 0.81 branches profusely in favorable environments.

Appendix 6 a and b shows the pooled ANOVA and the joint regression analysis of pods per plant. The results from the joint regression analysis indicate that, except for the environment, none of the sources are found to be significantly different. Regression on individual lines showed that 207958 with regression coefficient of 1.02 and significantly different than other lines ($p = 0.013$), is fairly adaptable to all production environments (Table 4 d). Its average number of pods per plant is among the highest. Likewise, Harar and 5E showed the tendency of general adaptability with the determination coefficient value above 0.80. But they both produced fewer pods per plant than the line 207958 and therefore were less preferable for immediate exploitation.

In a sense none of the lines seems to be adaptable to low yielding environment but Fincha with regression coefficient of 1.22 may produce a higher number of pods per plant than the rest in favorable environments. The number of pods per plant produced by Fincha is higher by 13 pods when compared with Harar. But the difference amounts to only 1 pod per plant when compared with the generally adaptable line, 207958 (Table 4 d).

Statistical analysis on seeds per pod show that year-site, line-year and line-year-site interactions were insignificant. The line effect showed no statistical difference. But the line-site interaction gave significant results, p = 0.001 (Appendix 7 a). The joint regression for number of seeds per pod also showed non significant for line, line-environment interaction, line slopes and residual effects. Regression analysis on individual lines, indicate that Fincha with regression coefficient of 1.07 and significantly different from zero (p = 0.016) appears to be generally adaptable. This line produced the second highest number of seeds per pod but has a determination coefficient value of 0.79, slightly lower than the statistically acceptable value for R^2 (Table 4 e). The R^2 value of all experimental lines except 5E, was very low.

The pooled ANOVA on plant height showed that both the one way and two way interactions were not significant (Appendix 8 a). Likewise the joint regression analysis showed that line-environment interaction, line slopes as well as the residual effects were not statistically significant (Appendix 8 b). Regression analysis on individual lines suggests that all lines showed highly significant differences (Table 4 f). According to the result, therefore, Fincha attained a resonable height of 140 cm at all the production sites. Similarly, line 111518 with regression coefficient of 0.98 and mean height of 131 cm appears to be shorter in stature across all the environments. The line Harar was among the tallest even in poorer environments (Table 4 f).

The statistical analysis for plant root depth is given in Appendix 9 a and b. Highly significant differences for year, site and year-site

Table 4

Various measures of adaptability determined for seeds per pod (e) and plant height (f) of eight sesame lines grown at three sites in Ethiopia 1987 and 1988.

(e)

number of seeds per pod				
Line	b	p	$\bar{x}$	R^2
7B	1.12 ns	0.141	63.55	0.45
Harar	2.18 *	0.044	68.72	0.68
111518	0.63 ns	0.191	68.28	0.38
Fincha	1.07 *	0.016	71.16	0.79
76/48R	0.20 ns	0.736	72.06	0.03
5E	1.14 **	0.009	66.53	0.84
207958	0.71 ns	0.071	70.89	0.59
111519	0.90 ns	0.240	67.22	0.32

(f)

Plant height				
Line	b	p	$\bar{x}$	R^2
7B	1.13 **	< 0.001	136	0.98
Harar	0.82 **	0.002	148	0.92
111518	0.98 **	< 0.001	131	0.98
Fincha	1.01 **	0.002	140	0.91
76/48R	1.14 **	< 0.001	151	0.95
5E	1.07 **	0.001	141	0.94
207958	0.94 **	< 0.001	149	0.99
111519	0.89 **	0.002	149	0.92

*, ** significant at 0.05 and 0.01 probability level respectively

ns non significant

b_2= regression coefficient

R^2= determination coefficient

$\bar{x}$ = mean

interaction were obtained. Significant differences (p=0.015) was also found for line effects (Appendix 9 a). But the line-year, line-site and line-year-site interaction effects were not significant. In the joint regression analysis no significant differences was obtained for line-environment interaction. As expected partitioning of the line-environment interaction further showed that line slopes and the residual were not significant (Appendix 9 b).

Regression analysis on individual lines indicates that all lines, with the exception of Harar were significantly different for root depth (Table 4 g). The line 76/48R with regression coefficient 0.96 has a mean root depth of 19.92 cms. The line 111518 appears to have an extended root depth only in favorable environment. None of the lines tested showed above average adaptability with a root depth longer than that with average adaptability (76/48R) or that with below average adaptability (111518) (Table 4 g).

The joint regression on one thousand seed weight suggests that environment, line and line-environment interactions are significant, $p < 0.001$ and $p = 0.034$, respectively (Appendix 10 b). In order to determine the source of the interaction, the partitioning of the Line-environment interaction revealed that residual rather than linear was found to be the main cause of the interaction (Appendix 10 b). The pooled ANOVA also showed insignificant interaction for line-year and line-site but the three way interaction was significant, $p = 0.024$, (Appendix 10 a).

Regression on individual lines suggests that Fincha with the lower one thousand seed weight was computed to have 'b' of 1.01 (Table 4 h). In contrast, 111518 has aregression coefficient of 0.90 but with relatively heavier seed weight of of 3.06 g per 1000 seed. Thus, 111518 has more

Table 4

Various measures of adaptability determined for root depth in cm (g) and thousand seed weight in g (h) of eight sesame lines grown at three sites in Ethiopia over two years

(g)

Root depth					
Line	b		p	$\bar{x}$	R^2
7B	1.22	**	0.003	19.75	0.90
Harar	0.51	ns	0.143	17.86	0.45
111518	1.29	**	0.001	22.26	0.94
Fincha	1.16	**	< 0.001	18.81	0.97
76/48R	0.96	**	0.005	19.92	0.88
5E	1.21	**	< 0.001	19.06	0.95
207958	0.80	**	0.009	17.44	0.84
111519	0.93	**	0.006	19.23	0.87

(h)

1000 seed weight					
Line	b		p	$\bar{x}$	R^2
7B	1.25	**	0.008	3.27	0.85
Harar	0.91	*	0.028	2.81	0.74
111518	0.90	*	0.016	3.06	0.80
Fincha	1.01	*	0.018	2.68	0.79
76/48R	0.84	**	0.008	2.88	0.86
5E	0.99	**	< 0.001	2.84	0.99
207958	0.77	**	< 0.001	2.58	0.98
111519	1.31	**	< 0.001	2.88	0.98

*, ** significant at 0.05 and 0.01 probability level respectively
ns non significant
b = regression coefficient
R^2 = determination coefficient

$\bar{x}$ = mean

chance to perform well across sites at the same time producing relatively heavier seeds. The lines with the highest one thousand seed weight have the tendency to perform better at highly productive environment (7B and 111519).

Analysis of variance on harvest index involving one year alone showed that line, site and line-site interaction effect was highly significant with probabilities ranging from less than 0.001 to 0.002 (Appendix 11 a). Joint regression also showed significant for all sources of variation but line slopes were not significantly different (Appendix 11 b). Therefore, the source of line-environment interaction was non linear in nature (Appendix 11 b). As shown in Table 4 i regression on individual lines for harvest index showed that the slopes are not significantly different from zero for all lines.

Table 4

(i)

Various measures of adaptability determined for harvest index (i) of eight sesame lines evaluated at three sites in Ethiopia over one year.

	Harvest index			
Line	b	p	$\bar{x}$	R^2
7B	0.03 ns	0.661	0.081	0.26
Harar	0.08 ns	0.334	0.057	0.75
111518	0.16 ns	0.467	0.117	0.55
Fincha	0.07 ns	0.181	0.070	0.92
76/48R	0.09 ns	0.358	0.077	0.71
5E	0.13 *	0.248	0.082	0.85
207958	0.12 ns	0.068	0.084	0.98
111519	0.11 *	0.276	0.090	0.82

ns non significant
b = regression coefficient
R^2 = determination coeffiecient

$\bar{x}$ = mean

4.1.3 Correlation of seed yield and yield components

The simple linear correlation coefficients of the agronomic characteristics were computed for each year separately. But also the data for the 1987 and 1988 seasons were pooled and that discussion on the the result is based on combined correlation coefficients as shown in Table 5 a. The data indicate that in all cases seed yield was either positively or negatively and significantly correlated with all the other yield components except with days to flowering, rooting depth and branching.

The number of days to maturity was positively correlated with seed yield (r=0.45). Also positively correlated with the seed yield are, the number of pods per plant (r=0.54) and 1000 seed weight (r=0.31) at p=0.01 significant level. In addition, plant height (r=0.43) and harvest index (r=0.57) were positively correlated with the seed yield. Of particular interest was the negative association of number of seeds per pod to seed yield (r=-0.25). This result suggests that heavier seeds are more important than number of seeds.

Root depth was positively correlated with the number of pods per plant (r=0.36), and number of seeds per pod (r=0.17). It is also positively and significantly correlated with plant height (r=0.43) and number of branches (r=0.51) p = 0.010. Based on these findings, selection for lines with extensive root system may be necessary to improve yield through the indirect increase of number of pods per plant, seeds per pod and good number of branches per plant.

Number of pods per plant was positively and significantly correlated with number of branches per plant (r=0.33) and plant height (r=0.46) It

Table 5 a.

Correlation coefficients between seed yield and yield traits for the 1987 and 1988 cropping seasons

	M	B	PD	S	PLH	RD
F	0.533[1] 0.341[2] (0.368)**	-0.255 -0.332 (-0.368)**	-0.201 0.013 (-0.309)**	0.020 -0.121 (-0.079)ns	-0.320 -0.451 (-0.406)**	-0.350 -0.553 (-0.487)**
M		-0.618 -0.113 (-0.283)**	0.035 0.427 (0.203)*	-0.060 -0.478 (-0.250)*	-0.392 0.392 (0.059)ns	-0.495 -0.355 (-0.292)**
B			0.016 0.004 (0.326)**	0.056 0.205 (0.172)*	0.353 0.493 (0.452)**	0.348 0.384 (0.505)**
PD				-0.236 -0.321 (-0.052)ns	0.493 0.319 (0.463)**	0.060 -0.168 (0.362)**
S					-0.256 -0.116 (-0.138)ns	-0.016 0.274 (0.169)*
PLH						0.379 0.356 (0.432)**

*, ** significant at P= 0.05 and 0.01 probability level respectively
ns non significant
1 denote 1987 correlation coefficients
2 denote 1988 correlation coefficients
( ) values in parenthesis denote combined correlation coefficients.

F= Flowering   M= Maturity   B= Branch
PD= Number of pod   S= Number of seed per pod
PLH= Plant height   RD= Root depth   S1= 1000 seed weight
G= Seed yield   HI= Harvest index

Table 5. (cont'd)

	S1	HI	G
F	0.269[1] -0.009[2] (0.095)^{ns}	- 0.235 (0.235)*	-0.009 0.056 (-0.068)^{ns}
M	0.488 0.579 (0.502)**	- 0.587 (0.587)**	0.357 0.577 (0.451)**
B	-0.350 -0.259 (-0.151)^{ns}	- -0.396 (-0.396)**	-0.287 -0.095 (0.155)^{ns}
PD	-0.186 0.380 (0.161)^{ns}	- 0.37237 (0.37237)**	0.566 0.411 (0.542)**
S	0.034 -0.416 (-0.062)^{ns}	- -0.203 (-0.203)^{ns}	-0.313 -0.322 (-0.251)**
PLH	-0.657 0.287 (-0.218)**	- 0.070 (0.070)^{ns}	0.379 0.407 (0.425)**
RD	-0.362 -0.142 (-0.100)^{ns}	- -0.327 (-0.327)**	-0.011 -0.150 (0.088)^{ns}
S1		0.517 (0.517)**	0.086 0.677 (0.309)**
HI			0.573 (0.573)**

*, ** significant at P= 0.05 and 0.01

1 denote 1987 correlation coefficients

2 denote 1988 correlation coefficients

( ) values in parenthesis denote combined correlation coefficients.

F=flowering M=maturity B=Branch PD=pod number
S=seed/pod PLH=plant ht. RD=root depth S1=1000 seed wt.
G=seed yield HI=harvest index

is therefore possible to infer that greater number of pods are to be expected from profusely branching and tall lines.

Positive correlation was observed between days to flowering on one hand and days to maturity (r=0.37) and Harvest index (r=0.24) on the other. Whereas, negative and significant association was computed for number of branches per plant (r=-0.36), number of pods per plant (r=-0.30) and plant height (r=-0.41). Thus, the earlier the experimental line to flower the earlier they mature and may increase seed yield through higher harvest index.

Days to maturity was significantly and positively correlated with harvest index (r=0.59), 1000 seed weight (r=0.50) and number of pods per plant (r=0.20). Similar to days to flowering, days to maturity was negatively correlated with number of branches per plant (r=-0.28), seeds per pod (r=-0.25) and root depth (r=-0.29).

The results obtained in the present study indicate that seed yield is influenced by number of pods per plant, plant height and 1000 seed weight. These findings are in agreement with the results obtained by previous workers in sesame (Khidir et al. 1970 ; Yadava et al.1980; Sharma et al. 1984, Ibrahim et al. 1983 and Shukla et al. 1983).

The analysis also shows the importance of Harvest index (r=0.58) to the contribution of high seed yield. Saha (1980) observed that a greater number of capsules per plant and harvest index appeared to be important factors in achieving improvement in sesame seed yield.

It is also in agreement with Rheenen van (1982) who reported that plant height contributed to seed yield. However, number of branches was found to be non significant and apparently not useful in achieving high seed yield. These findings are in variance with those of Plainswamy et al.(1978) and Murugenes et al. (1979) who claimed that branches per plant were important to seed yield.

The negative correlation between number of seeds per pod and seed yield may indicate that the size and weight of seeds could be more important to seed yield improvement than number of seeds per pod. Osman and Khidir (1974) found that seeds per pod is positively but not significantly correlated with seed yield.

The result so far obtained through the simple correlation coefficient analysis is only an indicative to what extent each trait might contribute to yield. The actual association of each trait with yield can be better estimated by adjusting one or more trait effects on yield. For this reason partial correlation coefficient of seed yield with most of the traits that showed positive and significant association in the simple correlation coefficient are computed as shown in Table 5 b.

Table 5 b

Partial correlation coefficients of seed yield and other variables adjusted to the effects of selected yield components

variables	adjusted for	r		p
10 6	4	-0.031	ns	0.768
10 9	4 2 5	-0.082	ns	0.599
10 5	2 8	0.208	**	< 0.001
10 7	1 2 4 5 6	0.115	ns	0.300
10 4	1 2 5 6 7	0.239	*	0.025
10 9	1 2 4 5 6 7	-0.011	ns	0.944

1= flowering 2= maturity 3= branch/plant 4= pod/plant
5= plant ht. 6= seed/pod 7= 1000 seed wt. 8= root depth
9= harvest index 10= seed yield
* significant at 0.05 level
ns non significant

As shown in Table 5 b partial correlation coefficient for seed yield adjusted to one or more character effects gave contradictory results from what was obtained by using simple correlation coefficient analysis. Except for pods per plant and plant height adjusted for almost all characters which previously gave significant and positive association with seed yield, most traits appeared to be unimportant as yield attributes. Moreover, the magnitude of the positive correlation observed for the two characters which showed significance ($p = 0.025$ and $p < 0.001$, respectively) are very low. Be that as it may, our findings are in agreement with Osman and Khidir (1974) who by using the partial correlation coefficient demonstrated that plant height and pod number per plant could have an influence on sesame seed yield.

4.1.4 **General Discussion**

Since the linear model fits the data for seed yield, the regression coefficient computed (Table 3) may estimate the true response of each line to the environment . However, in addition to the regression analysis and the procedural approach method used to describe the general response pattern of all lines with respect to the environments under study, the mean seed yield was also used as a complementary estimating parameter to the the regression method.

Thus, the line 207958 with relatively high mean seed yield and an acceptable determination coefficient could be considered as generally adaptable. This line could give reasonably good yield and even substitute 7B under the improved conditions such as Melka Werer.

Because of its quick response to changing environment and its high mean yield across environments, 7B can be characterized as more adaptable to favorable production environments. It is doubtful, whether this line will perform in all production environments as well as it does in favorable environment. 7B was also identified to be superior and generally adaptable by the procedural approach method. This line has the highest seed mean yield across all sites and has low [GE(MS)] as well.

According to the result on yield component, the experimental lines (7B and 207958) characterized to be generally adaptable by both the procedural approach method and the regression model have some of their yield components below or above average adaptability. However, line 207958 gave high mean pod number per plant while its regression coefficient value remained at 1.02. Furthermore, it matured early and produced high seed number per pod under unfavorable climatic conditions (Table 4 b and e).

In addition it scored the lowest value of 5.5 in 0 - 9 point scale for bacterial blight (*Xanthomonas sesami*) disease severity (Appendix 12 a). Thus, it is found to be more suitable to both the marginal and high rainfall regions of the country where chances of excessive rain or small and erratic distribution of it may not reduce yield to an uneconomically low level.

