SESAMUM INDICUM L.:

CROP ORIGIN, DIVERSITY, CHEMISTRY AND ETHNOBOTANY

BY

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THESIS

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CHAPTER 1

GENERAL INTRODUCTION

Species of *Sesamum* (Pedaliaceae) may have been among the first oil seed plants domesticated. Today *Sesamum indicum* L. is an important subsistence and cash crop of developing countries in tropical areas of both the Old and New World; yet our knowledge of it has advanced little since the monographic treatment of the genus by Joshi (1961). It is important to the people who grow it for its nutrition as well as an item of export. Since sesame tolerates drought, it is often the only oil crop and the only cash crop that can be grown in the Sahel and the drier parts of the Guinea savanna of Africa as well as semi-arid and sub-humid zones of Asia and Latin America. It shows promise for expanded cultivation as more marginal lands are brought into use. Its special adaptation to dryland conditions raises the crop's potential value beyond mere gross production. Unusually stable because of anti-oxidants it contains, sesame oil is especially important for tropical countries where refrigeration is a luxury.

Research on sesame has been neglected in nearly every discipline. There have been no systematic attempts to determine the origin and evolution of the crop and these questions remain widely disputed in the literature (Nayar, 1971; Weiss, 1971). Therefore, this study is an attempt to describe the crop's cultural history. Its lignans, valuable minor chemical constituents of the seed oil that are useful biodegradable insecticides and antioxidants, have been insufficiently utilized despite their low hazard as environmental pollutants. The ancient history of sesame has been ignored, disputed and eventually its very existence in the ancient Near East was denied (Helbaek, 1966). The crop has not been considered to be sufficiently valuable to warrant a mandate for study by the International Center for Agricultural Research in the Dry Areas (ICARDA) nor the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); its germplasm is not thoroughly collected, protected, nor analysed for disease resistance and other agronomically useful traits. Even the International Board of Plant Genetic Resources (IBPGR) of the Food and Agriculture Organization (FAO) of the United Nations ranks it at low priority compared with other crops. Until now, they sponsored only one consultation about sesame status and improvement, in 1980, and expeditions to collect sesame cultivars are infrequent, compared with other crops.

The crop itself requires analysis and classification. Hiltebrandt, (1932), proposed that sesame originated in Africa and that centers of diversity developed in India and China. Earlier, Vavilov (1926), had suggested multiple origins for the crop: Ethiopia, India and Central Asia, with a secondary center in China. De Candolle (1886) believed that the crop originated in the Sunda Islands.

A taxonomic look at the cultivated crop is long overdue. Neither the progenitor nor the nearest wild relatives have been known for certain, but a poorly-collected wild form has been identified in India. The wild gingelly of Malabar is distinguished from cultivated sesame primarily on fruit and seed morphology. Described as *Sesamum orientale* var. *malabaricum* Nar. var. nov., (John, Narayana & Seshadri, 1950), this variety is found only on uncultivated laterite hilltops or rocky outcrops and is always self-sown. Capsules are decidedly smaller than cultivated ones. The seed faces are rugose and bounded by a raised margin. The corollae have a deep purple lip and anthers a brown-purple stripe, not seen on cultivated material.

Another species, Sesamum latifolium Gillett, has been named the crop progenitor (Ihlenfeldt and Grabow-Seidensticker, 1979). It is a robust plant, highly branched, and grows up to 12 ft tall. It too, grows in crevices of rock outcrops and is a pioneer invading abandoned cultivations. Its capsules are coarse and bear black, reticulate seeds, rounder than those of cultivated sesame. Sudanese breeders have desired to incorporate genes from it into cultivated sesame because of its resistance to bacterial leaf spot, its success in heavy clay soils and its indehiscent capsules. Attempts by Sudanese breeders to germinate the dormant seeds had not been successful (M. O. Khidir and M. A. Mahmoud, pers. comm.).

Chromosome numbers for a few species of Sesamum including S. indicum have been determined as 2n=26 (Nayar, 1971) though the cytogenetics of the family and genus is poorly understood (Nayar & Mehra, 1970). The wild taxon described as S. orientale var. malabaricum is reported to possess the same chromosome number as cultivated sesame. Its potential as an ancestral species to cultivated sesame had not been studied (Nayar, 1971) though a report (John, Narayana & Seshadri, 1950) states that the wild variety freely crosses with other cultivated types giving a high percentage of fertile hybrids.

The chromosome number for S. latifolium, on the other hand, is 2n=32 (Ihlenfeldt and Grabow-Seidensticker, 1979).

There is considerable variation in sesame. Plants from different populations growing in a similar climate, which are geographically isolated, look distinct. This study examines the extent of divergence in a world germplasm collection grown and studied in Urbana.

It is necessary to determine which characters are most useful for distinguishing morphological groups. Preliminary observations suggest that Sesamum indicum has considerable phenotypic plasticity. Genetically fixed traits such as leaf color and pubescence are generally more reliable than environmentally moderated ones such as height or flowering date.

The species which might be useful as genetic sources for plant breeding are poorly defined and the usable gene pool has not been determined. It is known that some forms are highly drought tolerant whereas others endure high rainfall enough that they can grow on the Malabar Coast of India. The sources of such adaptations have not yet been identified. The patterns of geographic and ecological races have not been established, and we do not know which combinations might yield heterosis, higher oil content and protein quality, disease resistance, and so on. Although the research proposed here does not directly affect improvement of sesame cultivars, assessment of the variability in the taxon is an important preliminary step in any such program. The biosystematics of sesame must be defined before its evolution and ethnobotany can be fully understood and before complete use can be made of the genetic variability found in the species to improve the agronomic fitness of the crop.

1.1. OBJECTIVES OF THE STUDY

1) To assemble a representative sample of the geographical, morphological and ecological variability of sesame and its nearest wild relatives.

2) To study the assembled collection morphologically to establish the patterns of variation and to classify it into useful groups or races.

3) To define the usable gene pool by crossing sesame with its wild relatives.

4) To sample the groups with respect to oil content and quality of constituents.

5) To study the ancient history and ethnobotany of sesame.

1.2. REFERENCES

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CHAPTER 2

PATTERNS OF MORPHOLOGICAL VARIATION IN *SESAMUM INDICUM* L.

2.1. ABSTRACT

Cultivars of sesame from twenty countries were sampled for morphological variability. Taximetric methods, including factor, cluster, discriminant, and principal components analyses, established patterns of similarities and were used to generate groupings among the taxa. The complementary results of the analyses indicate that eight major groups can be discerned.

2.2. INTRODUCTION

The morphological diversity of sesame has been recognized for a long time. A review of studies on regional collections can be found in Weiss (1971). Morphological analysis of a world germplasm collection of sesame is desirable to describe its genetic diversity and to characterize agronomically useful qualities. Assessment of a collection for date of maturity, dwarfness, resistance to pests and diseases, drought and cold tolerance or other worthwhile traits is necessary before embarking on a breeding program (Krull and Borlaug, 1970). However one of the major problems that arises in genetic resources work is the inability to classify plant collections satisfactorily (Burt, 1983).

Classification below the species level is difficult because the limits of subspecies and cultivars are ill-defined and often controversial (Williams, 1983). Identification of genotype-complexes can be achieved by grouping accessions having similar appearance and performance, however the variability of cultivars creates special problems in classification because there may be no clearly definable discontinuity within a species. The existence of many transitional forms, the fuzzy boundaries of cultivars with intergrading variation, and the susceptibility of cultivars to environmental influences all contribute to this problem. Both genetic variability and plasticity of genotype play a significant role in determining phenotypic diversity (Baum, 1970, 1981). For these reasons there are a number of unique problems associated with classification at the infraspecific level; these difficulties are just beginning to be addressed by researchers. This study represents an attempt to locate structure within the variation, and it demonstrates a method for analyzing continuous variation below the species level.

The total collection of seeds of sesame cultivars in the Crop Evolution Laboratory (CEL) at the University of Illinois, Urbana-Champaign, consists of about 1000 accessions, obtained from the USDA and agricultural research stations in India, Korea, Nigeria and Sudan. The CEL collection represents a reasonable portion of sesame diversity, however the sensitivity of sesame to photoperiod prevented many tropical lines from flowering at Urbana's 40°N latitude. Therefore this study emphasizes temperate and subtropical cultivars, and it represents African and tropical Asian lines less well.

This report describes 353 accessions of sesame cultivars from 20 countries. Sample size varies with country. Attention was given to authentic indigenous lines having variation in genetic constitution which could be attributed to place of origin rather than modification through manipulation by breeders at research stations.