On the other hand 7B produced the heaviest seeds and a relatively longer root system and shorter stature under improved environments. It is also early to flower and mature even under poor environments. 7B could be a promising line under the irrigated conditions of the middle and lower part of the Rift valley (Melka Werer) as an alternate crop in a double cropping system. Of particular interest is the line 111518 which posseses certain characteristics such as short stature (131) and extensive root system (22.26), and perhaps may be important in marginal areas with insufficient rainfall and void of windbreaks. As a result of this attributes, line 111518 has the lowest lodging value of 28% (Appendix 12 b).

Seed yield is a function of genetically inherited traits called yield components. These traits are affected by the interaction of lines with the environment which often helps explain why a reduction in yield occurs.

As indicated by the pooled analysis of variance (Appendix 2 Table a) and by the joint regression analysis (Appendix 2 Table b), environment effect were highly significant. The variability detected among lines, years and site can be attributed to the differences in soil type, temperature, soil moisture and disease conditions during the growing seasons

A close look at some of the environmental factors (Appendix 1 Table a, b and c) indicates that variability within the lines at different sites is the result of differences in soil fertility, moisture and temperature.

At Melka Werer where the temperature is warmer, lines took longer time to mature especially in the second year of testing (Appendix 13 a). This can be attributed to unusually moist conditions for this dry site which had received a total of 262 mm of rain during the month of August in 1988 where the crop was supposed to mature with reserve moisture alone (Appendix 1 b). The maturity date was also delayed by two weeks taking 116 days instead of 103 days which is normal for most lines grown in that site (Appendix 13 a). The maturity date was hastened in Abobo for an entirely different reason, that is, due to heavy infestation of bacterial blight (*Xanthomonas sesami*). At Bisidimo the crop matured in a relatively warm and dry climate.

At Melka Werer, despite the availability of supplemental irrigation at different growth stages, crop performance was affected by excessive heat at the time of early flowering and fertilization (June) in both cropping seasons. Unusually wet and damp conditions during full bloom and pod filling stage (July and August) in the second year of the trial, at this extremely dry and hot site, affected crop performance seriously. The average yield variation between the two cropping seasons was about 30% (Table 2).

At Abobo, excessive rainfall and poor natural drainage conditions throughout the growing season in both years promoted disease infection and flower dropping. Furthermore, lodging was so high that in some cases entire seed was lost to the ground (Appendix 12 b). The effect of severe disease infection on almost all the lines at this site and not at the other two increased the line-site-year interaction. Disease severity was the same in both years (Appendix 12 a). Furthermore, high daily temperatures, although not always, coinciding with the fertilization period must have also contributed to the low yield scored by many of the lines at this site (Table 2). As is always the case in the rainy season with this high rainfall site, cloudy periods were more presented than clear sunshine days to further affect crop performance.

Seed yield variation was more evident at Bisidimo in the second year of the experimentation than in the first year. The low seed yield achieved in 1988 was perhaps due to erratic distribution of rainfall and a long drought spell in September as well as poor soil conditions (poor water holding capacity and soil fertility, Appendix 1, table b and c).

As indicated earlier, during the second half of the crop growing stage heavy rainfall at all the sites in 1988, caused flower and pod reduction either by mechanical impact of the dropping rains or by damaging the floral part of the crop (Appendix 1 Table b). Number of pods was reduced from 57 to 27 at Bisidimo, 61 to 22 at Abobo and from 87 to 38 at Melka Werer (appendix 13 b).

However, warm temperatures and abundant rainfall during the vegetative stage of growth encouraged plant height to attain a maximum of 187 cm in Melka Werer and 170 cm at Abobo (appendix 13 c). This coupled with the heavy infestation of bacterial blight (<u>Xanthomonas sesami</u>) caused severe lodging, loss of seed and vegetative parts of the genotypes at Bisidimo (Appendix 12 a and b).

Rooting depth was extensive at Melka Werer and Abobo where the soil type was from heavy clay to alluvial. While at Bisidimo the root length was 18 and 15 cm for the 1987 and 1988 respectively (Appendix 13 d). This result contradicts that of Weiss (1983) who reported that sesame grown under light soil has an extensive root system.

The number of branches were higher at Abobo ranging from 5.50 to 8.13 against 3.13 to 4.63 at Bisidimo indicating lines branched profusely at the former site with abundant rainfall (Appendix 13 e). But branches bore fewer leaves due to bacterial blight disease. Such conditions ultimately decrease the photosynthesis process resulting in very low seed yield. Likewise, the harvest index was extremely low at Abobo (0.026) when compared to Melka Werer (0.143), Appendix 13 f.

The result of simple correlation coefficient analysis indicates that for possible high seed yield, lines with early maturing characteristics, high number of pods and seeds per pod, tall stature and having heavier seeds with high harvest index are essential. Both plant height and number of pods per plant were found to be important yield attributes by the partial and simple correlation coefficient analysis.

It is statistically untenable to compare the two parametric statistics, for the simple reason that the Finlay and Wilkinson model (1963) uses regression coefficient and the mean value as a selection criteria, while the procedural approach relies on the Pi value instead of the 'b' or the 'mean' to estimate the response of lines to environmental variables. For example, the line 207958 which was detected to be generally adaptable at all the environments by the regression model was to the contrary, found to be a line with a higher Pi value (significant at 0.05 level) and not quite as superior a performer as 7B. Despite its high Pi value, 207958 has lower [GE(MS)] to be remotely characterized as less specific in its adaptability.

The clustering approach of dissimilarity index (Fig. 3) grouped lines without defining their true response to the environment, as is the case when using the linear regression or the procedural approach methods. Both groups of statistics underlined the inherent differences of the two lines. However, because of the basic differences that exists between the parametric and non parametric statistics, comparison between the two methods are no more than an intellectual exercise.

4.2 **Chemical Composition**

4.2.1 Oil Quantity

The mean oil content of the experiments conducted at three sites over two years varied from 41.39 to 47.61%. The highest mean oil content were obtained from the 1987 trials and specifically from Bisidimo (Table 6). At Bisidimo, the average growing period for most lines, except for Harar and 76/48R was intermediate (Appendix 13 a) while the mean temperature remained cooler relative to the other two sites. Earlier work by Sosuslski *et al.* (1964) on flax seed, showed that cool climatic conditions delay maturity and thus provide a longer period for oil deposition.

Pooled ANOVA on the data show that year and site taken separately have a significant influence on oil content. There were also significant differences among lines for oil content (Appendix 14 a). The line-year interaction was not significant, indicating that the relative performance of the lines regarding oil percent, averaged over sites, did not differ from year to year. By contrast, the line-site interaction was highly significant ($P < 0.001$) suggesting that the ranking of lines for oil content was inconsistent at the three sites. Non significant results in the second order interaction further indicates that lines did no responded differently at each sites in both years.

Joint regression analysis on oil content is shown in Appendix 14 b. Significant difference were obtained for environment and line effects on oil content ($p < 0.001$). There was also differences among slopes ($p = 0.006$). Because of the significance of the heterogeneity of the regression slopes obtained, it is correct to assume that some lines are different than others in their response to the environment.

Table 6

Mean oil content in percent of eight sesame lines grown at three sites in Ethiopia 1987 and 1988

	Environment						
	1987			1988			
Lines	Bisidimo	Abobo	Melka W.	Bisidimo	Abobo	Melka W.	Line means
7B	47.30 a	42.27 d	44.70 a	45.07 ab	39.83 e	42.80 de	43.66
Harar	47.23 a	42.67 cd	45.10 b	44.57 b	41.33 cd	42.57 e	43.91
111518	48.27 a	44.03 ab	47.00 a	45.77 a	42.57 ab	44.53 ab	45.36
Fincha	47.23 a	44.93 a	46.77 a	44.87 b	43.57 a	45.03 a	45.40
76/48R	47.93 a	42.27 d	44.50 a	44.87 ab	40.70 de	42.90 de	43.86
5E	47.40 a	43.73 bc	45.23 a	45.83 a	41.03 cd	43.80 bcd	44.50
207958	47.37 a	43.53 bc	45.60 a	44.30 b	40.47 de	44.00 abc	44.21
111519	48.17 a	43.27 bcd	45.47 b	45.77 a	41.67 bc	43.17 cde	44.59
mean	47.61	43.34	45.55	45.13	41.39	43.60	

Standard error = 0.383

'Within each environment, line means followed by the same letter are not significantly different at the 0.05 level by Duncan's multiple range test.'

Thus, Fincha with a 'b' value of 0.57 but with high mean oil percent across all environments is more adaptable to less favorable environments (Table 7). The reason is that its response to changing environment is less obvious, that is, with improved environmental conditions the increase of oil percent is small when compared with 7B which tends to perform and produce more oil as the environmental conditions improve. However, despite its insensitivity to changing environment, Fincha has also the highest oil mean percent,thus making it suitable in unimproved conditions On the other hand, the line 111518 with regression coefficient 0.96 and a mean oil of 45.36% , synt esized oil in more or less constant fashion across all the environments. Although, 5E has a regression coefficient of 1.01, its mean oil percent is very low to characterize it as generally adaptable (45%) Instead, line 111518 can be generally described as adaptable to all the environmental conditions. The response pattern of Fincha and 111518 is shown in Fig. 4.

Based on the procedural approach of superiority measure, the lines 111518 and Fincha could be characterized as being desirable and overall not different from maximum response. Because of their closeness to the Pi value which is 0, these lines are considered as superior in their performance (Table 7). It must be noted that the Pi value is measured over all sites, and as such estimates superiority in the sense of general adaptability. Therefore, to determine the pattern of their relative adaptability , the values of 111518 and Fincha are plotted with the maximum response against the mean of the lines across sites (Environmental Index). Thus, the result of the plotting reveals that while 111518 is high yielding but only in a favorable environment and Fincha synthesize more oil under unfavorable environments (Fig. 5).

Table 7

Various measures of adapatability determined for oil content of eight sesame lines grown at three sites in Ethiopia in 1987 and 1988.

Environment Loc.&year)	Max. Response (%)	Line	Min. Response (%)	Line	Response Range
Bisidimo '87	48.27	111518	47.23	Harar	1.04
Abobo '87	44.93	Fincha	42.27	7B & 76/48R	2.66
Melka Werer'87	47.00	111518	44.50	76/48R	2.50
Bisidimo '88	45.77	111518 & 111519	44.30	207958	1.47
Abobo '88	43.57	Fincha	39.83	7B	3.74
Melka Werer'88	45.03	Fincha	42.57	Harar	2.46

Line	Mean oil (%)	Pi	MS (GE)	b	p	R^2
Max. Response	45.76	0	-	0.76		
7B	43.66	2.9475 *	0.6275 *	1.14 **	< 0.001	0.88
Harar	43.91	2.2950 *	0.0400 ns	0.99 **	< 0.001	0.97
111518	45.36	0.2251 ns	0.1916 ns	0.96 **	< 0.001	0.96
Fincha	45.40	0.2715 ns	0.1666 ns	0.57 *	0.013	0.81
76/48R	43.86	1.8131 *	0.4333 *	1.17 **	< 0.001	0.98
5E	44.50	0.8840 *	0.3441 ns	1.01 **	< 0.001	0.96
207958	44.21	1.2871 *	0.4616 *	1.05 **	0.001	0.93
111519	44.59	1 2657 *	0.4400 *	1.08 **	< 0.001	0.97

*, ** significant at 0.05 and 0.01 probability level respectively
ns non significant
Pi = superiority measure
MS (GE)= mean squares of genotype - environment
R^2= determination coefficient
b =regression coefficient
'cut off' point for Pi = 0.3099
'cut off' point for GE(MS) = 3202

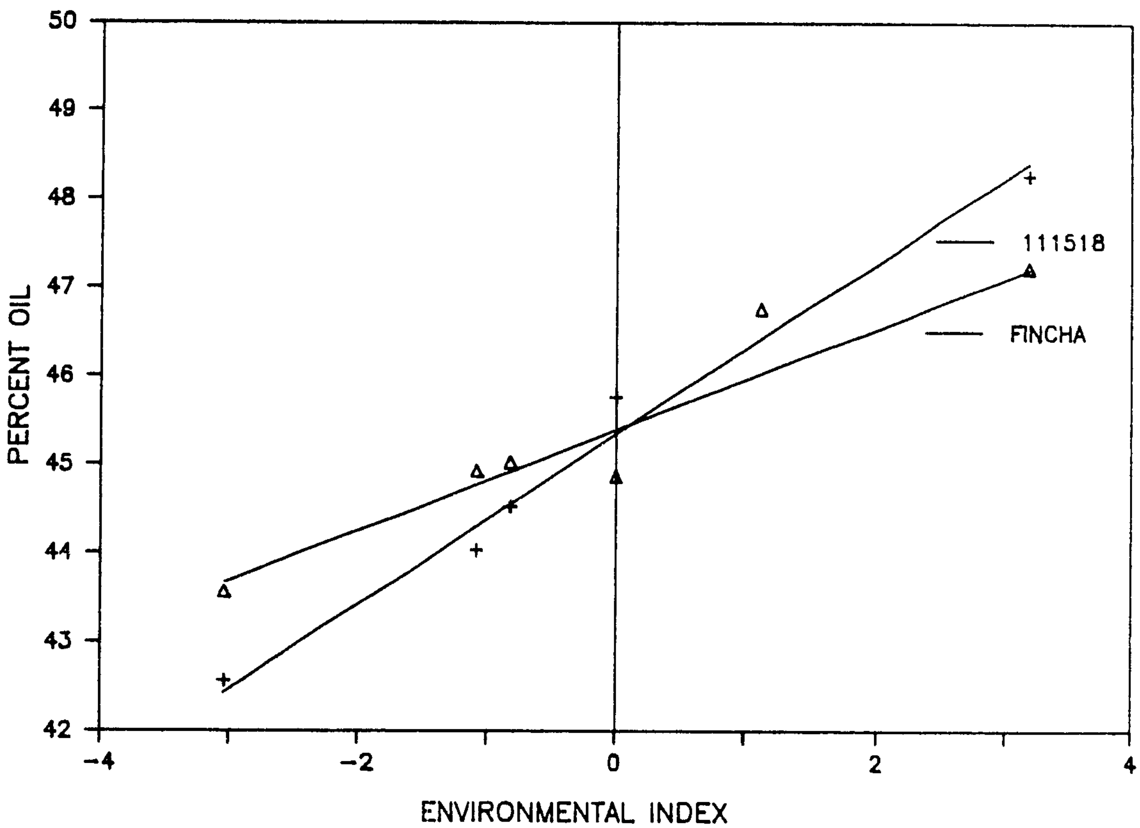

Fig. 4

Regression of two lines with varying degree of adaptability for oil content.

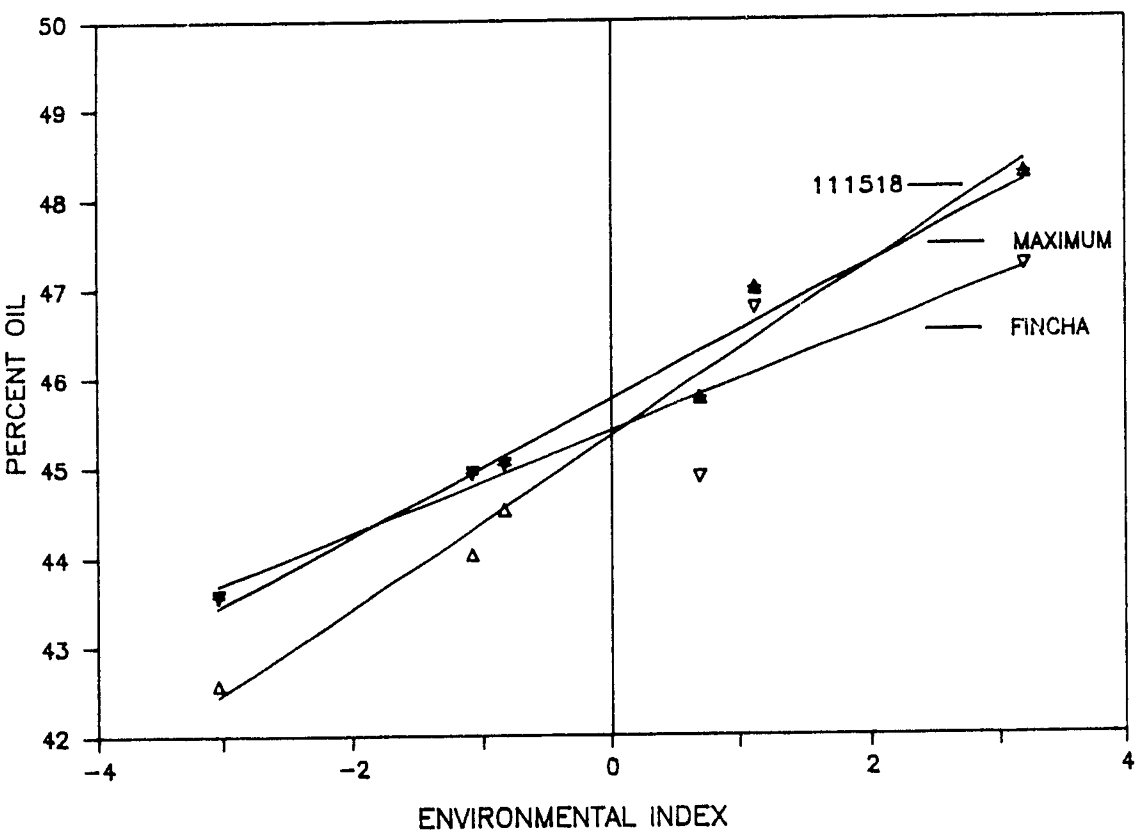

Fig. 5
The relationship of two superior lines with the standard, evaluated at several environments

According to the cluster method of analysis, 111518 and Fincha were grouped as similar in their behavior. The dissimilarity index of both lines' oil percent was found to be 0.64. Despite falling under same category or grouping, the difference between each other amounts to 40%. This results are in agreement with those results obtained by using the procedural approach of superiority measure or the regression model which designated both lines as either above average (Fincha) or below average in adaptability (111518).

The dendrogram (Fig. 6) put the difference between 111518 and Fincha in one hand and the remaining six lines on the other as 100%. Fincha and 111518 are landraces developed through progeny selection. While this method identified both lines as similar in their response to the environment, it also underscored the magnitude of the difference that exists between them (40%). Both lines are landraces collected from the Blue Nile gorge and are presumed to be evolved distinctly through time under the protective nature of the gorge.

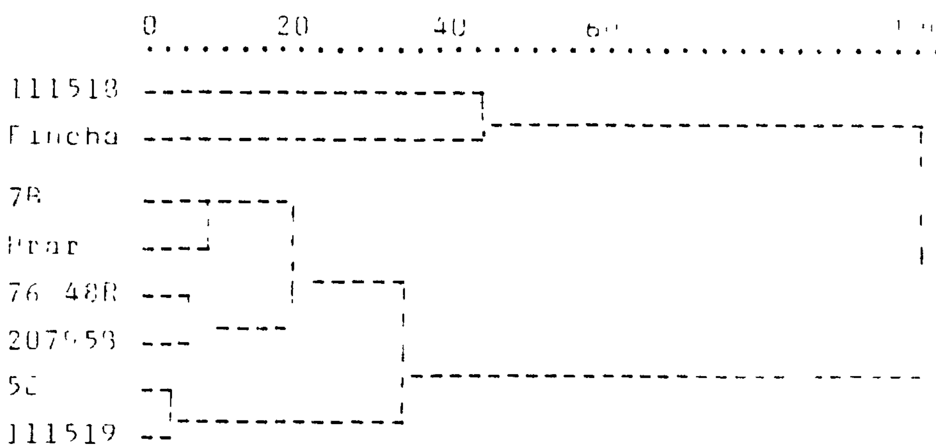

Fig. 6

Dendrogram of all test lines showing the degree of their relationship for oil content

4.2.2 Oil Quality

The major fatty acids of sesame are oleic and linoleic acids, which occur in approximately equal amounts and account for about 86% of the total fatty acids. Most of the fatty acid contents of sesame analyzed in this study fell within the codex ranges of FAO/WHO (O'connor 1970) and are similar to those values determined by Yermanos (1964).

The fatty acid values ranged from 6.94 to 7.64% for palmitic acid, 4.50 to 6.07% for stearic acid, 36.08 to 40.35% for oleic, 45.28 to 49.98% for linoleic (Table 8).

Table 8

Fatty acid composition percentage of eight sesame lines grown at three sites 1987 and 1988.

	Bisidimo		Abobo		Melka Werer	
Fatty acids	1987	1988	1987	1988	1987	1988
Palmitic	6.94 (0.34)	6.90 (0.43)	7.39 (0.51)	7.51 (0.46)	7.64 (0.32)	7.51 (0.34
Stearic	5.88 (0.18)	6.07 (0.54)	4.78 (0.26)	4.50 (0.61)	5.26 (0.31)	4.97 (0.41)
Oleic	37.10 (0.93)	36.08 (1.53)	40.35 (2.32)	39.60 (1.72)	39.88 (1.28)	38.96 (1.18)
Linoleic	49.18 (2.61)	49.98 (1.76)	45.28 (0.92)	46.63 (2.55)	46.30 (1.50,	47.39 (1.66)
Other *	0.60	0.97	2.2	1.76	0.92	1.17

Data are means of three replicates from a composite seed samples

Figures in paranthesis are standard errors

* other minor sesame fatty acids

4.2.2.1 Palmitic Acid.

Pooled analysis of variance shows that sites and lines have highly significant effects ($P < 0.001$) on palmitic acid. The line-site interaction was also found to be significant (Appendix 15 a). There was no significant effect observed for year, line-year and line-year-site interactions. From the results of the analysis it can be concluded that lines behaved differently at each site. It also shows that the ranking of lines for palmitic acid differed from one site to the other. Conversely the lines showed no difference when planted at the three sites over the two years of experimentation. Since it is difficult to obtain a general picture on the performance of each line and their individual response to the environment in question by simply analysing the data biometrically, it was further analyzed by the regression method. The result showed that line and environment effects were highly significant. The analysis also showed that lines highly interacted with the environments for palmitic acid content. Further partitioning of the GE interaction mean squares indicated that the interaction was mainly due to non linear effects (Appendix 15 b).

However, non heterogeneity of slope lines (linear) does not preclude the fact that regression of some lines taken separately may prove to be significantly different when tested against their own remainder mean square (Perkins and Jinks 1968). Table 9 shows that all lines, except for Harar, showed significant slope differences at various probability levels.

7B with modest mean palmitic acid percent and regression coefficient b = 0.93 can be regarded as adaptable to all the production environments for palmitic acid synthesis. This line had a significant slope at 0 008

Table 9

Various measures of adaptability determined for palmitic acid of eight sesame lines grown at three sites in Ethiopia in 1987 and 1988.

Environment (Loc.&Year)	Max Response (%)	Line	Min Response (%)	Line	Response Range
Bisidimo '87	7.60	Harar	6.67	5E & Fincha	0.93
Abobo '87	8.33	111518	6.90	5E & 207958	1.43
Melka Werer '87	8.13	111518	7.17	207958	0.96
Bisidimo '88	7.27	111518	6.43	5E	0.84
Abobo '88	8.27	Harar	7.17	5E	1.10
Melka Werer '88	7.97	Harar	7.10	111519	0.87

Lines	mean palmitic (%)	Pi	MS(GE)	b	p	R^2
Max. response	7.92	0	-	0.60		
7B	7.28	0.3841 *	0.0614 **	0.93 **	0.008	0.85
Harar	7.80	0.0224 ns	0.0150 ns	0.88 ns	0.057	0.63
111518	7.83	0.0181 ns	0.0112 ns	1.27 *	0.015	0.80
Fincha	7.16	0.3615 **	0.0651 *	0.82 *	0.033	0.72
76/48R	7.32	0.2133 *	0.0303 ns	1.19 **	< 0.001	0.95
5E	7.10	0.0404 *	0.0624 *	1.27 *	0.026	0.75
207958	6.97	0.0533 *	0.0346 ns	0.72 **	0.004	0.89
111519	7.06	0.0395 *	0.0216 ns	0.92 **	0.002	0.92

*, ** significant at 0.05 and 0.01 probability level respectively
ns non significant
Pi = superiority measure
MS(GE)= mean squares of genotype - environment
R^2= determination coefficient
b =regression coefficient
'cut off' point for Pi = 0.0382
'cut off' point for MS(GE) = 0394

probability level. The line 207958 with lowest mean palmitic acid percent and regression coefficient of 0.72 is poorly adaptable to all the production environments. On the other hand 111518 with the highest palmitic acid content. but regression coefficient value below average can be categorized as more adaptable to all the productive environments. Together with Harar, line 111518 gave the highest palmitic acid mean across sites (Table 9). Based on their regression coefficients and their mean values, three lines with variable response to environment are plotted for illustration (Fig. 7).

Since temperature effect is believed to influence the fatty acid composition of oilseed crops, in that high temperatures favor the synthesis of saturated fatty acids (Harwood and Russsell, 1983) results in the present study also show that at the warmer sites more of the saturated fatty acids were synthesized than in the cool site of Bisidimo. At Abobo and Melka Werer the palmitic acid produced during the 1987 cropping season when compared with the relatively cooler location of Bisidimo was substantial higher (Table 10). The trend continued in the 1988 cropping season with Abobo and Melka Werer producing the same amount of palmitic. It is important to point out here that ,although, relatively cool,Bisidimo, had a mean seasonal maximum temperature of 26^{o}C during the crop growth period. While at Abobo and Melka Werer the mean seasonal maximum temperature were 33^{o}C and 36^{o}C, respectively (Appendix 1 a).

Results of the analysis by the procedural approach method indicates that the Pi value of all lines but two were different from the maximum response for palmitic acid synthesis (Table 9). The two with Pi value closer to the maximum response has also have the lowest line-environment

Table 10

Mean palmitic acid percent of eight sesame lines grown at three sites in Ethiopia in 1987 and 1988.

	Environment						
	1987			1988			
Lines	Bisidimo	Abobo	Melka W.	Bisidimo	Abobo	Melka W.	Line mean
7B	6.80 b	7.53 c	7.60 b	7.00 ab	7.33 b	7.47 bc	7.28
Harar	7.60 a	7.93 b	7.80 ab	7.23 a	8.27 a	7.97 a	7.80
111518	7.27 a	8.33 a	8.13 a	7.27 a	8.07 a	7.93 a	7.83
Fincha	6.70 b	7.00 d	7.47 bcd	7.00 ab	7.30 b	7.47 bc	7.16
76/48R	6.87 b	7.40 c	7.80 ab	6.83 bc	7.40 b	7.60 ab	7.32
5E	6.87 b	6.90 d	7.77 abc	6.43 c	7.17 b	7.43 bc	7.10
207958	6.70 b	6.90 d	7.17 d	6.67 bc	7.23 b	7.13 c	6.97
111519	6.67 b	7.16 cd	7.37 cd	6.73 bc	7.33 b	7.10 c	7.06
mean	6.94	7.39	7.64	6.90	7.51	7.51	

Standard error = 0.135

'Within each environment, line means followed by the same letter are not significantly different at the 0.05 level by Duncan's multiple range test.'

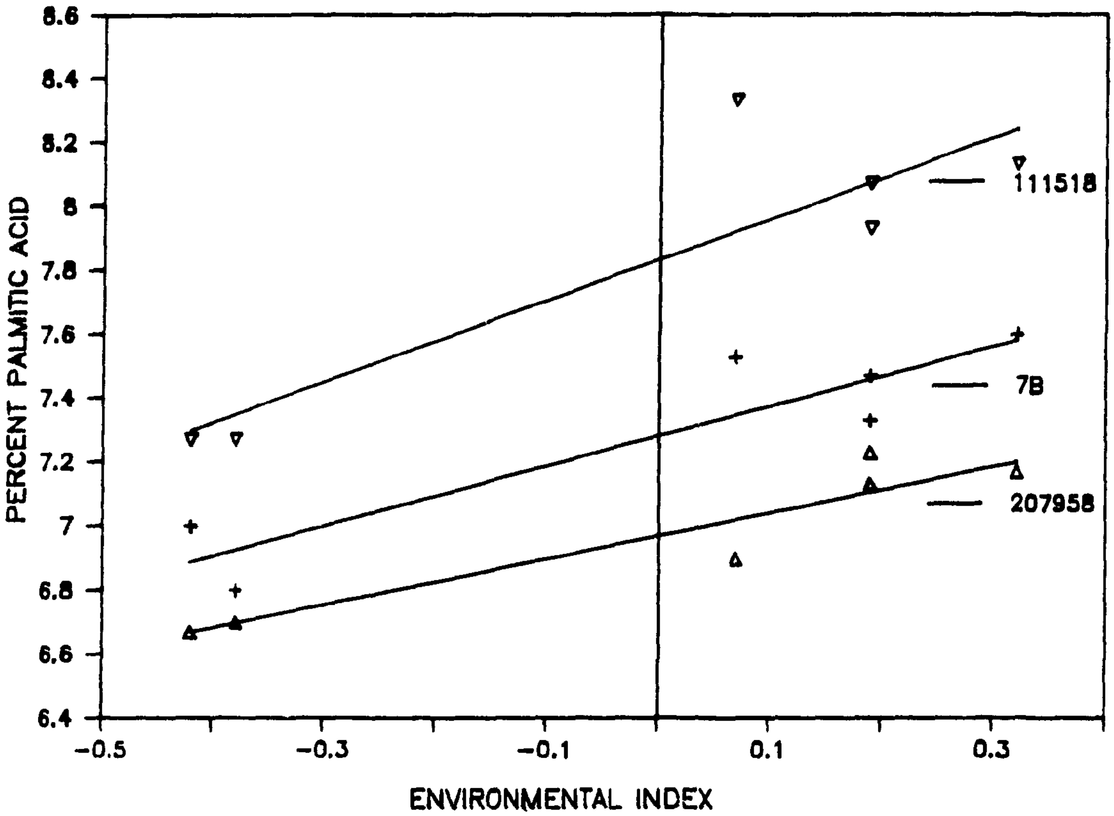

Fig. 7
The response of three lines of sesame with varying degree of adaptability for palmitic acid

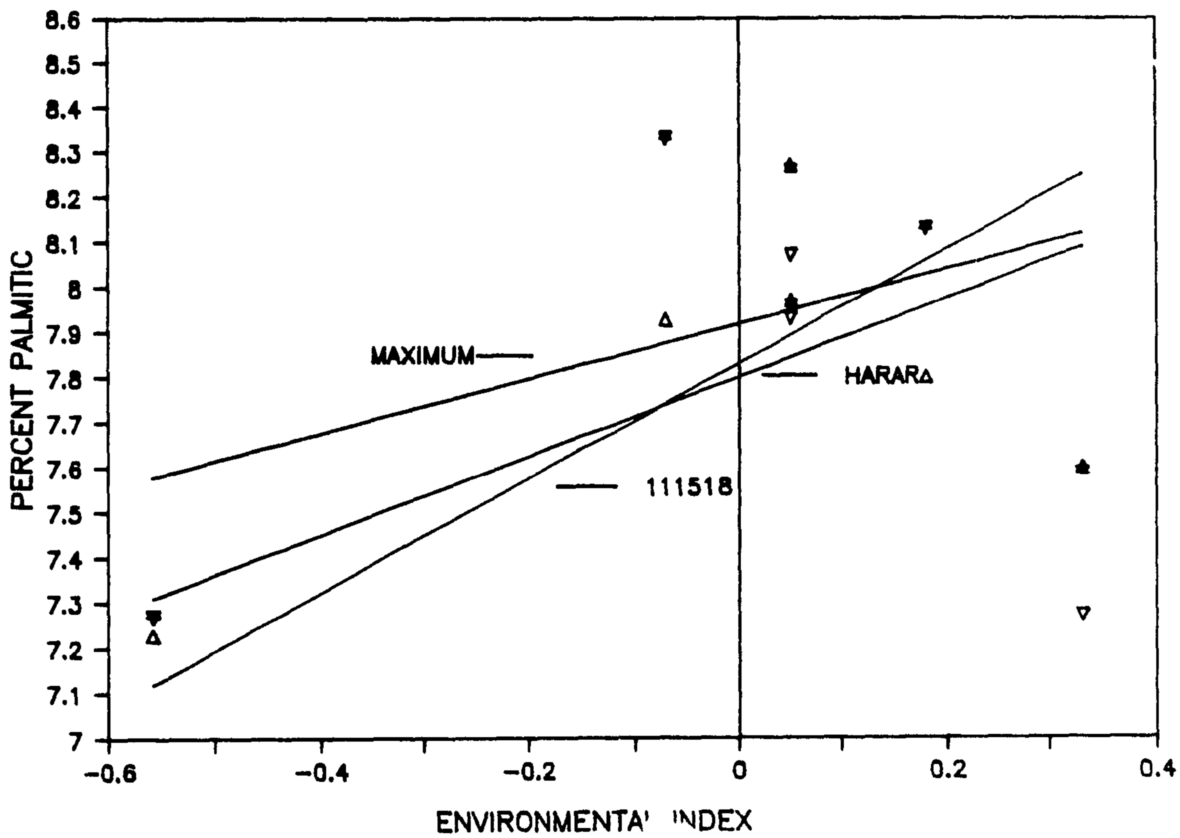

Fig. 8
Comparison of two elite sesame lines with the standard, maximum response

interaction mean square [GE(MS)] to be considered as superior. Based on their Pi values the experimental lines 111518 together with Harar are selected and therefore, plotted with the maximum response to identify their relative adaptability. Fig. 8 shows that line 111518 is superior yielding in improved environments, while Harar runs more or less parallel to the maximum response indicating that it is good across all sites.

4.2.2.2 Stearic Acid

Results of the pooled analysis of variance for stearic acid are shown in Appendix 16 a. With the exception of line-site and line-year-site interaction which showed no significant effect on stearic acid synthesis, the remaining sources were significant differences with probabilities ranging from 0.004 to less than 0.001.