The wild ancestor of sesame has not been established with certainty and the literature asserts with equal frequency that the center of origin of the crop is in Africa and Asia (Nayar and Mehra, 1970). We regard the probable ancestor of cultivated sesame as the taxon known in India as the wild gingelly of Malabar (John, Narayana and Seshadri, 1950). The description of wild gingelly has been included in the analysis as the 354th accession. Our reasons for regarding this taxon as the progenitor of sesame are discussed elsewhere (Bedigian, Seigler and Harlan, 1984).

2.3. MATERIALS AND METHODS

Three hundred to five hundred cultivars of sesame were grown and studied each season at the University of Illinois South Farm, Urbana, during the summers of 1978, 1980 and 1981. Voucher specimens of most of the materials studied have been deposited at the CEL herbarium.

The nursery was planted about May 30 each season, after the danger of frost was past and the soil was warm. Each 3 to 4 m row represented an accession and consisted of 10-16 plants. Within each accession, sampling was done on plants representing the majority of the sample. When two or more morphological types co-occurred, each cultivar was recorded separately and treated as a different cultivar from the same location. This seemed justifiable because many of the samples were originally collected at markets or from fields where seed mixtures were grown. Subsistence farmers often grow mixtures and pool the harvested seed for the next growing season (pers. observ.). Sesame from different fields and from different regions may be pooled at the market, thus a sample from such mixed seed lots would not be as genetically uniform as a sample collected from an individual plant. This is especially important to consider for largely self-pollinated plants such as sesame (Baker, 1953). One would expect morphological resemblance to be sustained if the population were genetically uniform.

Data collection started in mid-July, at the onset of flowering, and continued through the summer. Sampled plants were mature, disease-free, robust specimens showing full branching pattern. Initially, measurements were taken from all plants for every anatomical structure, but in subsequent examinations, representative plants from each row were measured.

Several types of morphological data were recorded. There were numeric, measured or counted, continuous characters such as plant height or number of branches; ordinal observations such as degree of hairiness, that can be graded; and nominal, falling into a small number of classes or states that cannot be ordered, such as leaf shape. A binary attribute is a special case of the nominal type that records the presence or absence of a structure. A series of binary variables are needed to represent the presence/absence of multi-state characters such as seed color and leaf shape.

2.4. SELECTION OF MORPHOLOGICAL CHARACTERS

The human brain integrates an enormous variety of visual stimuli that is difficult to reduce to a few descriptive words. To permit a detailed description of the variation in sesame, as large a number of characters as could be easily observed were measured. Initially it was thought that a large number of characters would be necessary for delineation of groups; ninety-six characters were originally included. Later, numerical analyses and additional biological information gathered during field observations were used to choose those characters that best contributed to group formation and limit the number that were utilized in the final analyses.

Plant morphology is influenced by weather, _e_. _g_. the amount of rainfall affected plant height. To reduce these effects as much as possible, characters that were less sensitive to environmental changes, such as reproductive characters were emphasized as much as possible. Also, invariant characters were deleted.

In numerical taxonomy, highly correlated characters may weight the data and conclusions in a particular direction. Therefore, the first step of the analysis involved an examination of the interrelationships among the variables. Pearson's correlation coefficient was used as a measure of association. Any two characters that had correlation coefficients above 0.60 were reexamined, and the one contributing more detailed biological information was included in the analysis while the other was dropped.

2.5. MATRIX REDUCTION AND GROUPING PHILOSOPHY

At the beginning of our numerical analyses we tried the traditional approaches such as Principal Components Analysis (PCA) and Discriminant Analysis (DA) that are discussed below. Our preliminary attempts to find structure among the cultivars were unsuccessful. The enormous natural diversity in our world collection, and the many independent characters in the analysis, gave confusing and unintelligible results.

Unlike classic results of numerical taxonomic analyses, these data yielded no significant principal components. Each character contributed something to the total variability, but no character contributed very much. Repeated trials with different combinations of characters gave similarly uninformative results. The first 5-10 principal components should account for 70-80% of the variance (Sneath and Sokal, 1973). In our original treatment of characters the first principal component explained 6-7% of the variation, the second explained 5-6%, and 10 components explained just 40% of the variance. However, components having low associated eigenvalues are likely to be describing error variance, or to be representing influences that affect only one or a few of the variables in the system (Harris, 1975). This unsatisfactory output led to a search for other ways to handle the data set. The large number of variables that we had entered caused part of the difficulty so we sought a method to reduce the number of variables systematically.

Several steps were taken. The most useful visual characteristics that distinguish morphotypes were defined. We also grouped cultivars geographically and ecologically to examine how they differed. Each of the 96 original characters was then tested with ANOVA to determine whether their F-tests were significant with respect to country of origin or ecological zone of seed source. In each comparison, F-values higher than 3.0 were considered to be significant. These procedures were used as preliminary steps to decide which characters are most important for group separation. We recognize that the approach was an approximation.

Finally, factor analysis (FA) was used as a method of reducing the number of characters to a set that contributed most information. FA permits one to look at each variable separately and to determine its contribution to the total pattern of variation. It is a systematic approach for reducing the data set.

Factor loading is a general term referring to a coefficient in a factor pattern or structure matrix. Characters were dropped if their factor loadings were consistently below 0.2 in the first five factors. A reduced, optimum set of 32 uncorrelated characters was retained (Table 1).

The reduced data set was still rather large, which prevented us from using the software package most commonly employed for these types of analyses, NTSYS, without extensive modification. Alternate methods were sought to decrease the size of the data matrix without losing significant characters and cases. Principal components and factors are expressions of a combination of variables or attributes that represent the complexity of variation. PCA and FA scores were obtained from the reduced data set. These scores are more numerically manageable and were subjected to a cluster analysis to produce a phenogram.

Table 1. Characters used in taximetric analyses of sesame.

HTM	Height at maturity	m
NBR	number of primary branches	c
BRA	number of secondary branches	c
APP	size of foliar appendages	m
PBR	bract pubescence	o
DTF	days to flower	c
NOF	nodes to first flower	c
COR	corolla length	m
NOD	number of capsules per node	c
COL	color exterior corolla	o
YEL	yellow behind lip of corolla	o
YET	yellow in throat of corolla	o
FOC	foveola color	o
FOP	foveola pubescence	o
FOS	foveola shape	b
CAW	capsule width	m
BEA	length of capsule beak	m
SUR	surface hair of capsule	o
PED	length of pedicel	m
CAP	bicarpellate/tetracarpellate	b
LFC1	leaf color yellow-green	b
LFC2	leaf color blue-green	b
LFC4	leaf color purple	b
LFS1	leaf shape entire	b
LFS3	leaf shape divided	b
LEA2	leaflets lobed	b
LEA3	leaflets tripartite	b
LEA4	leaflets trifoliate	b
MAR3	leaf margin dentate	b
TEE1	teeth regularly spaced	b
INF	inflorescence compact/diffuse	b
PET	petiole color green/purple	b

Abbreviations refer to character type: b=binary, c=counted, m=measured, o=ordered.

2.6. NUMERICAL ANALYSES: PRINCIPAL COMPONENTS METHODS

For this study, the goal of establishing groups was to seek structure from within the data rather than by imposing a structure on the data by *a priori* judgement about the number of groups. For this reason, principal component scores and factor scores were the objective evaluation procedures used to determine groups. Their composition was later evaluated by discriminant analysis. The ultimate test of the methods was success at grouping similar-looking cultivars.

PCA can be used to reduce the dimensions of the data in such a way that two or three abstract components contain most of the information found in the original variables. The procedure generates a reduced set of derived functions from linear combinations of the variables, as measured by eigenvalues, called components, factors or axes. These factors contain most of the same information (variance) as the original character set. Characters can be plotted as vectors that represent the characters that contribute most strongly to the distribution of cases. In numerical taxonomic analyses, cases or accessions being studied are called operational taxonomic units (OTUs).

Principal components are sets of composite variables. The first component is a linear combination of variables that accounts for more of the variance in the data than any other possible linear combination. The second component is the best linear summary of variance remaining in the data after the effect of the first component has been removed. The process continues until all the variance in the data has been removed.