The non significant effect of line-site interaction indicates all lines behaved in similar fashion in all sites. The major significance of the line-year interaction suggests that lines responded differently to environmental changes for stearic acid synthesis

Unlike palmitic acid, the synthesis of stearic was not enhanced by warm climate as indicated by the high environment mean obtained for stearic acid at Bisidimo (Table 11). The average seasonal temperature for Bisidimo was 26°C while the other two warmer sites were approximately 35° C. The difference in stearic content between Abobo and Bisidimo in the 1987 and 1988 trial season is 1.10 and 1.57% respectively. This amounts to almost 30% less of stearic acid accumulated at Abobo.

Similar to palmitic acid, the regression slopes for stearic acid were found to be homogeneous (Appendix 16 b). In this case the significance

Table 11

Mean stearic acid percent of eight sesame lines grown at three sites in Ethiopia over two years

	Environment						
	1987			1988			
Lines	Bisidimo	Abobo	Melka W.	Bisidimo	Abobo	Melka W.	Line mean
7B	6.63 a	4.47 b	5.23 b	5.90 b	4.67 abc	4.83 ab	5.29
Harar	6.10 ab	4.47 b	5.07 b	6.13 b	4.33 c	5.03 ab	5.19
111518	5.80 b	5.13 a	5.33 ab	6.30 ab	5.03 a	5.20 ab	5.47
Fincha	5.90 b	4.77 ab	5.20 ab	6.80 a	4.60 abc	5.17 ab	5.41
76/48R	5.71 b	4.83 ab	5.83 a	6.23 ab	4.97 ab	5.27 a	5.47
5E	5.93 b	4.80 ab	5.47 ab	6.10 b	4.43 abc	5.03 ab	5.30
207958	5.77 b	4.70 ab	4.87 b	5.30 c	3.57 d	4.63 b	4.81
111519	5.97 b	5.03 ab	5.07 b	5.77 bc	4.37 bc	4.60 b	5.14
mean	5.88	4.78	5.26	6.07	4.50	4.[illegible]	

Standard error = 0.193

'Within each environment, line means followed by the same letter are not significantly different at the 0.05 level by Duncan's multiple range test.'

line-environment interaction observed in the analysis was mainly due to non linear effect which showed significant differences ($p = 0.039$).

Regression analysis on individual lines shown in Table 12 indicates that the experimental line 5E with regression coefficient 1.00 and stearic acid mean percent of 5.30 is relatively well buffered against environmental variations and hence generally adaptable. On the other hand lines 111518 and 76/48R with the highest stearic mean content and regression coefficient value above average, responded less to changing environment and can be regarded as suitable to less favorable environment. Harar and Fincha are more adaptable to favorable environment (Fig. 9)

None of the lines tested gave any superior performance by the procedural approach method of statistic. That is, all the lines have higher Pi value and their distance mean squares from the maximum response is large. They all have small line-environment mean square which indicate that most lines exhibited similar response patterns at all sites. (Table 12). Since all of the experimental lines showed significance at 0.05 level and are, therefore, not superior in performance, plotting the observed values of any of the experimental lines with that of the maximum response against the site mean is not necessary.

Table 12

Various measures of adaptability determined for stearic acid content of eight sesame lines grown at three sites in Ethiopia in 1987 and 1988.

Environment (Loc.&Year)	Max. Response(%)	Line	Min. Response(%)	Line	Response Range
Bisidimo '87	6.63	7B	5.71	76/48R	0.92
Abobo '87	5.13	111518	4.47	111518 & 7B	0.66
Melka Werer'87	5.83	76/48R	4.37	207958	0.96
Bisidimo '88	6.80	Fincha	5.30	207958	1.50
Abobo '88	5.03	111518	3.57	207958	1.46
Melka Werer'88	5.27	76/48R	4.60	111519	0.67

Line	Mean steric(%)	Pi	MS(GE)	b	p	R^2
Max. response	5.78	0	-	1.20		
7B	5.29	0.1607 *	0.0390 ns	1.19 **	0.009	0.84
Harar	5.19	0.1427 *	0.0148 ns	1.19 **	< 0.001	0.96
111518	5.47	0.0994 *	0.0493 ns	0.72 **	0.004	0.89
Fincha	5.41	0.1045 *	0.0342 ns	1.19 **	0.005	0.88
76/48R	5.47	0.1054 *	0.0578 ns	0.74 *	0.020	0.77
5E	5.30	0.1363 *	0.0171 ns	1.00 **	< 0.001	0.98
207958	4.81	0.5531 *	0.0778 ns	1.03 *	0.015	0.80
111519	5.14	0.2473 *	0.0383 ns	0.92 **	0.005	0.88

*, ** significant at 0.05 and 0.01 probability level respectively
ns non significant
Pi = superiority measure
MS(GE)= mean squares of genotype - environment
R^2= determination coefficient
b =regression coefficient
'cut off' point of Pi = 0.0798
'cut off' point for MS(GE) = 0824

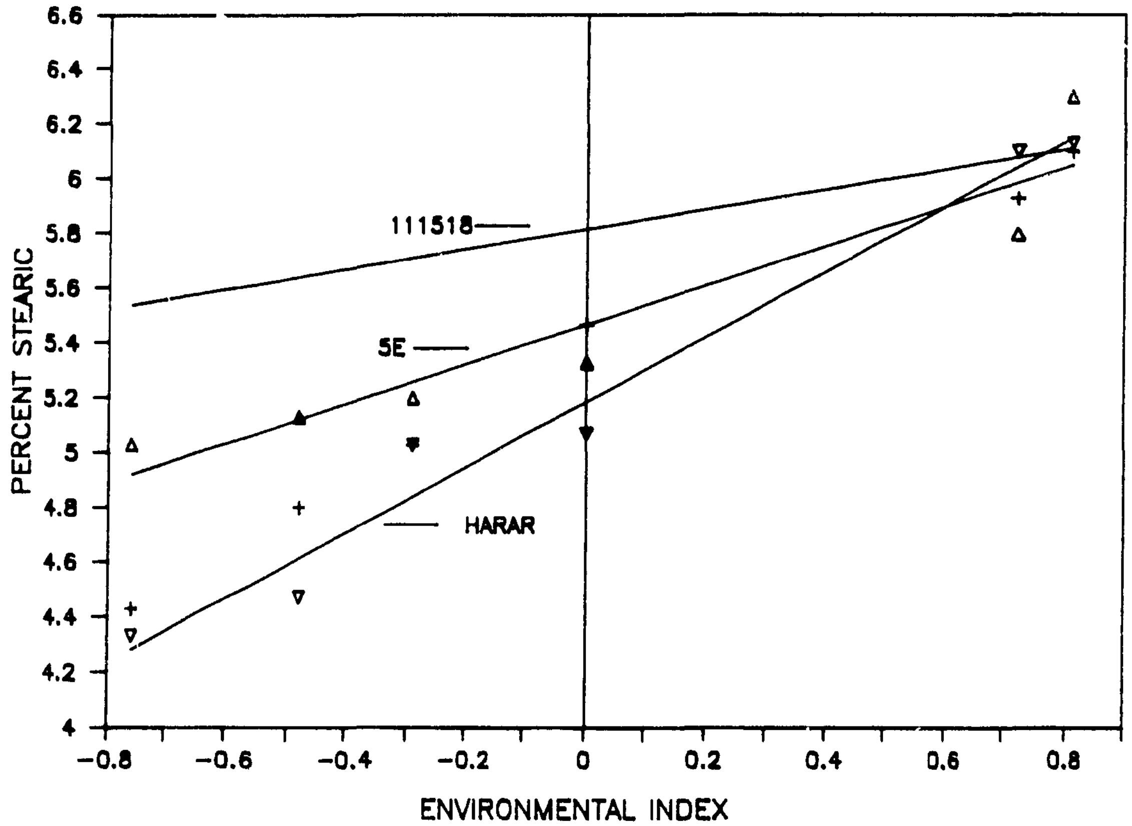

Fig. 9

Stearic acid response of three sesame lines tested at several environments

4.2.2.3 Oleic Acid

By simply looking at the site mean, one finds that the amount of oleic acid produced is higher at the warm climate sites of Abobo and Melka Werer. The percent of oleic acid produced at Bisidimo during the 1987 and 1988 cropping season is lower by 3.45 and 3.52% than at Abobo (Table 13). When compared with Melka Werer, the difference amounts to 2.78 and 2.88% for both years. This results are in agreement with

Table 13

Mean oleic acid percent of eight sesame lines grown at three sites in Ethiopia in 1987 and 1988.

	Environment						
	1987			1988			
Lines	Bisidimo	Abobo	Melka W.	Bisidimo	Abobo	Melka W.	Line mean
7B	35.20 d	40.43 ab	40.27 abc	37.27 a	39.73 ab	38.87 a	38.63
Harar	33.63 e	40.17 ab	37.10 d	35.20 b	38.63 bc	39.20 a	37.32
111518	41.23 a	40.47 ab	41.50 a	37.80 a	40.87 a	39.60 a	40.25
Fincha	37.33 bc	41.57 a	39.93 bc	35.60 b	40.90 a	39.23 a	39.09
76/48R	36.23 cd	39.53 b	40.37 abc	35.03 b	37.77 c	38.33 a	37.88
qE	37.20 bc	40.67 ab	39.70 bc	35.40 b	40.33 a	38.73 a	38.67
207958	37.87 b	41.53 a	39.30 c	35.27 b	37.90 c	38.77 a	38.44
111519	39 70 a	40.00 ab	40.90 ab	37.07 a	40.70 a	38.93 a	39.54
mean	37.10	40.55	39.88	36.08	39.60	38.96	

Standard error = 0.470

'Within each environment, line means followed by the same letter are not significantly different at the 0.05 level by Duncan multiple range test.'

those reported for soybean in the U.S.A. where warmer climate is believed to favor the production of the mono-unsaturated fatty acid (Cherry J.H et al 1985).

Pooled analysis of variance indicates that all sources, except for year-site interaction effects, showed significant difference for oleic acid production (Appendix 17 a).

The joint regression analysis (Appendix 17 b) also showed that there is a significant effect of environment on oleic acid synthesis ($p < 0.001$). Hence, environmental factors played a role in the behavior of lines for oleic acid synthesis. Line-environment interaction was also significant ($p < 0.001$) indicating the different response pattern of lines to environmental variations. Further partitioning of line-environment interaction showed that slopes are homogeneous (P=0.279) and that the larger part of the interaction is due to the non linear component of the interaction.

According to Table 14 the line 7B with b=0.99 and 207958 with regression coefficient 1.06 could be characterized as having responded moderately to the environment and may be regarded as adaptable at all the sites. However, their mean stearic acid content is not among the highest and they have low R^2. Since none of the lines evaluated showed a slope closer to 1.00 and a mean high enough to qualify as generally adaptable at all sites, 7B and 207958 may be cautiously regarded as that. Fincha was found to be as suitable in high yielding environment. Fig. 10 shows the response pattern of 7B and Fincha.

Table 14

Various measures of adaptability determined for oleic acid content of eight sesame lines grown at three sites in Ethiopia in 1987 and 1988.

Environment (Loc.&Year)	Max. Response(%)	Line	Min. Response	Line	Response Range
Bisidimo '87	41.23	111518	33.63	Harar	7.60
Abobo '87	41.57	Fincha	40.00	111519	1.57
Melka Werer' 87	41.50	111518	37.10	Harar	4.40
Bisidimo '88	37.80	111518	35.03	76/48R	3.10
Abobo '88	40.90	Fincha	37.77	76/48R	3.13
Melka Werer' 88	39.60	111518	38.33	76/48R	1.27

Line	Mean oleic(%)	Pi	MS(GE)	b	p	R^2
Max. Response	40.43	0	-	0.63		
7B	38.63	3.4463 *	1.8173 *	0.99 *	0.036	0.70
Harar	37.32	7.5960 *	2.7548 *	1.19 *	0.049	0.66
111518	40.25	0.1009 ns	0.0786 ns	0.50 ns	0.183	0.39
Fincha	39.09	1.8876 *	0.9898 *	1.30 **	< 0.001	0.96
76/48R	37.88	4.1267 *	0.8585 *	1.09 **	0.007	0.85
5E	38.67	2.2610 *	0.7093 *	1.17 **	< 0.001	0.97
207958	38.44	2.6935 *	0.7076 *	1.06 *	0.019	0.77
111519	39.54	0.5156 ns	0.1255 ns	0.66 ns	0.056	0.64

*, ** significant at 0.05 and 0.01 level respectively
ns = non significant
Pi = superiority measure
MS(GE)= mean squares of genotype - environment
R^2= determination coefficient
b =regression coefficient
'cut off' point for Pi = 0.5216
'cut off' point for MS(GE) = 0.5390

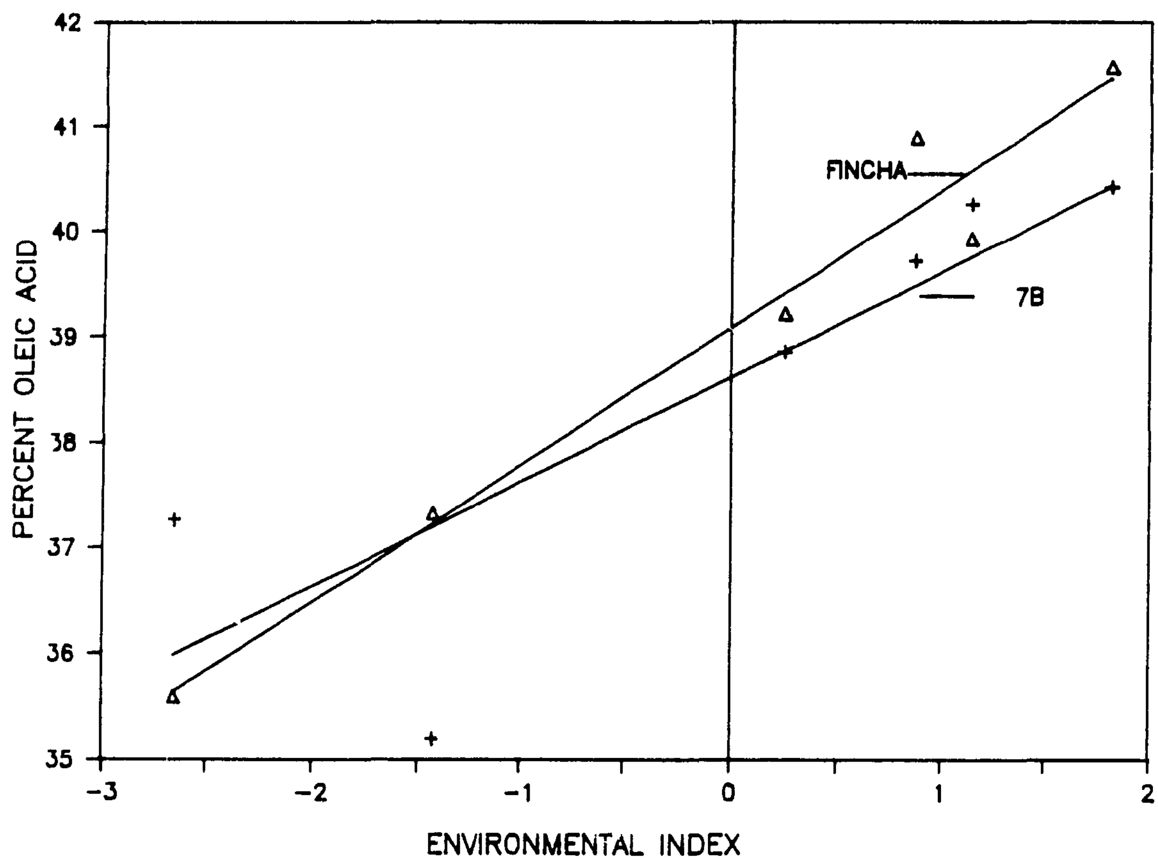

Fig. 10
Response of two sesame lines for oleic acid
to several environments

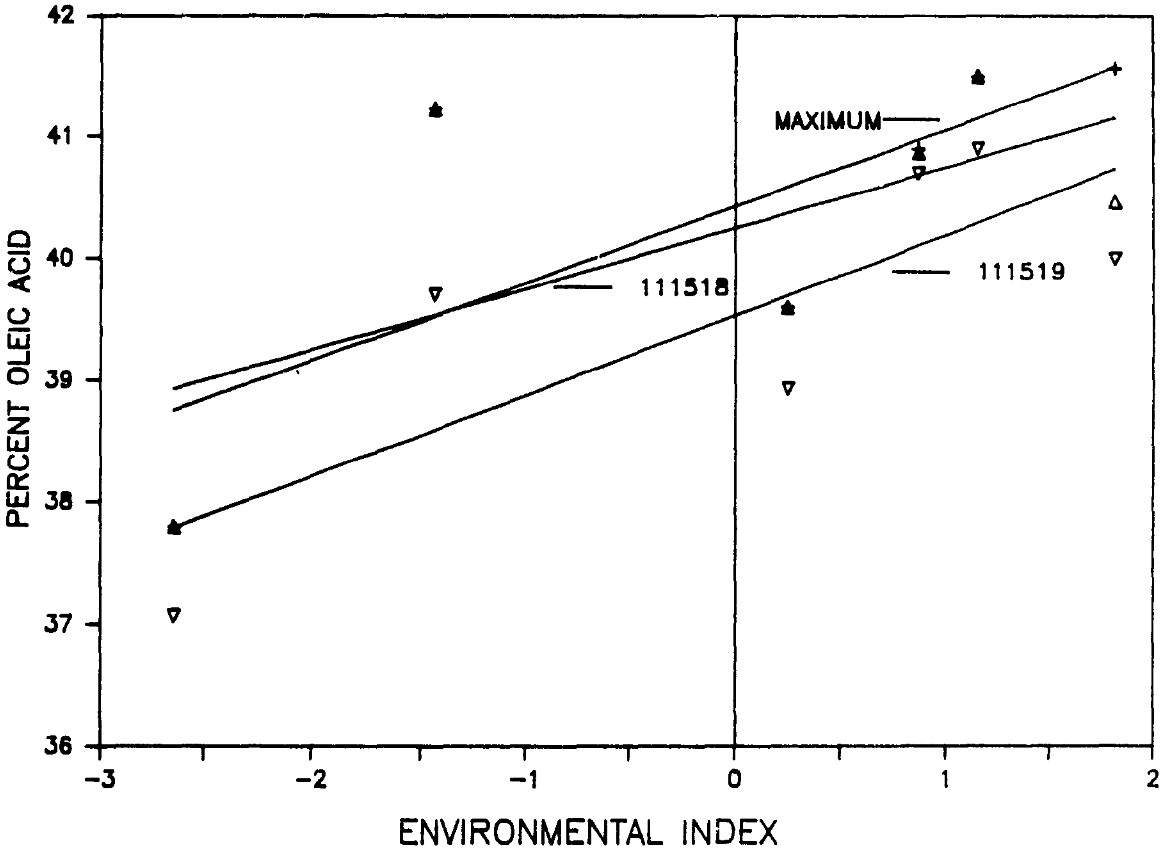

Fig. 11
The relationship of two superior oleic acid yielders to the maximum response