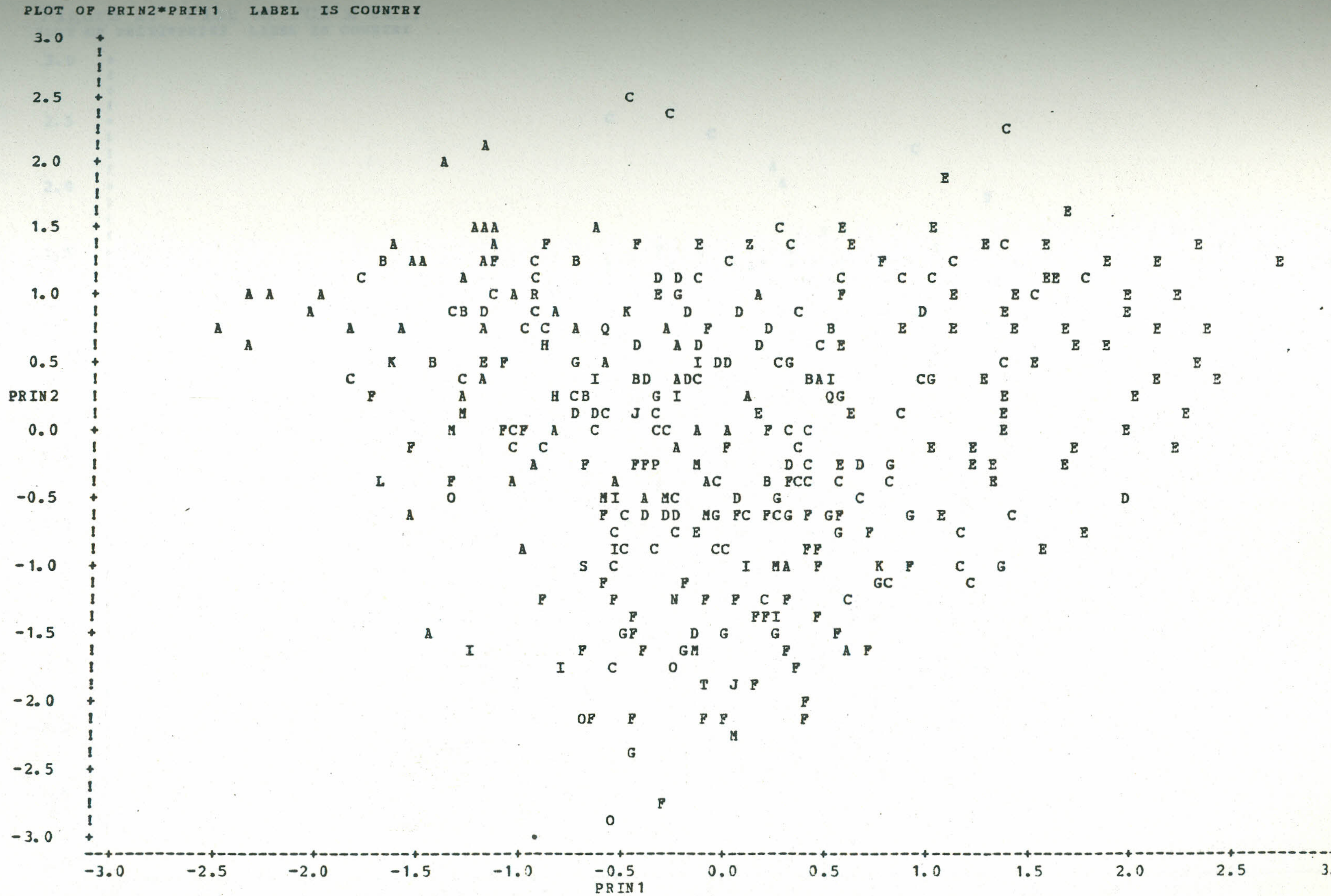
Each successive axis accounts for part of the residual variance of the original data set that is left after all previous axes have been extracted. The percentage of total variance accounted for by axes can be compared with the eigenvalues. Successive axes contribute less to variance, and hence, less to separation of OTUs. Usually only axes I-II, I-III and II-III are considered, with I-II being the most useful, (Sneath and Sokal, 1973). PCA uses variance among individual OTUs when the OTUs are considered as a single population.

All preliminary numerical analyses were done using the Statistical Analysis Systems (SAS) 1982 procedures on an IBM 4341 computer. Data from 354 OTUs were subjected to the procedures outlined below. The data were standardized for all numerical analyses.

The principal component analysis was done with the SAS package procedure called FACTOR, that we manipulated to obtain principal component scores and factor loads. These were plotted as character vectors. Figures 1-3 illustrate the distribution of sesame accessions obtained by plotting the first three principal component scores. The OTUs are plotted using country of origin as label. The country labels are:

A India	B Pakistan	C China
D Japan	E Korea	F Turkey
G USSR	H Afghanistan	I Iran
J Azerbaydzan	K Iraq	L Egypt
M Israel	N Greece	O Jordan
P Ethiopia	Q Mozambique	R Nigeria
S Angola	T Yugoslavia	Z proposed progenitor

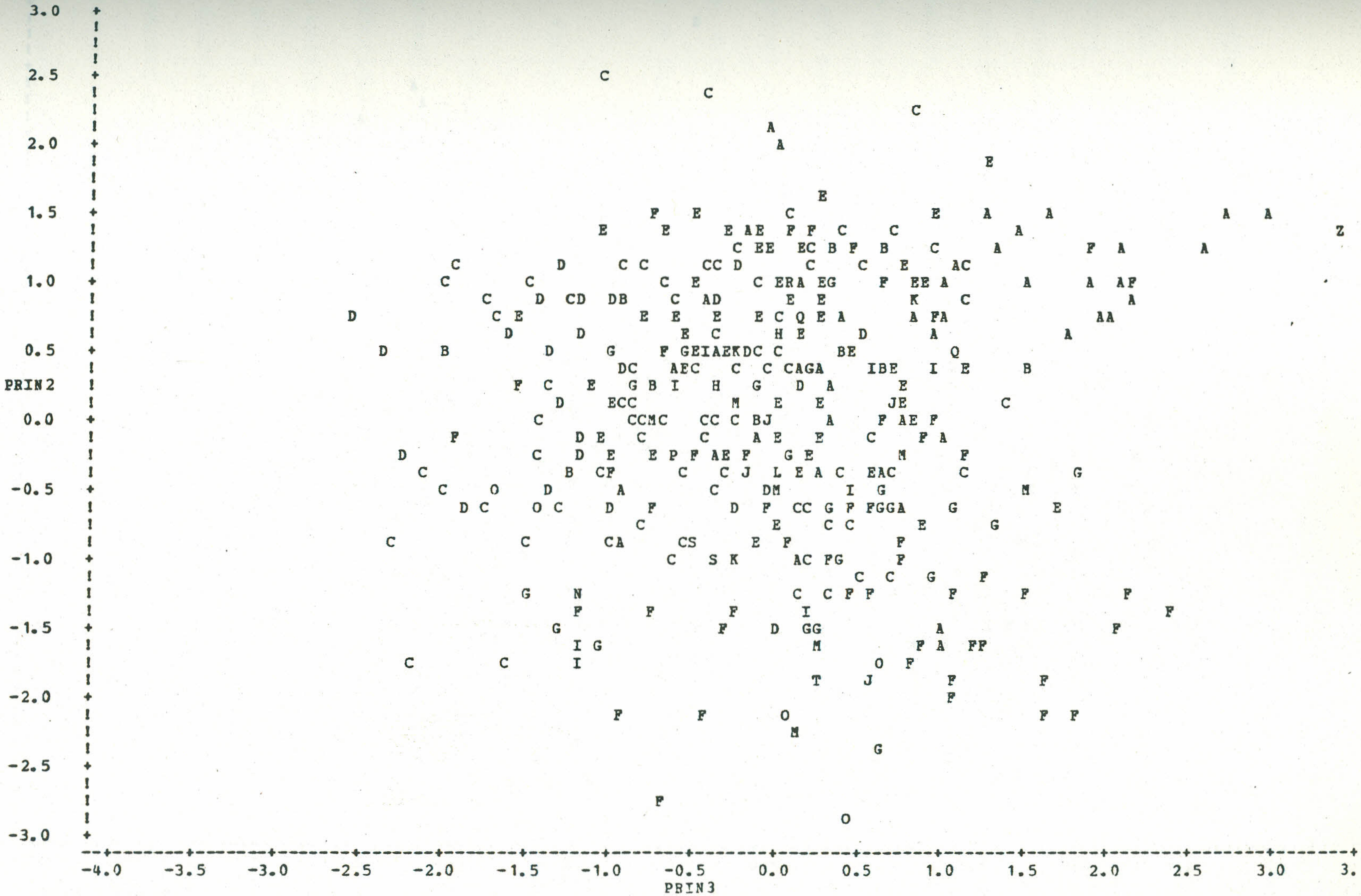
Figure 1. Plot of PC2 x PC1.



NOTE: 35 OBS HIDDEN
PRINCIPAL COMPONENTS ANALYSIS 32 FINAL VARIABLES

Figure 2. Plot of PC2 x PC3.

PLOT OF PRIN2*PRIN3 LABEL IS COUNTRY

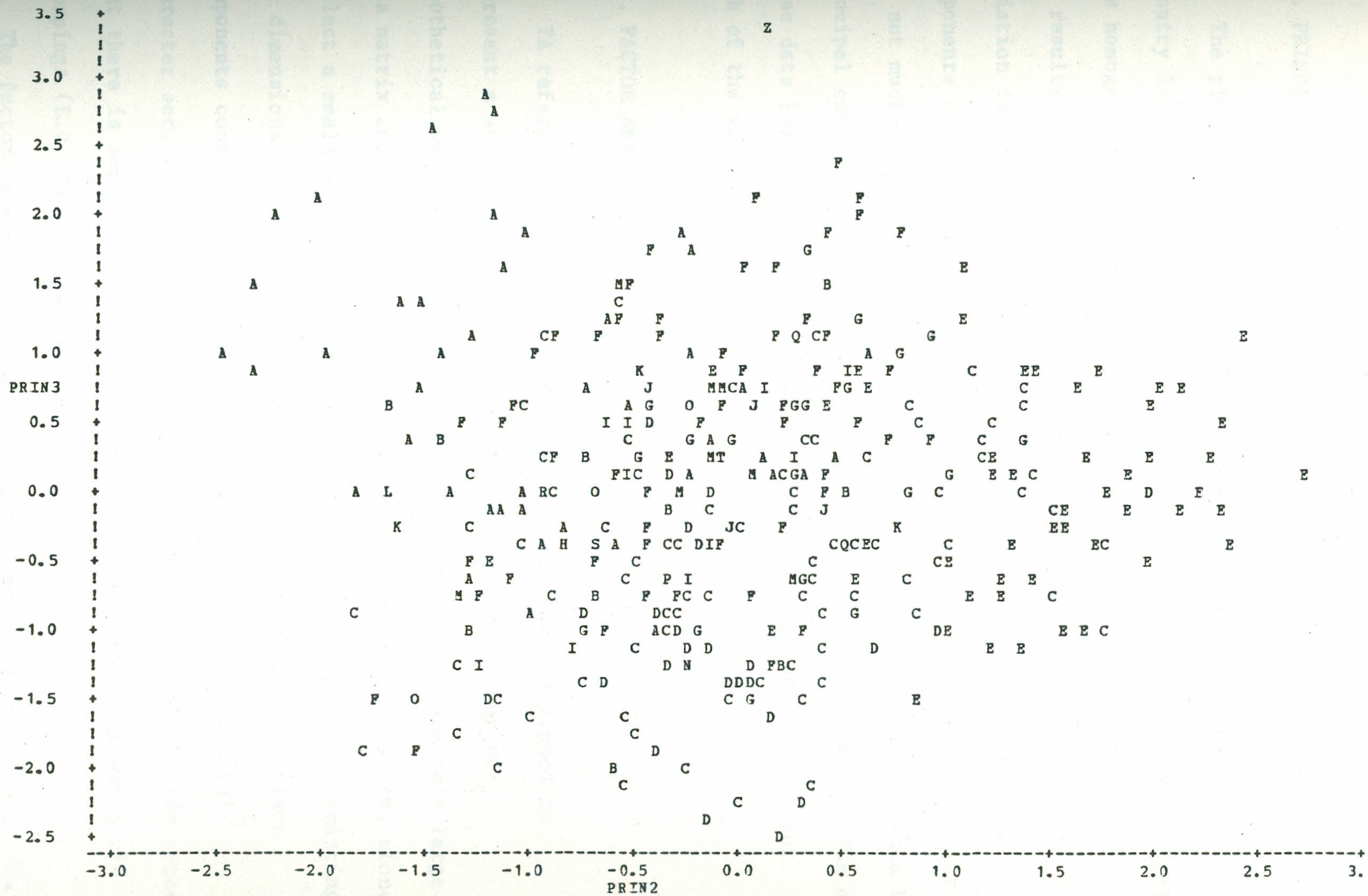


NOTE@D 33 OBS HIDDEN

PRINCIPAL COMPONENTS ANALYSIS 32 FINAL VARIABLES

Figure 3. Plot of PC3 x PC1.

PLOT OF PRIN3*PRIN1 LABEL IS COUNTRY



NOTE@D 32 OBS HIDDEN

PRINCIPAL COMPONENTS ANALYSIS 32 FINAL VARIABLES

2.7. PRINCIPAL COMPONENTS RESULTS

The plots show a fair degree of homogeneity within Korean samples (country label E). Turkish (label F) and Indian (label A) accessions are less homogeneous, because the OTUs are more diverse. Using 32 variables, the results of the PCA were still unsatisfactory because only 31% of the variation is explained by the first 3 components. Seven principal components are required to explain 50% of the variation. These results are not much more satisfactory than those with all 96 variables, when 10 principal components were needed to explain 50% of the variation. PCA of these data has low explanatory value because it does not account for much of the variance.

2.8. FACTOR ANALYSIS

FA refers to a variety of statistical techniques designed to represent a set of characters in terms of a smaller number of hypothetical variables. It was chosen as a method to handle this large data matrix and to reduce the number of variables, each of which, alone, reflect a small portion of the variation. FA can be useful for reducing the dimensions of the data in such a way that two to five abstract components contain most of the information found in the original character set. FA concentrates on what is commonly shared. To the extent that there is something in common one can distinguish the sources of groupings (L.R. Tucker, pers. comm.).

The factor procedure generates a reduced set of derived functions, known as factors, from linear combinations of the variables (as measured by eigenvalues). The factor scores can in turn be clustered. Factor scores can also be plotted, and their distribution suggests some approximate grouping of cases.

Each successive factor accounts for part of the residual variation of the original data that remains after the previous factors have been extracted. The percentage of total variation accounted for by factors can be compared with the eigenvalues. Successive factors contribute less to variance; usually the factors I-II, I-III and II-III are the most useful.

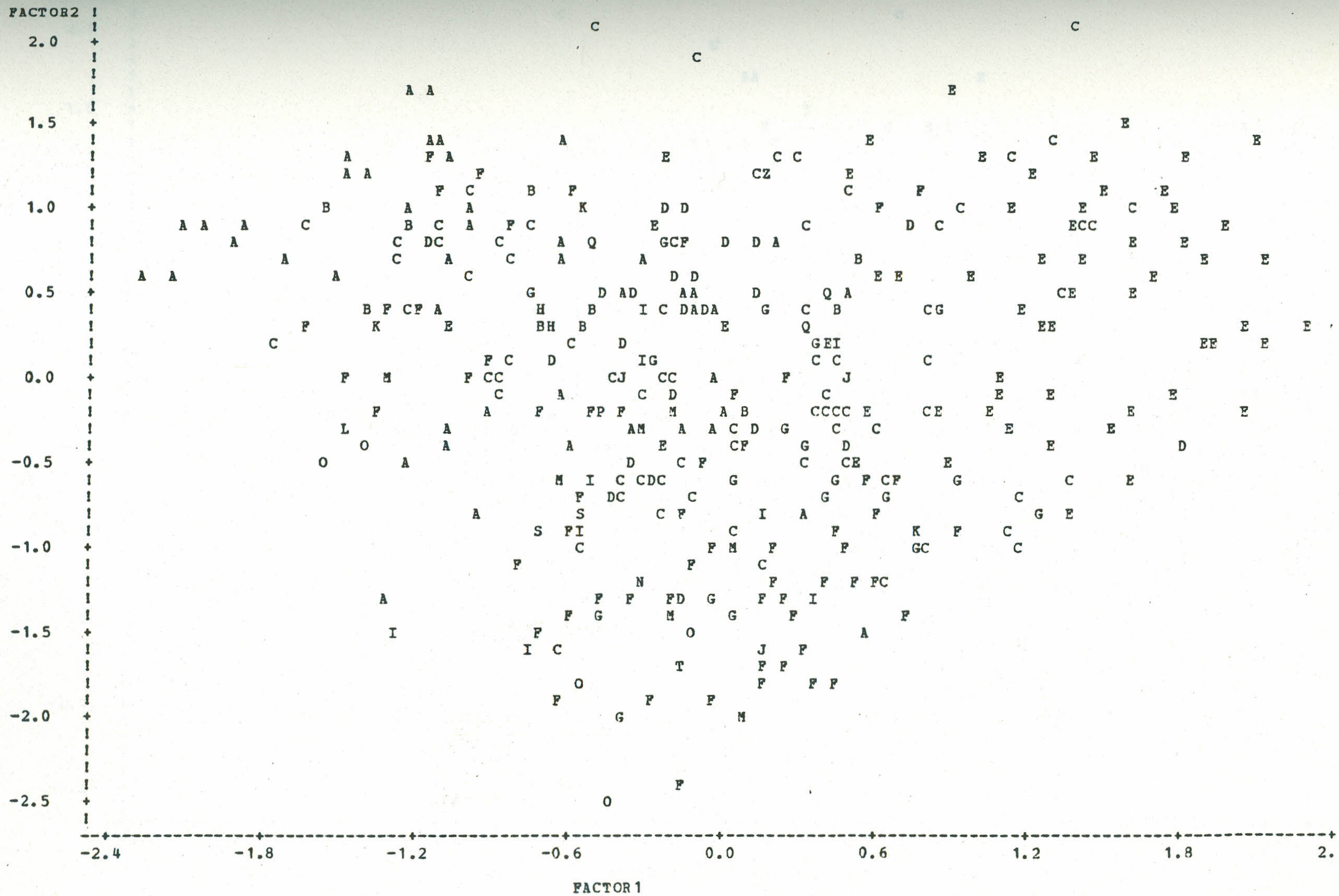
Figures 4-6 illustrate the groupings of sesame cases when the first three factor scores are plotted. Another presentation of these data is a three-dimensional plot of factors I, II and III, using the centroid of each country group as the coordinates plotted (Figure 7). Country labels are identical for Figures 1-7.