The procedural approach method of statistics identifies lines 111518 and 111519 as closer to the maximum response (Table 14). They also have lower [GE(MS)] than any of the experimental lines under evaluation. It is,however, important to note that the production variation as measured by the determination coefficient is lower for these lines, and one cannot state conclusively that they are indeed superior to the other lines. Fig. 11 demonstrates the response pattern of line 111518 and 111519 in relation to the standard, the maximum response. According to Fig. 11 line 111519 runs parallel to the maximum response and therefore it is suitable at poor and productive environments alike. On the other hand 111518 runs further away from the standard as the environment improves and may be considered as adaptable to poorer environment.

4.2.2.4 <u>Linoleic acid</u>

More linoleic acid was synthesized in the cooler environment of Bisidimo than in Abobo and Melka Werer. The variation being 3.90 and 2.88% for the year 1987 and 3.25 and 2.49 for the 1988 respectively (Table 15). These results are consistent with previous report by Harris et al. (1969) on flax, sunflower and castor bean.

The data were subjected to analysis of variance to determine the significant of site, year and line effects on linoleic acid composition. All sources except year-site interaction had significant effect on linoleic synthesis. The significant line-year and line-site interactions , indicate a yearly environmental variation causing lines to behave differently (Appendix 18 a).

Table 15

Mean linoleic acid content of eight sesame lines grown at three sites in Ethiopia in 1987 and 1988.

Lines	1987 Bisidimo	1987 Abobo	1987 Melka W.	1988 Bisidimo	1988 Abobo	1988 Melka W.	Line mean
7B	51.37 ab	45.40 a	45.67 bc	49.27 bc	45.90 bc	47.97 a	47.60
Harar	52.57 a	44.80 a	48.67 a	52.37 a	46.67 b	46.13 a	48.60
111518	44.00 d	45.03 a	44.63 c	47.73 cd	44.13 c	46.10 a	45.13
Fincha	49.67 b	44.53 a	46.17 bc	51.17 ab	43.27 d	47.17 a	46.97
76/48R	50.10 b	46.20 a	44.77 c	51.37 a	47.87 ab	47.47 a	47.95
5E	49.90 b	45.53 a	45.53 bc	51.53 ab	46.27 bc	47.50 a	47.71
207958	49.13 b	44.83 a	47.43 ab	51.73 ab	49.07 a	48.47 a	48.44
111519	46.70 c	45.93 a	45.53 bc	45.80 d	49.83 a	48.33 a	47.02
mean	49.18	45.28	46.30	49.88	46.63	47.39	

Standard error = 0.730

'Within each environment, line means followed by same letter are not significantly different at the 0.05 level by the Duncan's multiple range test.'

The joint regression analysis indicates environment and line had significant effect on linoleic percent ($p < 0.001$). But the partitioning of line-environment interaction into linear and non linear components indicates a non significant effect for the linear source (Appendix 18 b). In other words, the regression model was unable to predict the response of lines to different environments for linoleic acid production. In such case it is admissible to rely upon the site mean and the regression coefficient (b) computed for individual lines tested against their own remainder mean square, to estimate the performance of the experimental lines with respect to environmental effects.

According to Table 16 the line 76/48R with a mean of 47.95% and 'b' = 1.06 can be interchangeably considered with 7B with a mean of 47.60% and regression coefficient of 0.99 as suitable for all production environments. The line 5E appears to synthesize more linoleic acid in favorable environment. On the other hand line 207958 with regression coefficient of 0.92 and the highest linoleic acid mean can be characterized as adaptable to poor production environment. Fig.12, shows the adaptability feature of 76/48R, 5E and 207958 based on their regression slopes and overall mean.

The procedural approach of superiority measure failed to identify lines with superior performance across all sites. The Pi value of all lines were very high. The highest linoleic acid yielding line had a Pi value of 1.3962, slightly higher value than the 'cut off' point which determines whether the experimental lines under test is superior and generally adaptable. Despite their high Pi value the majority of the lines have low line- environment interaction mean square [GE(MS)] which demonstrates not their superior performance, but their ability to grow in the testing sites without much environmental influence.

Table 16

Various measures of adaptability determined for linoleic acid content of eight lines evaluated at three sites in Ethiopia in 1987 and 1988.

Environment (Loc.& Year)	Max. Response(%)	Line	Min. Response(%)	Line	Response Range
Bisidimo '87	52.57	Harar	44.00	111518	8.57
Abobo '87	46.20	76/48R	44.53	Fincha	1.67
Melka Werer'87	48.67	207958	43.80	111518	4.87
Bisidimo '88	52.73	Harar	47.73	111518	5.00
Abobo '88	49.07	207958	43.27	Fincha	5.80
Melka Werer'88	48.47	207958	46.10	111518	2.37

Line	Mean Linoleic(%)	Pi	MS(GE)	b	p	R^2
Max. response	49.61	0		0.75		
7B	47.60	3.4969 *	0.6653 ns	0.99 *	0.025	0.75
Harar	48.60	1.9167 *	0.9134 ns	1.40 *	0.023	0.76
111518	45.13	11.6081 *	4.2081 *	0.45 ns	0.191	0.38
Fincha	46.97	6.2816 *	0.2873 ns	1.33 *	0.006	0.88
76/48R	47.95	3.0986 *	1.0007 ns	1.06 *	0.009	0.84
5E	47.71	3.1259 *	0.5646 ns	1.79 **	< 0.001	0.98
207958	48.44	1.3962 *	0.6634 ns	0.92 *	0.032	0.72
111519	47.02	5.9423 *	1.8714 *	0.66 ns	0.047	0.66

*, ** significant at 0.05 and 0.01 level respectively
ns = non significant
Pi = superiority measure
MS(GE) = mean squares of genotype - environment
R^2 = determination coefficient
b = regression coefficient
'cut off' point for Pi = 1.1193
'cut off' point for MS(GE) = 1.1566

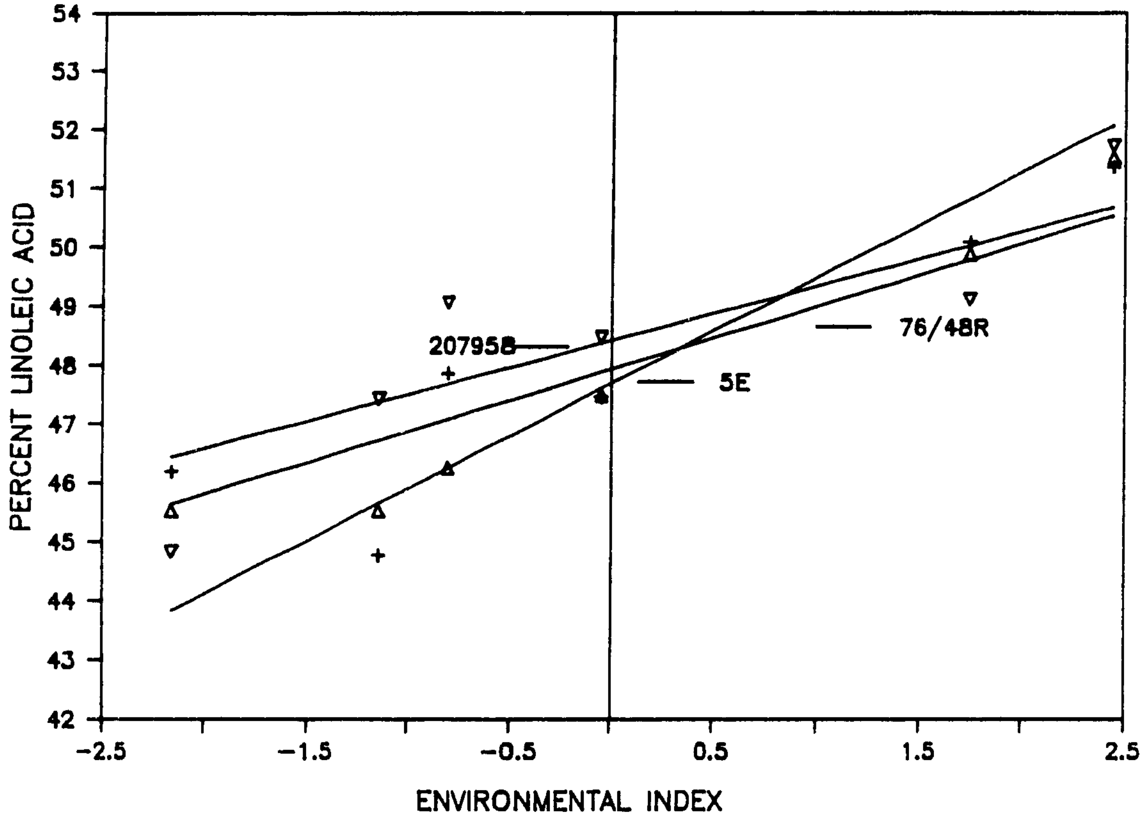

Fig. 12

Three sesame lines with varying degree of adaptability to the environment for linoleic acid

4.2.3 <u>Protein Content</u>

The crude protein mean value ranged from 26.59% at Abobo to 22.65% at Bisidimo 1987. In 1988 the site mean differences were not as large as those of 1987 (Table 17). In general the protein value was relatively higher in the 1987 season at two sites.

Table 17

Mean protein percent of eight sesame lines grown at three sites in Ethiopia in 1987 and 1988

	Environment						
	1987			1988			
Lines	Bisidimo	Abobo	Melka W.	Bisidimo	Abobo	Melka W.	mean
7B	20.37 d	28.13 a	26.60 bc	23.97 bc	22.03 c	24.87 b	24.32
Harar	26.97 a	25.63 cd	25.20 c	22.60 cd	24.70 b	24.83 b	24.98
111518	20.38 d	24.50 d	26.33 bc	23.13 cd	23.33 c	23.53 b	23.53
Fincha	23.37 bc	26.37 bc	25.60 c	22.27 d	25.07 b	27.30 a	24.50
76/48R	22.37 bc	26.47 bc	27.67 ab	24.77 ab	25.10 b	25.03 b	25.24
5E	22.20 bc	27.17 ab	25.10 c	25.80 a	26.57 a	23.53 b	25.07
207958	23.60 b	26.83 abc	28.23 a	24.60 ab	24.93 b	23.93 b	25.35
111519	21.97 c	27.63 ab	26.50 bc	25.27 ab	25.03 b	24.43 b	25.14
mean	22.65	26.59	26.30	24.05	24.60	24.68	

Standard error = 0.479

'Within each environment, line means followed by same letter are not significantly different at the 0.05 level by the Duncan's multiple range test.'

Pooled analysis of variance (Appendix 19 a) showed highly significant differences for all sources ($p < 0.001$).

The joint regression analysis on the data is given in Appendix 19 b. All sources, except for heteregenous 'b', showed significance ($p < 0.001$). Thus, the results indicate that there are diferences among the lines for protein content as well as variations in the environments in which they grew. Significant line-environment interaction was found to be due to residual effect and was highly significant ($p < 0.001$). Be that as it may, lack of significance for linear response does not rule out the possibility that some lines taken separately may have significant slope differences (Perkins and Jinks 1968). Testing the regression slope values with their remainder mean square revealed that five out of eight lines under study gave significantly different linear response (Table 18).

The line 207958 with the highest protein mean value and regression coefficient 'b' of 1.07 was found to be generally adaptable to all production environments. As shown in Fig. 13 line 7B is well suited to favorable environments.

The procedural approach of superiority measure of statistics failed to identify genotypes with superior protein value. Hence, none showed a closer and parallel response when compared with the maximum response , a standard measurement against which other lines are evaluated for their pattern of adaptability. As shown in Table 18, the Pi and [MS(GE)] values of all lines are larger than the 'cut off' point figure (0.4819) and (0.4980) respectively. This implies that some lines are less than superior in performance and their response pattern is variable across all sites.

Table 18

Various measures of adaptability determined for protein content of eight sesame lines grown at three sites in Ethiopia, 1987 and 1988.

Environment (Loc.&Year)	Max. Response(%)	Line	Min. Response(%)	Line	Response Range
Bisidimo '87	26.97	Harar	20.37	111518 & 7B	6.60
Abobo '87	28.13	7B	24.50	111518	3.63
Melka W. '87	28.23	207958	25.10	5E	3.13
Bisidimo '88	25.80	5E	22.27	Fincha	3.53
Abobo '88	26.57	5E	22.03	7B	4.54
Melka W. '88	27.30	Fincha	23.53	111518 & 5E	3.77

Lines	Mean Protein(%)	Pi	MS(GE)	b	p	R^2
Max.Response	27.17	0	-	0.45		
7B	24.32	7.8603 *	4.3181 *	1.78 **	0.007	0.85
Harar	24.99	3.2601 *	1.0969 *	0.08 ns	0.873	0.00
111518	23.53	7.7720 *	1.5186 *	1.21 **	0.008	0.85
Fincha	24.50	3.7320 *	1.5861 *	0.78 ns	0.199	0.38
76/48R	25.24	3.0659 *	1.3946 *	1.15 **	0.002	0.92
5E	25.06	4.1371 *	2.1411 *	0.84 ns	0.148	0.44
207958	25.35	3.0563 *	1.1713 *	1.07 *	0.018	0.79
111519	25.14	3.9837 *	2.1213 *	1.22 **	0.005	0.88

*, ** significant, $p > 0.05$ and 0.01 level respectively

ns non significant

Pi = superiority measure

MS(GE)= mean squares of genotype - environment

R^2= determination coefficient

b =regression coefficient

'cut off' point for Pi = 0.4819

,cut of ' point for MS(GE) = 0.4980

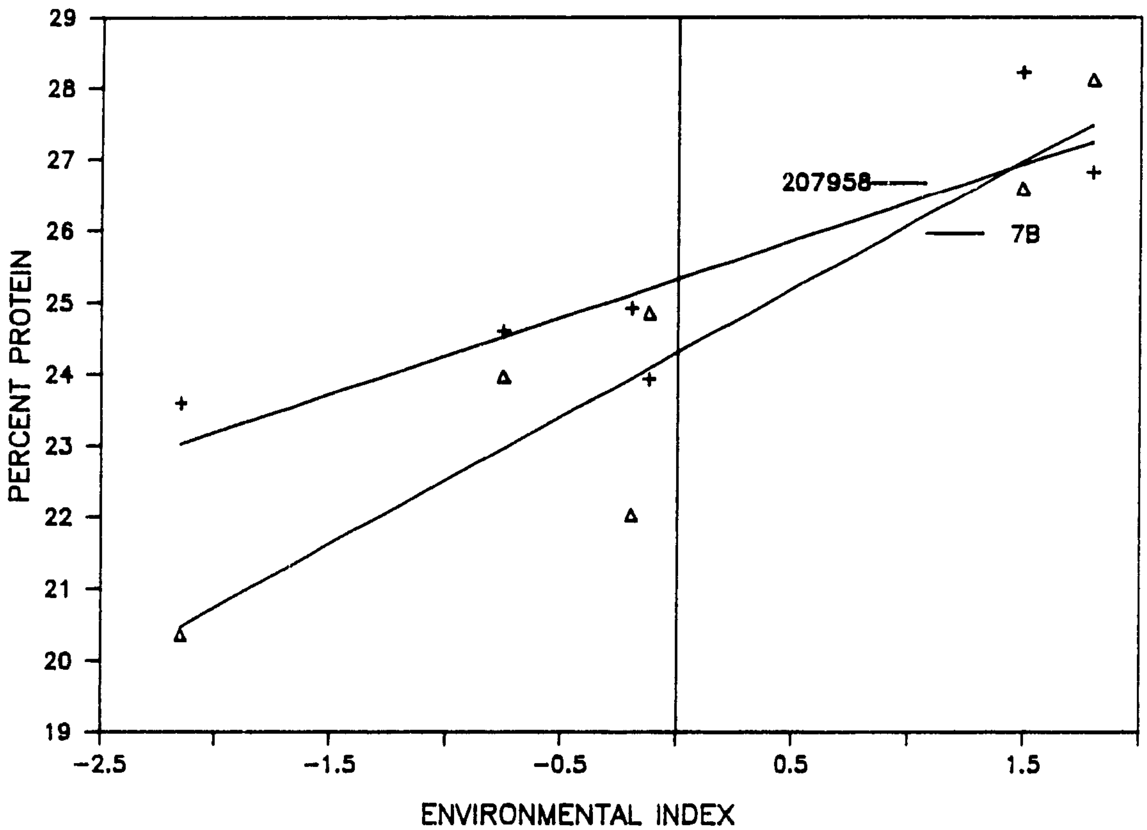

Fig. 13
Protein content response of two sesame lines evaluated at several environments

4.2.4 Correlation of the chemical constituents

The combined correlation covering the 1987 and 1988 cropping season for the chemical constituents of sesame seed are presented in Table 19, a and b. The result of the analysis indicates a negative association of protein with oil content. The negative correlation between protein and oil content is of modest magnitude (r=-0.47) and statistically significant, $p < 0.001$, (Table 19 a).