2.9. FACTOR ANALYSIS RESULTS

FA contributes more information to this study since the first 5 factors explain 90% of the variation in the data. The first two factors alone explain 53% of the variation, a considerable improvement over the PCA routine. The cases grouped reasonably well by country of origin. The homogeneity of Korean material is illustrated, as is the greater diversity of Turkish and Indian materials. The group centroids for Turkey, India and Korea lie in different quadrants of the three-dimensional plot of factors I, II and III (Figure 7), indicating a reasonable separation of these morphotypes. Clustering procedures were used to gain further information about these groups.

Figure 4. Plot of factor 2 x factor 1.

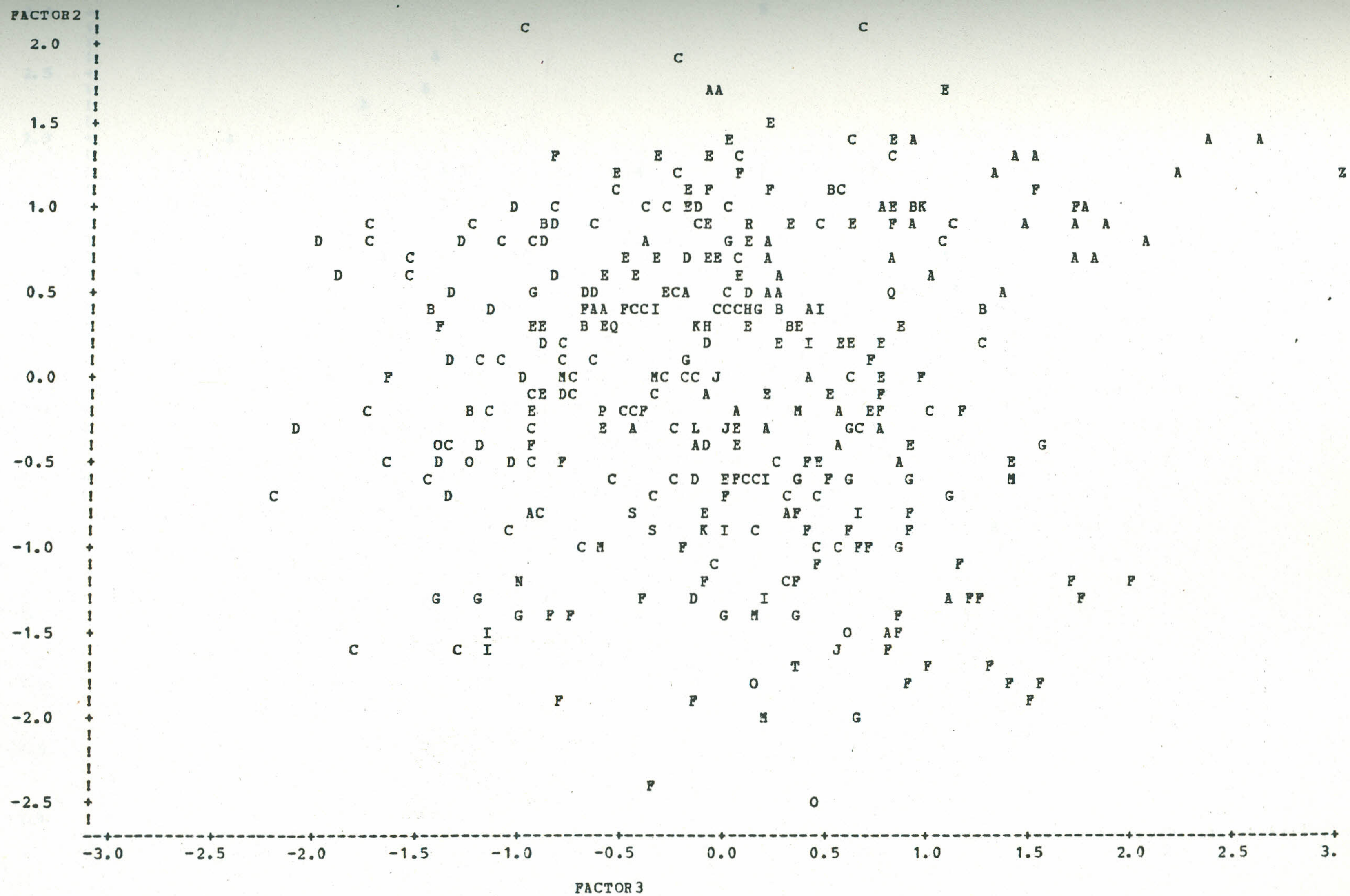
PLOT OF FACTOR 2*FACTOR 1 LABEL IS COUNTRY
SYMBOL IS VALUE OF LABEL



NOTE@D 25 OBS HIDDEN
PRINCIPAL FACTOR ANALYSIS 32 FINAL VARIABLES

Figure 5. Plot of factor 2 x factor 3.