Association between stearic on one hand and oleic and linoleic on the other gave significant positive and negative correlation respectively. Likewise, oleic and linoleic are highly significant and negatively associated (r=-0.95) (Table 19 b). Although, palmitic acid is significantly and negatively associated with stearic acids, the magnitude of the association is low (r=-0.25). There was no significant correlation between palmitic on one hand and oleic and linoleic on the other.

The association of linoleic and oleic acids adjusted to palmitic and stearic acid effects gave a highly significant negative correlation of r= -0.88 (Table 19 c). Similarly, highly significant negative associations were obtained for palmitic and linoleic acids adjusted to stearic and oleic acids (r=-0.69). On the other hand the association of palmitic and oleic acids adjusted for stearic and linoleic acids gave a negative and significant r value (r=-0.55). The correlation between palmitic and stearic acids also showed significance at 0.015 probability level and a negative association of lower magnitude (r=-0.25).

The negative association of protein with oil is in conformity with previous findings in sesame (Dhawan et al. 1972, Dhindsa K.S et al. 1975, Udayasekhara P.R et al. 1981).

Table 19 a.

Combined correlation coefficients for the 1987 and 1988 of days to maturity, oil and protein content

variables			r	p
protein %	vs	oil content	-0.474^{**}	< 0.001
maturity	vs	protein	-0.224^{**}	0.007
maturity	vs	oil content	0.385^{**}	< 0.001

Table 19 b

Correlation coefficients among fatty acids for the combined years of 1987 and 1988

	Fatty acid composition of oil in %			
	Palmitic	Stearic	Oleic	Linoleic
Palmitic	-	-0.2505^{**} 0.0025	-0.1536^{ns} 0.0660	-0.1739^{ns} 0.8361
Stearic	-	-	0.6821^{**} < 0.001	-0.7698^{**} < 0.001
Oleic	-	-	-	-0.9543^{**} 0.001

Table 19 c

Partial correlation coefficient of the chemical constituents of sesame seed

variables			adjusted for		r	p
1	4	.	2	3	-0.693^{**}	< 0.001
3	4	.	1	2	-0.882^{**}	< 0.001
1	2	.	3	4	-0.252^{*}	0.01
1	3	.	2	4	-0.549^{**}	< 0.001

1 = palmitic 2 = stearic 3 = oleic 4= linoleic

In sesame oleic acid is negatively correlated with linoleic acid (Yermanos et al. 1972, Brar 1982). Yermanos et al. (1967) also, working with safflower found significant negative correlation between oleic acid and linoleic acid as well between oleic and palmitic acid.

With Brassica campestris Ahuja et al. (1989) found positive but not significant relationship between palmitic and stearic and palmitic and linoleic. This result does not agree with our finding.

4.2.5 General Discussion

The influence of environmental factors, specifically moisture and temperature on the composition of fatty acids, protein and oil content of sesame has not been extensively reported in the literature. Seegeler (1983) reported the decrease of oil content in sesame seed in Ethiopia with increasing elevation. The claim that cold climate reduces sesame seed oil content could be based on the fact that because of the intermediate habit of flowering, late developed sesame capsules may mature before they are fully developed and this could decrease oil percent (Saha 1984).

Friederich J.C (1949) working with linseed (Linum usitatissimum L) gave a different assessment on the effect of temperature and moisture on the deposition of oil. He observed that as a result of factors such as high temperature and low moisture reserve in the soil the crop ripens rapidly giving little time for oil formation in the seed.

Weiss (1983), reviewing other works in relation to oil yield stated that trials in Venezuela gave the highest oil percent at lowest altitudes and in El Salvador a decrease of oil percent was recorded in regions with elevations above 600 m. The same can be said of the research findings obtained from Nepal. Canvin (1965) reported high oil content for tropical and semi tropical oil seeds with increasing temperature.

The present study shows that production of oil was higher at the high altitude and relatively colder site of Bisidimo (Table 6). The present findings is further corroborated by the 1985 preliminary test results obtained in Ethiopia, in which oil percent was higher at Babile, a site not far from Bisidimo (1450 m.a.s.l.) but higher by 200 m. The lowest oil percent was recorded at Meiso with an elevation of 900 m and a seasonal rainfall of 400 mm (Ann. 1985). Harris et al. (1978) also reported a decrease of oil content in sunflower with elevated temperature. However, he attributed this phenomenon to other confounding effects in the field such as moisture stress during the plant growth and seed development stage.

Both moisture and nutrients, especially nitrogen, are known to decrease oil yields in sesame (Singh et al. 1987 and Mitchel et al. 1976). In India, increased nitrogen application was observed to reduce oil percent drastically (Chakraborty 1984). Similar results were obtained in cotton seed (Sawan et al. 1988). The results obtained in this study also show that environmental factors such as low moisture and nutrient reserve in the soil and colder climate positively influenced the total oil content.

In barley, high protein content was associated with high soil nitrogen and warm climate (Foster et al. 1987). Singh et al. (1960) reported the increase of protein in sesame seed at the expense of oil with the addition of nitrogen.

The present study shows that Bisidimo, with relatively low fertility and cool temperatures, (Appendix 1 Table a, and c) has relatively lower protein content per seed (Table 17). There was also report which suggests that high moisture in the soil is inversely related with protein. In this study the sites with abundant moisture seem to encourge the synthesis of more protein.

Kinman (1954) reported that the chemical composition of oil seeds are affected not only by their genetic make up but also by the agro-climatic conditions under which the crop is grown. Similar results were reported in India on sesame, where location influenced fatty acid synthesis (Brar 1982a).

The most extensively studied environmental factor that is believed to influence the biosynthesis of fatty acids is temperature. Cold temperature induces the enzymatic activity of the desaturase that leads to more synthesis of polyunsaturated fatty acids (Saastamoinen et al. 1989)). The present study lead us to believe that may be the case.

In agreement with the literature reviewed low palmitic acid values were obtained at the mid-altitude and relatively cool site of Bisidimo in both years of experimentation. In contrast the values for stearic acid synthesized at each environment are not also in agreement with the previous findings in sesame by Brar (1980). In other words, the effect of altitude and consequently temperature on greater amount of stearic acid production is not apparent at the warmer locations of Abobo and Melka Werer (Table 8).

The proportion of the unsaturated fatty acids was also altered with changing temperature. The mono-unsaturated oleic acid content was found to be higher at the warmer environments of Abobo and Melka Werer than at

Bisidimo. Schofield and Bull (1944) and Alders (1949) observed that increase of linoleic and linolenic acids in soybean were accompanied by decrease in oleic acid at lower temperature. Conversely, in Korea, sesame grown under mild southern climate gave higher oleic acid content than those grown in the northern region of the country (Lee *et al.* 1981). Cherry *et al.* (1985) also reported that soybean seeds produced in the southern production area (on average of 5.5^{o}C hotter than the northern area) gave significantly higher oleate than linoleate acid.

Among the lines, 111518 gave the highest mean stearic and oleic acids over all environments (Tables 11 and 13). However, line 111518 was found to be statistically insignificant for oleic acid and adaptable to poorer environments for stearic acid. Over environments, 5E and 7B was found to be generally adaptable across environment for stearic and oleic acids respectively. Nevertheless, 7B has modest oleic acid mean and low R^2 value to be confidently relied upon.

The line 207958 with the lowest palmitic acid mean value is less adaptable to all production environments when compared with 7B which have a modest overall mean and regression coefficient near 1.00. On the other hand, Harar, was found to be superior and generally adaptable to all production environments by the procedural approach of superiority method. This line along 111518 gave the highest palmitic acid value.

Interestingly enough line 111518 has also the highest overall mean for palmitic acid. Thus, 111518 may prove to be important as a source of breeding material in the improvement of lines which may have other desirable characters but lacking the potential of being high palmitic, stearic and oleic acid yielders. Moreover, in predictably low yielding peasant environment this line could prove to be indispensable for the production of such fatty acids.

The lines 7B and 76/48R showed a tendency of general adaptability for oleic and linoleic acids respectively. They both have above average mean values for oleic and linoleic acids. 7B has also been identified to be generally adaptable for linoleic acid.

Differences among lines for oil and protein contents were of modest magnitude. The line 111518 gave the highest oil percent but also the lowest protein value of 20.38%. This line along with 111519 was also characterized as being average in adaptability for oil content. Line 207958 with higher mean protein value showed average adaptability for protein content.

Protein and oil contents are negatively correlated. This implies that selection for both characters may be difficult because of relatively narrow range of variability within the test lines.

The positive and significant correlation between oil percent and maturity shown in Table 19 a seems to confirm earlier reports by Khidir and Osman (1970) and Saha and Bahrgava (1984) who observed that maximum oil concentration occurs in sesame 28-30 days after anthesis. Thereafter, there is a gradual decrease of oil of up to 8% in 40-50 days-old seeds that may be attributed to an increase in seed dry weight without corresponding change in oil concentration. In this study, 111518 with early to flower and mature gave the highest amount of 45.36 percent oil, while Harar with very late to flower and mature gave the lowest oil percent.

Furthermore the results also suggest a solution to the problem of when to harvest sesame. It suggests that lines with some degree of uniform maturity could be harvested while the pods are still green and before the start of pod shattering with little effect on the yield of oil. The estimated loss of sesame seed due to pod shattering and hence dispersal of seeds to the ground is around 30% (Gerakis, et al. 1969).

Protein is negatively correlated with maturity (Table 19 a). A study on protein formation showed that the deposition of protein continues after the crop is declared to be physiologically mature in sesame (Khidir and Khattab 1972) and at least in one of two soybean cultivars (Yazdi Samedi et al., 1976). Thus early maturing lines are not necessarily with high protein value. That may explain in part that the early maturing lines such as 111518 and 7B gave low protein value (Table 34).

The partial correlation coefficient of the fatty acid combinations adjusted to one another for removing effects that may influence their actual relationship, in effect reveals the natural sequence of the fatty acid biosynthesis. Thus, the significant negative correlation that oleic acid had with linoleic adjusted to palmitic and stearic acids indicate that relationship between the two is temperature dependent, in that, with lower temperature oleoyl-CoA becomes an effective precursor for the desaturation of oleic acid to linoleic (Stymne and Applelqvist, 1978). A study on Nicotinia tabacum lipid cells showed a decrease of oleate desaturation by three fold at 17^{o}C incubated for one hour as compared to cells incubated at the same period but at 20^{o} to 26^{o} C. It is, therefore, possible to assume that the synthesis of linoleic acid from oleic acid by successive desaturation explains the high negative correlation found between the concentration of these acids.

Furthermore, the negative correlation between palmitic and linoleic can possibly be attributed to the synthesis of very long-chain fatty acids ($>C_{18}$) from palmitic by chain specific elongases (Harwood, 1988).

When considering the validity and similarity of the two statistical methods in describing the response of lines to the environment, one admits that there is but remote similarity. The main reason for this is that while the regression model considers treatment mean on top of the regression coefficient to provide a clue on the response of treatments to environmental variables under study, the procedural approach of superiority method uses a single parameter Pi for selection.

For example, those lines estimated to be superior fatty acid yielders and generally adaptable to all production environments by both the regression model and procedural approach method were not found to be the same.

The regression model has identified the line 7B to be generally adaptable to all production environments for palmitic, oleic and linoleic acid synthesis. On the other hand the procedural approach method estimated line 111518 as superior but adaptable to favorable environment for palmitic acid and to poorer environments for oleic acid. In addition both method of statistics identified 111518 as being superior yielding at favorable environments (procedural approach) and generally adaptable (regression model) for cil content.

Furthermore the procedural approach method failed to identify superior and generally adaptable lines for the production of stearic and linoleic acids. The same is true for protein (Table 18).

The merit of the procedural approach method is that useful information can be obtained by measuring the distance mean squares between the experimental lines and the maximum response averaged over all sites without equally emphasizing on the treatment means. The smaller the mean squares value (Pi) the better is the line. In addition, the difference between the mean of the maximum response and the mean of the highest line can provide an important information on the overall performance of lines across sites. When the difference is smaller than the estimated standard error the highest yielding line could be tentatively recommended for wider use.

On the other hand, the regression technique simply draws attention to the adaptation features of the lines in response to the environment. The regression model relies on its coefficient and the treatment mean to estimate the performance of the experimental lines. Because of its simplicity and wider use by breeders the regression technique could be more reliable than most stability or adaptability parameters.

5.0 Summary and Conclusion

Among the eight sesame experimental lines studied for seed yield few were found to have the potential of general adaptation to all the environments under investigation. The two statistical methods used to estimate the performance of the lines across the six environments tentatively identified the lines 207958 and 7B as having wider applicability in so far as the production conditions under study are concerned.

Generally speaking, both lines responded in similar fashion to the environment with 7B running parallel to the maximum response by the procedural approach method and 207958 giving a 'b' value near unity by the regression model. But the overall mean seed yield was substantially higher for 7B (493 g 6.4 m^{-2}) than 207958 (442 g 6.4 m^{-2}).

The two experimental lines also exhibited some interesting variation in their yield traits. They both mature earlier in unfavorable environmental conditions (b=0.72 and 0.79) without any effect on the total biomass acumulated or seed yield produced (HI= 0.081 and 0.084). Furthermore, both lines and in particular 7B flowered earlier than most lines under investigation. This characteristics is essential for regions with marginal rainfall and/or erratic rain distribution like that of Bisidimo.

The results of the study also show that the high yield obtained by line 7B is mainly due to heavier seeds (3.27 g/1000 seeds). The number of pods and seeds per pod figures are also the highest for 207958. Heavier seeds with high number of pods are estimated to be important contributors and highly correlated with seed yield.

It is also interesting to add that relatively speaking, line 207958 is the least affected by Xanthomonas sesami disease which has been the cause of devastation to most of the susceptible lines at Abobo.

Other promising lines worthy of attention for alternative production use in the event of unforeseen conditions, be it environment or otherwise are 111519 with seed yield of 479 g 6.4 m^{-2} for highly productive areas and Fincha with mean seed yield of 425 g 6.4 m^{-2} for marginal areas such as Bisidimo. However, in normal circumstance 207958 and 7B will be highly recommended not only to the favorable sites but also to unfavorable ones.

Those lines found to be high seed yielders and generally adaptable across all environments were not necessarily so for oil content. It was found that line 111518 has the characteristics of being a high oil yielder across all environments while Fincha performed remarkably well in such poor environment as Bisidimo to give oil yield as close as the maximum response value. Despite this, both lines have moderate mean seed yield, and are similar in adaptability for seed yield, that is, being both adaptable to unfavorable (Fincha) and favorable (111518) environments. Neverthless, line 111518 was estimated to be as generally adaptable by the regresion model.

Seed biochemical analysis showed 7B to be a fairly consistent performer across all environments. It also provided an acceptable palmitic, oleic and linoleic acid mean values by the regression model. In contrast, the procedural approach method identified lines 111519 and 111518 as superior with 111518 being more adaptable to unfavourable conditions for oleic acid. Similarly, line 111518 was also found to be superior but specifically adapted to high yielding production conditions for palmitic acid.

Moreover, 5E was identified to be generally adaptable for stearic acid by the regression model but not by the other statistic.

The line 207958 synthesized the highest protein value across all environments. Its response to the environment was average. On the other hand for 7B the potential of producing high protein content is good only at the favorable environment.

In the present study it was not possible to come up with a line or lines that combine all the characteristics under investigation. For example while the line 207958 responded favorably at all the production conditions for seed yield, protein content, and oleic acid its response to environment with regard to oil content, palmitic, stearic and linoleic acids was variable. Similarly, the response of 7B to the environments was average for seed yield, palmitic, oleic and linoleic acids. However, its response to protein and stearic acid synthesis was enhanced only when the production variables such as temperature, moisture and soil conditions are at their best.

There were differences in fatty acid synthesis where at the colder site, Bisidimo, more polyunsaturated fatty acid was produced while at the warmer sites produced more saturated and monounsaturated fatty acids were produced. Moreover, the colder site with low fertility status produced more oil and less protein. Conversely, the warmer relatively fertile sites showed the highest site mean for protein.

Given the production conditions in the sesame growing regions of Ethiopia where rainfall is erratic and sometimes too small to sustain extended crop growth , 7B and 207958 are ideal candidates to recommend, that is, in addition to being generally adaptable to all production environments for seed yield, they are also early maturing.

The author's past experience with peasant farmers in the eastern Harar and Rift valley region of Ethiopia indicates that early maturing but not necessarily high yielding groundnut and sorghum cultivars are more favored than late and high yielding ones. It is also important to recognize that cultivars with high oil and protein content as well as a good amount of unsaturated fatty acid but with low seed yield per hectare may equally be preferable if total production per hectare of the biochemical constituents of the cultivar is taken into account. Thus while lines 207958 and 7B are reasonably good seed yielders per hectare and fairly constant in their performances across sites, their oil content is not as high as line 111518 which is a relatively low seed yielder, suitable only for favorable environments.

In conclusion it is the socio economic conditions under which the farmer operates that determines the more profitable way of raising recommended cultivar or cultivars and their proper utilization of this oil seed in industry. After all, in Ethiopia, oil seeds are evaluated on the basis of seed weight and not on the quantity or quality of the biochemical constituents of the seed. Based on this objective condition, therefore, the author recommends that peasants may stand to benefit more from cultivating 7B (with high mean seed yield but low oil content) than line 111518 (with average seed yield but also high mean oil content). The reason for this is that the total oil per hectare produced by cultivating 7B is higher than that 111518. In addition line 111518 was found to be productive for seed yield only in favourable environment.

The choice of recommending 207958 for protein is obvious, that is, it is not only generally adaptable for seed yield and is also the highest protein yielder and adaptable for this variable across all the environments.

In the long run, the strategy of constituting an improved cultivar having high seed yield and oil content can be effected by intervarietial crossing with 7b and 111518 as the main breeding materials. If for economical reason, the improvement of a cultivar with high palmitic, stearic and oleic fatty acid content is required, line 111518 stands high above all the other lines. Moreover, if the objective is to select cultivars with characterstics of high protein and seed yield it could be achieved by crossing the line 7B with 207958.

6.0 CLAIM TO ORIGINALITY

1. Very few indepth investigations on sesame have been conducted in the Ethiopian region. This study is the first to investigate the performances of landraces of this species in a set of different environments in order to clarify genotype-environmental interactions.

2. Few studies exist concerning the fatty acid composition of this crop species. This study has investigated the effect of the environments on the experimental lines in relation to fatty acids, oil and protein content.

3. Findings specific to the Ethiopian region made it possible for peasant farmers to embody appropriate cultivars or landraces into their farming systems.

4. For the first time experimental lines which combine important agronomic characteristics such as high seed yield and general adaptability to diverse environmental conditions were identified. The performance of lines 207958 and 7B has been proven to be consistently productive under both marginal conditions (Bisidimo) and productive sites (Melka Werer and Abobo).

5. The two experimental lines which are generally adaptable across all sites are also early maturing which makes them preferable at Bisidimo where rainfall is not dependable and at Melka Werer where the practices of double cropping of sesame with other cash crops is contemplated.

6. A line that combines the characteristics of high seed yield, wider adaptability across environment and stablity for palmitic, oleic and linoleic acid synthesis was obtained. Thus, the experimental line 7B embodies all these requirements.

7. The study also found line 111518 was among the top yielders for oil, palmitic, stearic and oleic acids. This line is generally appropriate for the production of oil at Bisidimo, Abobo and Melka Werer. Moreover, this line synthesizes more stearic acid than any line in poorer environments. Moreover, when the environment improves it also performs better than any test line for palmitic acid. It is still the highest oleic acid producer among the entries.

8. It is reported for the first time the identification of a line (207958) with unique combinations of high protein content and generally adaptable for seed yield and protein content.

7.0 SUGGESTIONS FOR FUTURE EXPERIMENTS

1. Since important landraces with characteristics of general adaptability and productivity have been identified, this germplasm can be utilized in a breeding program to reconstitute a genotype with desirable attributes. For example, line 111518 is such a line with potentially high oil, palmitic, stearic and oleic acid content.

2. Studies should be conducted to determine more fully the biochemical contents of the 800 accessions presently available at the Plant Genetic Resource Center/Ethiopia.

3. Despite the diversity of the agro-ecological conditions of Ethiopia, sesame has been a familiar crop for most peasant farmers, save those inhabiting the rugged plateau above 2400 m.a.s.l. Thus sesame warrant regional testing to identify lines potentially high yielding and stable for seed, oil or protein. In the future, it is important that the traditional sesame growing regions of the north and northwest be included in the study.

4. A study should be initiated that will largely restore the eco balance, that is, to understand the co-evolutionary process that exist in nature between the crop and the most economically important disease, bacterial blight (*Xanthomonas sesami*) at Abobo. This can be achieved through studies on cultural practices that will ultimately determine the appropriate date of sowing at Abobo (Akpa 1988). I believe sowing date trials may be worth attempting in order to reduce disease incidence through the biological mechanism of avoidance or escape.

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Appendix 1 a

Seasonal maximum and minimum temperatures in celsius for the three sites in Ethiopia

Month	Melka Werer max	Melka Werer min	Bisidimo max	Bisidimo min	Abobo max	Abobo min
			1987			
May	34.9	20.8	27.5	16.7	34.7	16.8
June	38.2	24.9	26.4	17.1	34.2	18.3
July	38.1	24.8	25.2	18.1	31.8	18.5
Aug.	34.4	21.8	25.8	16.4	31.2	19.8
Sep.	36.3	21.6	26.8	15.7	33.4	17.9
Oct	34.8	19.3	27.1	13.9	34.2	18.7
			1988			
May	38.4	20.9	28.7	15.8	36.9	20.7
June	38.6	24.6	26.4	16.4	31.3	20.3
July	33.2	22.3	25.1	16.3	29.4	19.1
Aug.	32.1	20.8	26.4	16.8	33.6	19.9
Sep.	33.6	20.2	25.3	14.9	32.6	20.0
Oct.	32.9	17.6	28.1	14.6	35.4	19.3

Appendix 1 b

Seasonal rainfall in millimeter for the three sites in Ethiopia

month	Melka Werer 1987	Melka Werer 1988	Bisidimo 1987	Bisidimo 1988	Abobo 1987	Abobo 1988
May	43.70	5.70	267.80	183.50	480.30	160.50
Jun.	10.80	27.60	32.70	19.90	94.60	128.60
Jul.	36.30	107.20	32.10	54.30	98.70	206.70
Aug.	136.30	262.40	100.20	167.80	230.40	217.30
Sep.	34.50	80.10	168.90	135.00	57.10	229.60
Oct.	7.60	8.80	84.80	28.40	107.50	186.80
Total	269.20	491.80	686.5	588.9	1068.60	1129.50

Appendix 1 c

Physical and chemical properties of the Melka Werer, Abobo and Bisidimo soils

Location	Depth cm	Textural class	Ph	EC mmhos	CEC meq/100g	Organic matter%
	0-15		8.4	0.56	35.0	1.9
Melka Werer	15-30	silty	8.3	0.62	34.4	1.8
	30-45	clay	8.2	0.85	34.9	1.6
	0-15		7.7	0.31	30.5	3.3
Abobo	15-30	Clay	7.9	0.23	27.5	2.3
	30-45	loam	7.6	0.28	29.9	2.0
	0-15		8.2	0.41	9.9	1.7
Bisidimo	15-30	Sandy	8.2	0.41	6.1	1.6
	30-45	loam	8.1	0.46	10.0	1.9

Depth cm	Total N kg/ha	Available P kg/ha	K kg/ha	Moist.% 1/3 atm.	Available moist. %	Bulk Density
0-15	46.4	28.3	39.5	24.7	14.8	1.30
15-30	41.4	25.8	41.1	26.7	14.4	1.32
30-45	33.8	14.6	41.9	25.2	16.7	1.37
0-15	175.5	7.8	35.4	23.3	12.1	1.29
15-30	187.0	14.6	35.0	24.1	10.9	1.27
30-45	124.9	17.9	34.9	25.0	9.9	1.32
0-15	33.2	10.7	12.9	5.4	7.5	1.75
15-30	23.0	11.9	12.9	5.1	7.8	1.78
30-45	28.3	11.0	13.9	5.2	8.7	1.80

Appendix 2 a

Pooled ANOVA on seed yield of eight sesame lines grown at three sites in Ethiopia in 1987 and 1988.

source	d.f	mean squares		p
Years (Y)	1	1261503.00	**	< 0.001
Site (S)	2	5579782.00	**	< 0.001
Y*S	2	262713.00	**	< 0.001
Rep in YS-comb.	12	36738.00		
Lines (L)	7	89009.00	**	0.005
L*Y	7	45855.00	ns	0.147
L*S	14	92750.00	**	< 0.001
L*Y*S	14	78332.00	**	0.002
Pooled error	84	28706.00		

** significant at 0.01 probability level
ns non significant

mean	415.44
CV	40.00

Appendix 2 b

Joint regression analysis on seed yield of eight sesame lines grown at three sites in Ethiopia in 1987, '88.

source	df	mean squares		p
Environment	5	863099.3000	**	< 0.001
Line	7	29670.1000	**	0.005
Line * Env.	35	25867.9000	**	< 0.001
Heter. B	7	69008.0500	**	0.001
Residual	28	15082.9000	ns	0.058
Pooled error	84	9568.6666		

*, ** significant at 0.05 and 0.01 probability level respectively

Appendix 3 a

Pooled ANOVA on days to flowering of eight sesame lines grown at three sites in Ethiopia,1987 and 1988.

source	df	mean squares		p
Year (Y)	1	564.0625	**	< 0.001
Site (S)	2	705.7152	**	< 0.001
Y*S	2	9.1458	ns	0.633
Rep in YS-comb.	12	25.2152		
Lines (L)	7	165.1180	**	< 0.001
L*Y	7	72.3958	**	0.001
L*S	14	27.9930	ns	0.169
L*Y*S	14	33.4553	ns	0.075
Pooled error	84	19.9136		

** significant at 0.01 probability level
ns non significant
mean 54.4930
CV 8.1870

Appendix 3 b

Joint regression analysis on days to flowering of eight sesame lines grown at three sites in Ethiopia, 1987 and 1988

source	df	mean squares		p
Environment	5	132.9209	**	< 0.001
Line	7	55.0394	**	< 0.001
Line * Env.	35	13.0196	**	0.006
Heter. B	7	5.3306	ns	0.919
Residual	28	14.9419	**	0.002
Pooled error	84	6.6346		

** significant at 0.01 probability level
ns non significant

Appendix 4 a

Pooled ANOVA on days to maturity of eight sesame lines evaluated at three sites over two years

source	df	mean squares		p
Year (Y)	1	693.4444	**	< 0.001
Site (S)	2	13719.1736	**	< 0.001
Y*S	2	5358.2569	**	< 0.001
Rep in YS-comb.	12	63.1667		
Lines (L)	7	405.8571	**	< 0.001
L*Y	7	46.1587	ns	0.197
L*S	14	153.4911	**	< 0.001
L*Y*S	14	103.6855	**	0.001
Pooled error	84	31.8889		

** significant at 0.01 probability level
ns non significant

mean	93.0556
CV	6.0684

Appendix 4 b

Joint regression analysis on days to maturity of eight sesame lines grown at three sites over two years

source	df	mean squares		p
Environment	5	2589.9280	**	< 0.001
Line	7	135.2850	**	< 0.001
Line * Env.	35	37.3630	**	< 0.001
Heter. B	7	120.3838	**	< 0.001
Residual	28	16.6080	ns	0.069
Pooled error	84	10.9173		

** significant at 0.01 probability level
ns non significant

Appendix 5 a

Poled ANOVA on number of branches per plant of eight sesame lines grown at three sites in Ethiopia, 1987 and 1988.

source	df	mean squares		p
Year (Y)	1	128.4444	**	< 0.001
Site (S)	2	108.0486	**	< 0.001
Y*S	2	6.6736	*	0.027
Rep in YS-comb.	12	1.2847		
Lines (L)	7	1.2023	ns	0.688
L*Y	7	0.6031	ns	0.932
L*S	14	3.0327	ns	0.067
L*Y*S	14	4.0228	*	0.011
Pooled error	84	1.7688		

* ** significant at 0.05 and 0.01 probability level respectively
ns non significant
mean 4.9305
CV 26.9743

Appendix 5 b

Joint regression analysis on number of branches per plant of eight sesame lines grown at three sites in Ethiopia, 1987 and 1988

source	df	mean squares		p
Environment	5	23.8598	**	< 0.001
Line	7	0.4007	ns	0.688
Line * Env.	35	0.9810	*	0.030
Heter. B	7	1.2158	ns	0.258
Residual	28	0.8926	ns	0.076
Pooled error	84	0.5896		

*, ** significant at 0.05 and 0.01 probability level respectively
ns non significant

Appendix 6 a

Pooled ANOVA on number of pods per plant of eight sesame lines tested at three sites in Ethiopia over two years

source	df	mean squares		p
Year (Y)	1	52022.0069	**	< 0.001
Site (S)	2	6375.8819	**	< 0.001
Y*S	2	1051.5069	ns	0.190
Rep in YS-comb.	12	549.4097		
Lines (L)	7	397.2529	ns	0.085
L*Y	7	210.1181	ns	0.447
L*S	14	362.5327	ns	0.070
L*Y*S	14	261.6657	ns	0.270
Pooled error	84	212.9494		

** significant at 0.01 probability level
ns non significant
mean 49.0972
CV 29.7305

Appendix 6 b

Joint regression analysis on number of pods per plant of eight sesame lines grown at three sites in Ethiopia, 1987 and 1988

source	df	mean squares		p
Environment	5	4458.4520	**	< 0.001
Line	7	132.4170	ns	0.085
Line * Env.	35	97.2350	ns	0.122
Heter. B	7	36.3414	ns	0.937
Residual	28	112.4580	ns	0.056
Pooled error	84	71.0226		

** significant at 0.001 probability level
ns non significant

Appendix 7 a

Pooled ANOVA on number of seeds per pod of eight sesame lines grown at three sites over two years.

source	df	mean squares		p
Year (Y)	1	544.4444	*	0.016
Site (S)	2	1420.0278	**	< 0.001
Y*S	2	75.0278	ns	0.440
Rep in YS-comb.	12	70.5208		
Lines (L)	7	142.4444	ns	0.155
L*Y	7	35.6508	ns	0.904
L*S	14	252.5040	**	0.001
L*Y*S	14	65.6151	ns	0.745
Pooled error	84	90.6954		

*, ** significant at 0.05 and 0.01 probability level respectively
ns non significant
mean 68.5555
CV 13.8915

Appendix 7 b

Joint regression on seeds per pod of eight sesame lines grown at three sites over two years

source	df	mean squares		p
Environment	5	235.6362	**	< 0.001
Line	7	47.4820	ns	0.155
Line * Env.	35	44.7927	ns	0.074
Heter. B	7	51.7934	ns	0.333
Residual	28	43.0425	ns	0.110
Pooled error	84	30.2316		

*, ** significant at 0.05 and 0.001 level respectively
ns non significant

Appendix 8 a

Pooled ANOVA on plant height of eight sesame lines grown at three sites in Ethiopia, 1987 and 1988

source	df	mean squares		p
Year (Y)	1	15314.0600	**	< 0.001
Site (S)	2	90661.1900	**	< 0.001
Y*S	2	386.5200	ns	0.242
Rep in YS-comb.	12	489.9200		
Lines (L)	7	876.5700	**	0.004
L*Y	7	410.0100	ns	0.168
L*S	14	316.5800	ns	0.305
L*Y*S	14	358.0700	ns	0.204
Pooled error	84	268.1500		

** significant at 0.01 probability level
ns non significant
mean 143.1458
CV 11.4394

Appendix 8 b

Joint regression on plant height of eight sesame lines evaluated at three sites in 1987 and 1988

source	df	mean squares		p
Environment	5	13160.6690	**	< 0.001
Line	7	292.2390	**	0.004
Line * Env.	35	117.2710	ns	0.157
Heter. B	7	105.3080	ns	0.537
Residual	28	120.2620	ns	0.153
Pooled error	84	89.3833		