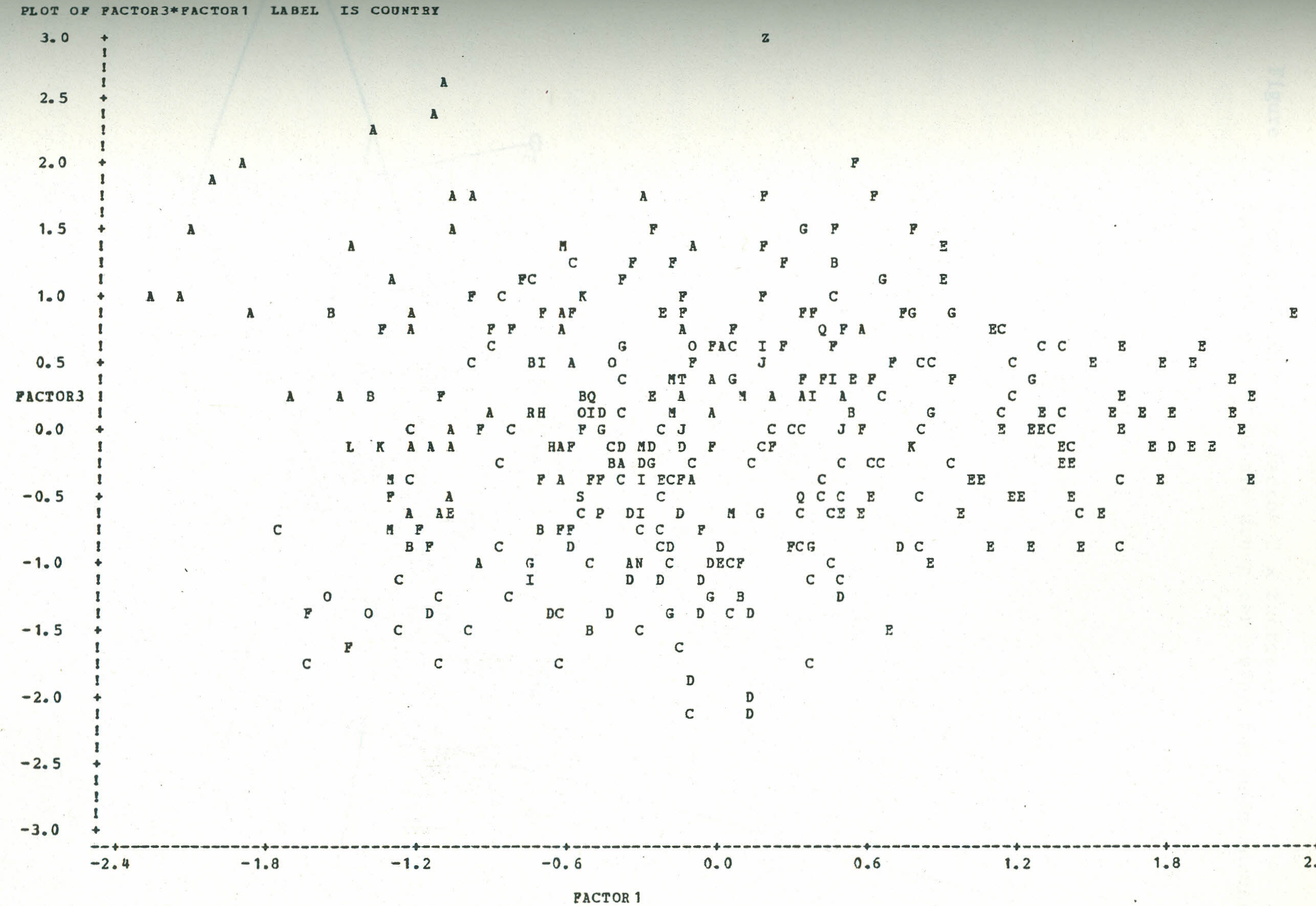
PLOT OF FACTOR2*FACTOR3 LABEL IS COUNTRY



NOTE@D 38 OBS HIDDEN

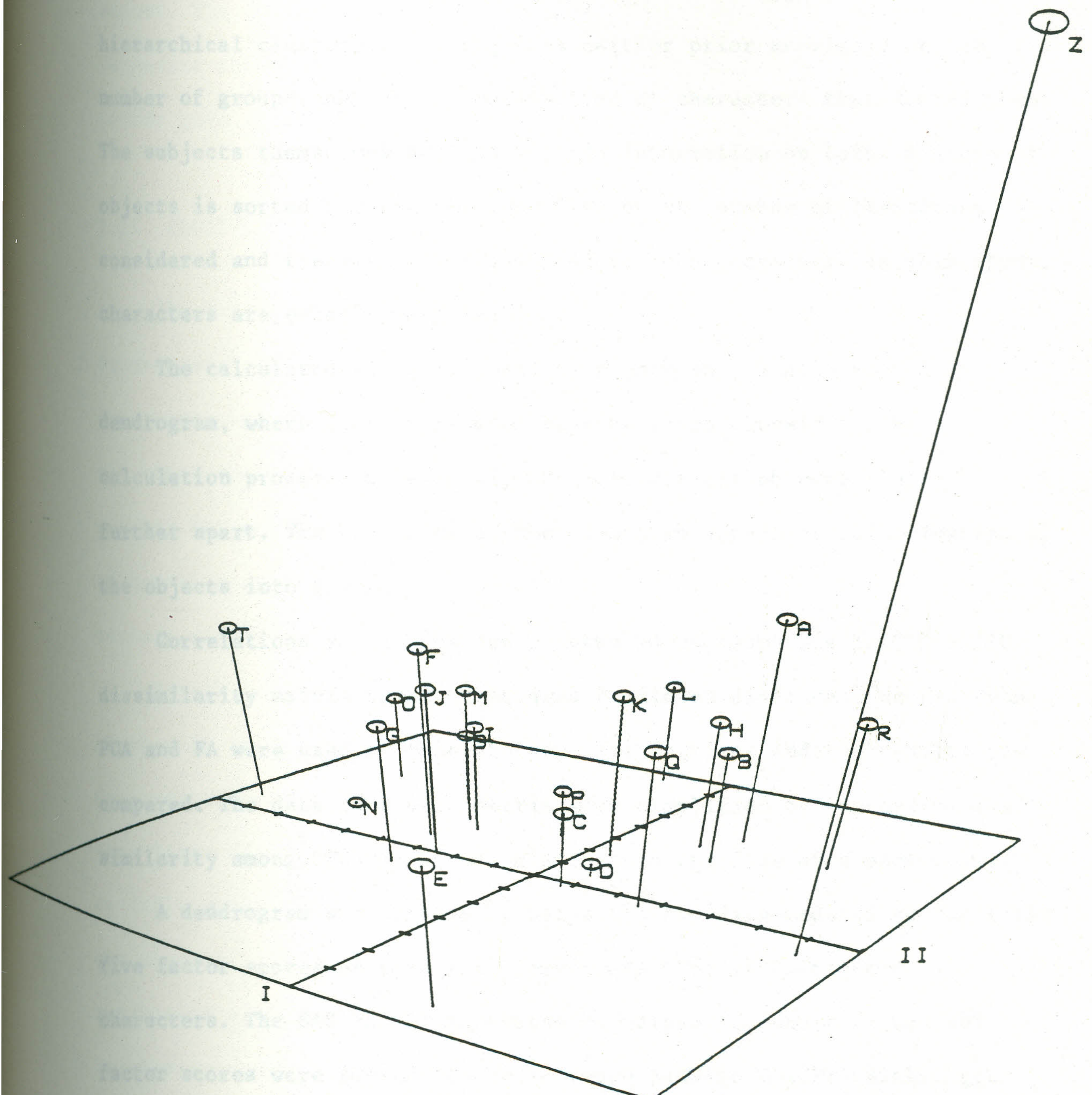
PRINCIPAL FACTOR ANALYSIS 32 FINAL VARIABLES

Figure 6. Plot of factor 3 x factor 1.



NOTE@D 32 OBS HIDDEN
PRINCIPAL FACTOR ANALYSIS 32 FINAL VARIABLES

Figure 7. Plot of factor] x factor 2 x factor 3.
Coordinates plotted are group centroids for each country.



2.10. CLUSTERING PROCEDURES

The form of cluster analysis that we used is aggregative hierarchical clustering. It requires neither prior knowledge of the number of groups, nor of the combination of characters that define them. The subjects themselves have to provide information on both. A group of objects is sorted differently depending on the number of characters considered and the importance assigned to each character. In this study, characters are equally weighted.

The calculated similarity can be presented visually with a dendrogram, where closely related objects score closely by the calculation procedures selected, and more distant objects cluster further apart. The branching of the phenogram separates main clusters of the objects into groups.

Correlations among OTUs can be studied by computing an OTU x OTU dissimilarity matrix based on squared Euclidean distances. Scores from PCA and FA were used to generate separate matrices and the results are compared. The data from each matrix were simplified by expressing the similarity among OTUs as visual clusters in the form of a phenogram.

A dendrogram was created by using the raw data reduced to the first five factor scores or principal components from 32 unweighted characters. The SAS FACTOR-generated Principal component scores and factor scores were passed to the software package DSTCMP (Bieber *et. al.*, 1976), that calculated a dissimilarity matrix based on squared Euclidean distances. Then AGCLUS (Olivier, 1973) was used to generate the final dendrograms. This approach to clustering is described by Hopke

(1983). The trees were prepared by a computation that uses measurements of unweighted pair groups. Figure 8 is the dendrogram generated from FA scores. The dendrogram is redrawn schematically in Figure 9, to represent the distances from origination of each group accurately. PCA scores gave similar groupings.

2.11: CLUSTERING RESULTS AND DISCUSSION

The clustering of OTUs gives some clear patterns of variation. The dendrograms produced from data reduction by FA and PCA are useful for comparison and each provides insight into the classification patterns of the other analysis. Dendrograms produced by the two methods are quite similar but not identical. The complementary differences give useful information about the nature of the combination of characters that cause certain cases to fall into one cluster rather than another.

Sneath and Sokal (1973) briefly address the reliability of clustering solutions achieved from ordinations by PCA and FA. Ordinations by PCA give reliable representation of intergroup distances over large distances (*i. e.* between major clusters), but are not reliable among closely spaced OTUs within clusters. By contrast, many of the sequential agglomerative clustering techniques do a reliable job of estimating similarities among OTUs within a cluster but become increasingly unreliable as larger taxonomic clusters are considered.