** significant at 0.01 probability level
ns non significant

Appendix 9 a

Pooled ANOVA on root depth of eight sesame lines grown at three sites in Ethiopia, 1987 and 1988

source	df	mean squares		p
Year (Y)	1	1193.1267	**	< 0.001
Site (S)	2	534.6659	**	< 0.001
Y*S	2	46.1238	*	0.046
Reps in YS-comb	12	19.2993		
Lines (L)	7	38.6695	*	0.015
L*Y	7	11.9489	ns	0.575
L*S	14	14.3055	ns	0.476
L*Y*S	14	13.4393	ns	0.533
Pooled error	84	14.5160		

*, ** significant at 0.05 and 0.01 probability level respectively

ns non significant

mean 19.3195

CV 19.7238

Appendix 9 b

Joint regression on root depth of eight sesame lines evaluated at three sites over two years in Ethiopia

source	df	mean squares		p
Environment	5	147.4602	**	< 0.001
Line	7	12.8887	*	0.014
Line * Env.	35	9.7896	ns	0.625
Heter.B	7	6.8003	ns	0.141
Residual	28	3.9200	ns	0.731
Pooled error	84	4.8386		

*, ** significant at 0.05 and 0.01 probability level respectively

ns non significant

Appendix 10 a

Pooled ANOVA on one thousand seed weight of eight sesame lines evaluated at three sites in Ethiopia in 1987 and 1988

source	df	mean squares		p
Year (Y)	1	4.6944	**	< 0.001
Site (S)	2	7.2742	**	< 0.001
Y*S	2	8.1146	**	< 0.001
Rep in YS-comb.	12	0.0291		
Lines (L)	7	0.8428	**	< 0.001
L*Y	7	0.0782	ns	0.686
L*S	14	0.1972	ns	0.066
L*Y*S	14	0.2332	*	0.024
Pooled error	84	0.1145		

*, ** significant at 0.05 and 0.01 probability level respectively
ns non significant
mean 2.8763
CV 11.7672

Appendix 10 b

Joint regression on one thousand seed weight of eight sesame lines evaluated at three sites in 1987 and 1988

source	df	mean square		p
Environment	5	2.3647	**	< 0.001
Line	7	0.2809	**	< 0.001
Line * Env.	35	0.0626	*	0.034
Heter. B	7	0.0550	ns	0.545
Residual	28	0.0644	*	0.035
Pooled error	84	0.0381		

*, ** significant at 0.05 and 0.01 probability level respectively
ns non significant

Appendix 11 a

Analysis of variance on harvest index of eight sesame lines tested at three sites 1988

source	df	mean squares		p
Site (S)	2	0.0775681	**	< 0.001
Reps in S	6	0.0008389		
Lines (L)	7	0.0027175	**	0.002
L*S	14	0.0042014	**	< 0.001
Error	42	0.0007008		

** significant at 0.001 level

mean	0.0827778
CV	31.9802100

Appendix 11 b

Joint regression on Harvest index of eight sesame lines grown at three sites in 1988

source	df	mean square		p
Environment	2	0.0259	**	< 0.001
Line	7	0.0009	**	< 0.001
Line * Env.	14	0.0013	**	< 0.001
Heter. B	7	0.0008	ns	0.851
Residual	7	0.0019	**	< 0.001
Pooled error	42	0.0002		

** significant at 0.01 probability level
ns non significant

Appendix 12 a

Bacterial blight (*Xanthamonas sesame*) disease score in 0-9 point scale at Abobo

Line	Year 1987	1988	Mean
7B	7.5	7.0	7.5
Harar	8.0	8.0	8.0
111518	8.0	7.0	7.5
Fincha	6.0	6.0	6.0
76/48R	7.0	7.0	7.0
5E	6.0	5.0	5.5
207958	5.0	6.0	5.5
111519	7.0	8.0	7.5

0 denotes the crop is virtualy free of disease
9 denotes severe infestation by disease

Appendix 12 b

Plant lodging score in 0-100 point scale at Abobo

Line	Year 1987	1988	Mean
7B	65	42	54
Harar	22	44	33
111518	39	16	28
Fincha	23	29	26
76/48R	43	11	27
5E	30	67	49
207958	21	84	53
111519	38	47	43

0 the crop stands upright
100 the crop is horizontaly laying on the ground

Table 8
Appendix 13 a

Mean days to physiological maturity of eight sesame lines grown at three sites in Ethiopia over two years

Line	Days to maturity						Line mean
	1987			1988			
	Bisidimo	Abobo	Melka.W.	Bisidimo	Abobo	Melka.W.	
7B	103 b	73 a	101 b	79 a	84 a	107 d	91
Harar	126 a	74 a	119 a	83 a	80 ab	141 a	103
111518	106 b	74 a	96 b	76 a	72 b	103 d	88
Fincha	102 b	76 a	102 b	81 a	71 b	123 b	93
76/48R	120 a	75 a	102 b	79 a	74 b	116 bcd	94
5E	103 b	74 a	100 b	80 a	72 b	115 bcd	91
207958	101 b	75 a	102 b	81 a	87 a	110 cd	93
111519	101 b	77 a	101 b	81 a	72 b	113 bcd	91
mean	108	75	103	80	77	116	

Standard error = 3.260

'Within each environment, line means folllowed by the same letter are not significantly different at the 0.05 level by the Duncan's multiple range test.'

Appendix 13 b

Mean of number of pods per plant of eight sesame lines grown at three sites in Ethiopia 1987 and 1988.

Line	Number of pods per plant						
	1987			1988			
	Bisidimo	Abobo	Melka.W.	Bisidimo	Abobo	Melka.W.	Line mean
7B	49	66	88	21	37	39	50.00
Harar	31	50	92	26	15	39	42.11
111518	53	62	86	33	26	40	50.00
Fincha	83	61	99	23	32	35	55.50
76/48R	42	70	79	22	30	29	45.33
5E	54	55	96	32	22	46	50.83
207958	77	76	79	33	17	44	54.33
111519	69	44	74	28	20	34	44.83
mean	57.25	60.50	86.63	27.25	21.50	38.25	

Standard error = 3.440

'Lines means averaged over environments are not significantly different at the 0.05 level by the F-test.'

Appendix 13 c

Mean plant height in cm of eight sesame lines grown at three sites in Ethiopia in 1987 and 1988.

Line	Plant height						
	Bisidimo	Abobo	Melka.W.	Bisidimo	Abobo	Melka.W.	Line mean
	1987			1988			
7B	80	162	190	78	149	159	136
Harar	102	184	180	111	151	160	148
111518	88	160	167	74	144	155	131
Fincha	113	172	188	70	156	140	140
76/48R	86	182	200	97	168	171	151
5E	108	172	191	72	132	168	141
207958	107	170	194	96	163	163	149
111519	128	166	192	85	152	170	149
mean	102	169	188	85	154	159	

Standard error = 3.860

'Lines means averaged over environments are not significantly different according at the 0.05 level by the F-test.'

Appendix 13 d

Mean root depth in cm of eight sesame lines grown at three sites in Ethipopia in 1987 and 1988.

Line	Bisidimo 1987	Abobo 1987	Melka.W. 1987	Bisidimo 1988	Abobo 1988	Melka.W. 1988	Line mean
	Root depth in cm						
7B	18.60	30.00	22.67	14.80	16.67	15.80	19.75 ab
Harar	17.33	18.33	23.53	14.90	19.00	14.40	17.86 b
111518	20.80	30.00	28.37	14.53	22.00	17.87	22.26 a
Fincha	17.20	27.00	20.43	14.13	19.67	14.40	18.81 b
76/48R	18.20	27.00	21.00	16.67	22.33	14.13	19.92 ab
5E	16.20	28.67	21.13	14.63	20.00	13.73	19.06 b
207958	16.60	24.00	20.00	13.87	14.67	15.47	17.44 b
111519	19.93	25.67	20.10	13.37	22.00	15.57	19.44 b
mean	18.10	26.33	22.15	14.61	19.54	15.17	

Standard error = 0.898

'Witihn each environment, line means ˉollowed by the same letter are not significantly different at the 0.05 level by the Duncan's new multiple range test'

Appendix 13 e

Mean number of branches per plant of eight sesame lines grown at three sites in Ethiopia in 1987 and 1988.

Line	Bisidimo	Abobo	Melka.W.	Bisidimo	Abobo	Melka.W.	Line mean
	1987			1988			
7B	3 b	9 ab	4 b	3 a	6 a	3 a	4.67
Harar	4 ab	9 ab	5 b	4 a	6 a	4 a	5.33
111518	4 ab	5 c	8 a	3 a	5 a	3 a	4.67
Fincha	6 a	8 ab	5 b	2 a	5 a	4 a	5.00
76/48R	4 ab	10 a	4 b	3 a	5 a	5 a	5.17
5E	4 ab	9 ab	6 ab	3 a	5 a	4 a	5.17
207953	5 ab	7 bc	5 b	4 a	6 a	3 a	5.00
111519	5 ab	8 ab	5 b	3 a	6 a	4 a	5.17
mean	4.63	8.13	5.25	3.13	5.50	3.75	

Number of branches per plant

Standard error = 0.768

'Within each environment, line means followed by the same letter are not significantly different at the 0.05 level by the Duncan's multiple range test.'

Appendix 13 f

Mean harvest index of eight sesame lines evaluated at three sites in Ethiopia over one year

Line	Harvest index: Bisidimo 1988		Abobo 1988		Melka.W. 1988		Line mean
7B	0.07	ab	0.05	a	0.07	e	0.063
Harar	0.04	b	0.01	a	0.12	bc	0.057
111518	0.06	b	0.04	a	0.25	a	0.117
Finch	0.07	ab	0.03	a	0.11	cd	0.070
76/48R	0.06	b	0.03	a	0.14	bc	0.077
5E	0.07	ab	0.01	a	0.16	b	0.080
207958	0.11	a	0.01	a	0.13	bc	0.083
111519	0.08	ab	0.03	a	0.16	b	0.090
mean	0.070		0.026		0.143		

standard error = o.048

'Within each environment, line means followed by the same letter are not significantly different at the 0.05 level by Duncan's multiple range test.'

Appendix 14 a

Pooled ANOVA on oil content of eight lines of sesame grown at three sites each of two years

source	df	mean squares		p
Year (Y)	1	162.3500	**	< 0.001
Sites (S)	2	193.0671	**	< 0.001
Y*S	2	1.1646	ns	0.078
Rep in YS-comb.	12	0.3172		
Lines (L)	7	7.8909	**	< 0.001
L*Y	7	0.2297	ns	0.818
L*S	14	2.0485	**	< 0.001
L*Y*S	14	0.5488	ns	0.263
Pooled error	84	0.4400		

** significant at 0.01 level
ns non significant
mean 44.4400
CV 1.5000

Appendix 14 b

Joint regression analysis on oil content of eight sesame lines grown at three sites in Ethiopia 1987 and 1988.

source	df	mean squares		p
Environment	5	36.8907	**	< 0.001
Line	7	2.6543	**	< 0.001
Line * Env.	35	0.3556	**	< 0.001
Heter. B	7	0.8565	**	0.006
Residual	28	0.2303	ns	0.062
Pooled error	84	0.1476		

* , ** significant at 0.05 and 0.01 level respectively

Appendix 15 a

Pooled ANOVA on palmitic acid of eight sesame lines grown at three sites each of two years

source	df	mean squares		p
Year (Y)	1	0.0069	ns	0.722
Site (S)	2	5.9213	**	< 0.001
Y*S	2	0.1863	*	0.038
Rep in YS-comb.	12	0.0769		
Lines (L)	7	1.9703	**	< 0.001
L*Y	7	0.0726	ns	0.249
L*S	14	0.1440	**	0.003
L*Y*S	14	0.0770	ns	0.169
Pooled error	84	0.0548		

*, ** significant at 0.05 and 0.01 probability level respectively
ns non significant
mean 7.3138
CV 3.2024

Appendix 15 b

Joint regression analysis on palmitic acid of eight lines of sesame grown at three sites in Ethiopia 1987 and 1988.

source	df	mean squares		p
Environment	5	0.8148	**	< 0.001
Line	7	0.6567	**	< 0.001
Line * Env.	35	0.0343	**	< 0.010
Heter B.	7	0.0253	ns	0.363
Residual	28	0.0366	**	0.007
Pooled error	84	0.0182		

** significant at 0.01 probability level.
ns non significant

Appendix 16 a

Pooled ANOVA on stearic acid content of eight lines of sesame grown at three sites each of two years

source	df	mean squares		p
Year (Y)	1	0.7950	**	0.009
Site (S)	2	23.2308	**	< 0.001
Y*S	2	0.6536	**	0.004
Rep in YS-comb.	12	0.0999		
Lines (S)	7	0.9468	**	< 0.001
L*Y	7	0.3369	**	0.008
L*S	14	0.1439	ns	0.249
L*Y*S	14	0.1476	ns	0.216
Pooled error	84	0.1141		

** significant at 0.01 probability level
ns non significant
mean 5.2520
CV 6.4325

Appendix 16 b

Joint regression analysis on stearic acid of eight lines of sesame evaluated at three sites in Ethiopia 1987 and 1988.

source	df	mean squares		p
Environment	5	3.2375	**	< 0.001
Line	7	0.3156	**	< 0.001
Line * Env.	35	0.0613	*	0.039
Heter.B	7	0.0543	ns	0.548
Residual	28	0.0634	*	0.039
Pooled error	84	0.0380		

*,** significant at 0.05 and 0.01 probability level
ns non significant

Appendix 17 a

Pooled ANOVA on oleic acid content of eight lines of sesame grown at three sites each of two years

source	df	mean squares		p
Year (Y)	1	43.7802	**	< 0.001
Site (S)	2	165.3686	**	< 0.001
Y*S	2	1.0344	ns	0.255
Rep in YS-comb.	12	0.4780		
Lines (L)	7	17.4869	**	< 0.001
L*Y	7	3.0298	**	< 0.001
L*S	14	4.1857	**	< 0.001
L*Y*S	14	3.5354	**	< 0.001
Pooled error	84	0.6623		

** significant at 0.01 probability level
ns non significant
mean 38.6930
CV 2.2310

Appendix 17 b

Joint regresion analysis on oleic acid content of eight sesame lines grown at three sites in Ethiopia 1987 and 1988.

source	df	mean squares		p
Environment	5	25.1056	**	< 0.001
Line	7	5.8290	**	< 0.001
Line * Env.	35	1.2315	**	< 0.001
Heter.B	7	1.4849	ns	0.279
Residual	28	1.1681	**	< 0.001
Pooled Error	84	0.2484		

** significant at 0.01 probability level
ns non significant

Appendix 18 a

Pooled ANOVA on linoleic acid content of eight lines of sesame grown at three sites each of two years

source	df	mean squares		p
Year (Y)	1	57.2544	**	< 0.001
Site (S)	2	234.3146	**	< 0.001
Y*S	2	1.6909	ns	0.351
Rep in YS-comb.	12	2.0298		
Lines (L)	7	21.6307	**	< 0.001
L*Y	7	4.2671	*	0.015
L*S	14	7.1326	**	< 0.001
L*Y*S	14	5.0147	**	< 0.001
Pooled error	84	1.5989		

** significant at 0.01 probability level
ns non significant

mean	47.4277
CV	2.6661

Appendix 18 b

Joint regression analysis on linoleic acid content of eight sesame lines grown at three sites in Ethiopia 1987 and 1988.

source	df	mean squares		p
Environment	5	35.3436	**	< 0.001
Line	7	7.1964	**	< 0.001
Line * Env.	35	1.9141	**	< 0.001
Heter. B	7	2.3628	ns	0.281
Residual	28	1.8019	**	< 0.001
Pooled Error	84	0.5330		

** significant at 0.01 probability level
ns non significant

Appendix 19 a

Pooled ANOVA on protein content of eight lines of sesame grown at three sites each of two years

source	df	mean squares		p
Years (Y)	1	21.2744	**	< 0.001
Site (S)	2	78.7956	**	< 0.001
Y*S	2	42.6938	**	< 0.001
Rep in YS-comb.	12	0.4382		
Lines (L)	7	6.6177	**	< 0.001
L*Y	7	3.0392	**	< 0.001
L*S	14	3.9428	**	< 0.001
L*Y*S	14	9.1962	**	< 0.001
Pooled error	84	0.6886		

** significant at 0.01 probability level

mean 24.8555

CV 3.2155

Appendix 19 b

Joint regression analysis on Protein percent of eight sesame lines grown at three sites in Ethiopia 1987 and 1988.

source	df	mean squares		p
Environment	5	17.6274	**	< 0.001
Line	7	2.2061	**	< 0.001
Line * Env.	35	1.9545	**	< 0.001
Heter. B	7	3.1393	ns	0.108
Residual	28	1.6583	**	< 0.001
Pooled error	84	0.2295		

** significant at 0.01 probability level

ns non significant