The use of factor scores that were submitted to a distance matrix for generation of a phenogram is an approach that is not ordinarily used in systematic botany. Usually the raw data are converted by squared

Figure 8. Dendrogram of sesame cultivars. Factor scores 1, 2 and 3 subjected to the grouping procedure.

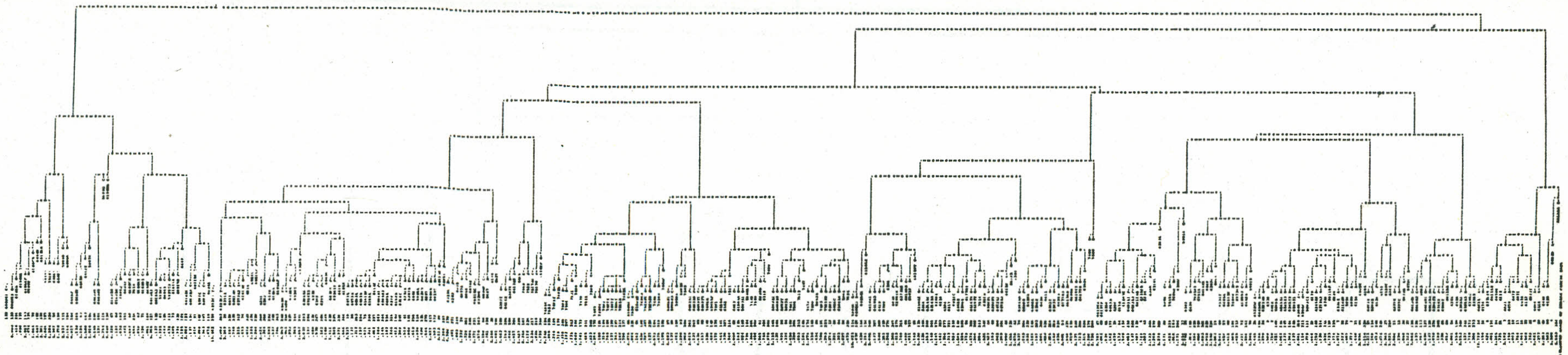
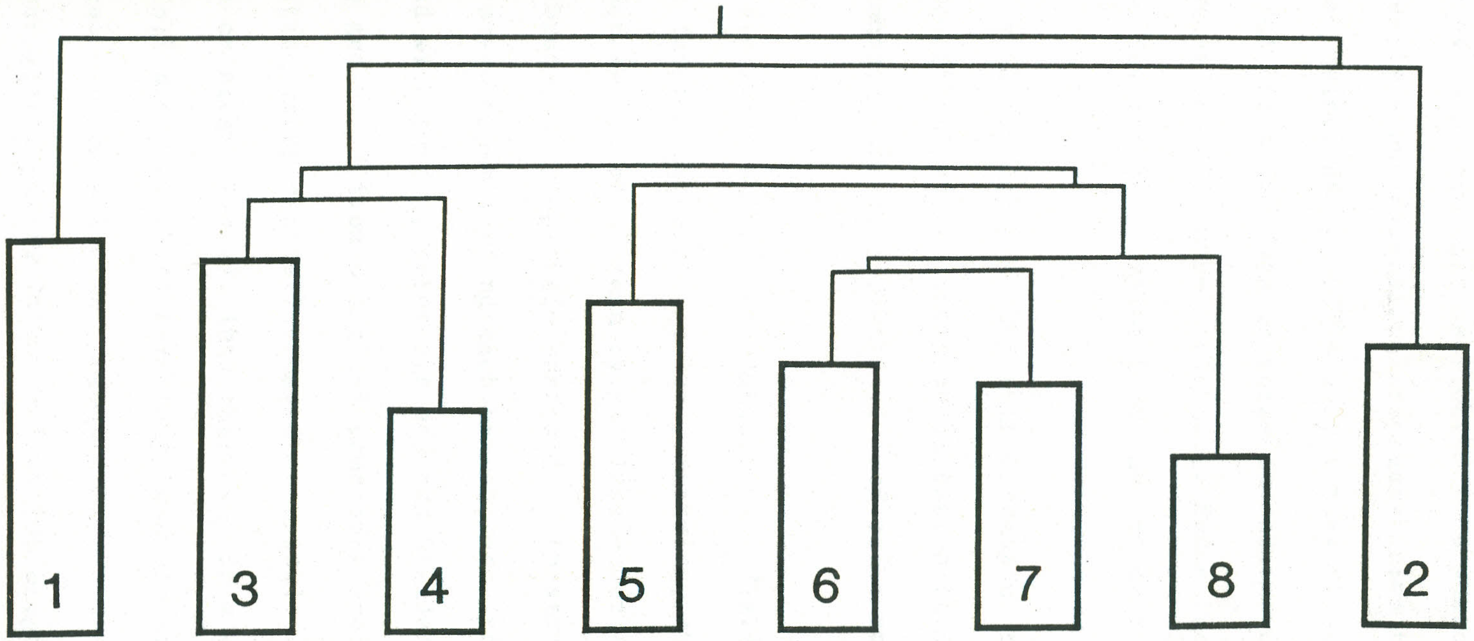


Figure 9. Schematic diagram of groups of sesame cultivars generated by the procedure shown in figure 8.



Euclidean distances to a form that is plotted on a phenogram. The phenogram is actually a one-dimensional representation that is better at representing close relationships (OTUs at the tips of branches) than long distances. PCA views the data in three dimensions and represents long distances among the OTUs more accurately. Hence the two procedures provide complementary results. Groups from the factor procedure are discussed here.

The results show clusters of OTUs that correspond to visual group delimitation. Superficial visual group delimitation is based on overall plant height, branching habit, pubescence, leaf color and shape, and maturity date.

Some group distinctions were straightforward. Field observations showed that most Turkish material was early maturing, short and highly branched, with entire leaves; Korean types, like other Far-Eastern forms were tall and unbranched to sparsely branched, with strap-shaped leaves and capsules arranged densely along each branch; and Indian materials were often tinged with purple, pubescent and had divided leaves.

Dendrograms generated from principal component scores and FA scores both display initial group separation based on capsule morphology (tetracarpellate or bicarpellate). This character is a useful indicator that denotes a full array of characters that separate tetracarpellate plant types (Group 1) from all other forms.

Most tetracarpellate plants in our collection originated in China and Japan, countries farthest from the center of origin. This recesive genotype (Langham, 1945) consists of yellow-green plant color, tall plant height, and considerably dissected trifoliate leaves, often with large foliar appendages along the petiole. They are separated farthest from the dominant purple genotype group on our dendrograms.

The bicarpellate group was further divided into two main clusters. The first branch (Group 2) of the bicarpellate group consists of about 35 cases that are mainly of Indian origin and have a distinct purple tinge. When Sesamum orientale var. malabaricum Nar., a proposed progenitor, is added into the data pool for analysis, it sorts with the purple India group. We noticed a close similarity between the wild taxon and the purple group in the field. Purple plant color is genetically dominant (Nohara, 1933; Langham, 1947, Khidir, 1973). The clustering of purple plant type with the progenitor makes good sense to us in terms of the evolution of sesame. We propose that India is the center of origin and that those plants of the dominant genotype having purple plant color, bicarpellate capsules, intense pigmentation of the corolla, stem, leaves and capsules, and black seed color, arose there (discussion section, this paper; Bedigian, Seigler and Harlan, 1984). Discriminant analysis scores later confirmed the association of these traits. Dendrograms formed from scores of both methods (PCA and FA) show similar groupings of cases.

Korean plant types showed a considerable degree of uniformity in the field. Both grouping analyses show one cluster composed mainly of Korean cases (Group 4), bearing capsules arranged three to a node. These are erect, monostem types with none or few robust branches and strap-shaped leaves. This capsule arrangement is a genetically recessive trait (Langham, 1945); also Korean OTUs cluster far from the dominant purple genotype on the dendrogram.

Turkish plants were grouped more compactly by the dendrogram generated from the matrix produced from principal component scores than the one produced from FA scores (Group 3). There is a natural diversity among the accessions from Turkey that is reflected by the lack of complete homogeneity in the cluster pattern. Some general trends among Turkish cases are early maturing, low, bushy plants bearing pubescent bicarpellate capsules and having primarily entire leaves.

We attempted to refine the overlapping diversity of Indian and Turkish accessions by considering their ecological habitat. Cases from each country were identified accordingly and the numerical procedures were repeated, but we were unable to detect associations between morphotypes and their zone of origination.

Accessions from some countries cannot be easily identified by a single plant type because the variation of morphotypes is vast. Chinese material illustrates this phenomenon well and one finds Chinese material scattered throughout the dendrogram.

It is important to remember that the use of a classificatory program makes the assumption that the population is discontinuous (Williams, 1983). Even if the population is everywhere continuous, or even random, the program finds discontinuities.

A fundamental problem of hierarchical clustering is the fact that each OTU is initially considered to be independent. Once a pairing is made, it cannot be unmade. At an early level of comparison two samples may best fit the criterion and be clustered whereas further down, when larger clusters have been defined, those samples might not go into the same group as the best split. Additionally, all samples have to go somewhere. Some samples might be put into the "best" group but this may not necessarily be "true". Thus we must be careful about over-interpretation of individual samples within a group (P. K. Hopke, pers. comm.).

2.12. DISCRIMINANT FUNCTION ANALYSIS

Some clusters are less easily classified by any pronounced combination of characters. Discriminant analysis (DA) was useful to discern the bases on which some other groupings were made (Blackith and Reyment, 1971). DA and PCA use similar techniques. Both form linear combinations of the variables such that the amount of variance accounted for by the first formed combination is maximized, and succesive combinations account for less and less of the variance. Discriminant functions are used when groups of OTUs are compared. DA compares variation within groups to variation among groups, and requires an *a priori* assignment as to the number of groups before the operation can be performed.

In discriminant analysis, combinations of characters are calculated so as to maximize group separation. In this study many more characters than necessary were measured to achieve satisfactory group separation.

The number of OTUs that were correctly classified depended on the number of variables utilized. When all 96 variables were included in the discriminant analysis, OTUs were correctly classified by country 90-100% of the time. Fewer variables resulted in some loss of accuracy of prediction, due to a considerable amount of intergrading minor variation that results in heterogeneity of morphotypes from a region. When the 32 final variables were studied, OTUs were correctly classified by country from 50% (China) to 90% (USSR) of the time. Variations within country might be affected, in part, by variations in ecosystems available for growing sesame. India and Turkey have such varieties of ecozones. China is a vast country with a great variety of ecological zones where appropriate sesame cultivars can be grown, as compared with the sesame-growing areas of the USSR that are more restricted to a few ecological zones.

Groups generated by the phenograms were studied with discriminant function analysis to discover which variables were most important for group delimitation. Examination of mean variable values for larger clusters can be useful in interpreting the basis of the clustering.

2.13: DISCRIMINANT ANALYSIS RESULTS

In this study, group designation for discriminant analysis (DA) was postponed until their structure was determined by the methods outlined above. The final groups from the dendrograms generated by AGCLUS using 32 variables were subjected to DA to learn what the major characteristics are that effect group formation. Eight groups were clearly separated with a minimum of overlap among them. Means of characters for each group were computed and compared. These results were useful to describe those groups that were more difficult to appraise.

The first major group distinguished by the dendrogram is characterized by tetracarpellate capsules. Discriminant analysis shows that other associated characters are tall, blue-green plants with few branches, mainly simple and trifoliate leaves with low pubescence and large foliar appendages, and many nodes to first flower. The inflorescence is compact. The capsule carpel number discriminant score is 33, a very large number, compared with the small negative scores of all other groups.

The purple Indian material is the second group to branch from the collection of cases. Characters associated with this group by discriminant analysis and compared with the overall means of characters are tall plants, many branches and frequent secondary branching, large number of nodes to first capsule, diffuse inflorescence with bicarpellate capsules, late maturity, small size and deep purple corolla color with heavy yellow color behind the lip of the corolla and dark yellow corolla throat, highly pubescent foveola, large foveola size, and mainly tripartite and trifoliate dentate leaves that are heavily dissected, highly pubescent and have a purple tint. The entire plant looks markedly purple. The discriminant score for purple color is 9 for this group, that is the highest value. All other groups have low positive or negative scores.

Korean material is distinguished by tall plants with few or no branches, leaves with foliar appendages, capsules borne three to a node and condensed compactly along the stem. The capsules are bicarpellate with long beaks. The corolla is long and the corolla throat is dark yellow. There is also a yellow region behind the lip. Otherwise, the corolla is white, lacking the purple pigmentation associated with other groups. Its foveola is deep yellow but has little pubescence. The tripartite leaves are blue-green and have dentate margins.

A Turkish group clusters away from the Korean material. It also has a blue-green plant color, but pubescence is low and leaves are mainly entire. Foliar appendages are entirely absent and margins are untoothed. Bicarpellate capsules arranged densely along the stem are one per node. The corolla has a bright yellow throat.

Chinese material is morphologically heterogeneous, but its uniqueness is in a yellow-green plant color; condensation of the inflorescence and increase in carpel number seems to be the main trend. Flowering starts early with capsules borne low to the ground. There are large yellow glands, and the plants exhibit considerable fasciation. The leaves are mainly entire, and sometimes trilobed or trifoliate. Corolla color is usually white, and purple pigmentation is largely absent.

Some of the clusters generated were more difficult to interpret than the five described above. This parallels our field observations as there, too, we were unable to identify some lines as belonging to any specific category. Certain cultivars just do not possess any clear combination of characters associated with a particular group.

One strategy for assigning structure to those less well-defined groups was to separate them into their constituents and work with the subsets assigned as new groups. This method allowed us to define a group composed of Japanese and Indian cases that flowers late, has bicarpellate wide capsules, a blue-green plant color and bears toothed trifoliate and trilobed leaves. The inflorescence is diffuse and there is no secondary branching.

2.14. CONCLUSIONS AND DISCUSSION

An evolutionary view of sesame as a crop must consider its antiquity and the geographic, social and political isolation of the regions from which the sesame plants that show the greatest morphological distinctiveness are derived. Geographic features include altitude, temperature, rainfall, soil type and other climatic features. Usually one can expect substantial similarity among cultivars from any one region and greater dissimilarity among cultivars from different regions. Any barrier to gene flow permits populations to fragment and accumulate genetic differences among the subpopulations (Stebbins, 1950; Baker, 1953; Harlan, 1970; Dobzhansky et. al, 1977). Deviations from this pattern may occur when a location is isolated in space and time and a secondary center of diversity has time to evolve (Harlan, 1975).

This classification relates to the evolutionary history of the crop in a number of interesting ways. Indian lines in our collection were all bicarpellate. The wild progenitor that we propose (Bedigian, Seigler and Harlan, 1984) is also bicarpellate and originates in India. It has an open branching pattern and a markedly purple color. Plant color is one of the more conspicuous features that can be used to describe a plant type. A distinctive purple form of sesame is found in India, nearest the center of origin that we propose. This illustrates the Vavilov effect, that suggests that near the center of origin more dominant genes are expressed. Farther from the center, more recessive genes are expressed. An important illustration of this is the genetically recessive tetracarpellate capsule type that is entirely absent from our study collection from India. Cluster analysis reveals that the tetracarpellate capsule group branches farthest from the purple India group. This is noteworthy because the dominant purple genes found in India are shared with the proposed ancestor of the crop. The proposed progenitor also fell into the purple Indian cluster. The most distant branch on the dendrogram is the recessive genotype found in Far Eastern tetracarpellate plants that grow farthest from the proposed center of origin. The two clusters that branched farthest apart on the dendrogram represent the extremes in variation visually and genetically, from dominant to recessive characters.

This study confirms the importance of capsule shape as an indicator of other morphological features that distinguish one morphotype from other types. It supports the taxonomic judgement of Hiltebrandt (1932), who suggested that both the bicarpellate and tetracarpellate forms of sesame be elevated to the level of subspecies. He favored this separation for the following reasons: differentiation by geographic areas, presence in both groups of suites of characters linked with the differences in the number of carpels, and parallelism in variation with regard to other characters. Tetracarpellate capsule is a derived character that may have been selected by farmers who saw its advantage in increasing yield.

In these analyses there was much better uniformity among Korean materials than Turkish, Indian or Chinese. This can partially be attributed to the intergrading variation of the plants themselves, but it may also be argued that the preservation of the collection obtained from the USDA encountered problems of mixing of lines over the years.

The Korean material that we include in this study was received directly from the Korean Crop Experiment Station, Suweon, Korea, and is likely to represent a collection of pure lines. This purity could well have been lost from material maintained and increased by the USDA in their world collection of germplasm. Baum (1970) reinforces our concern about difficulties working with world collections. In addition to errors in identification and labelling, some accessions may have become mingled or modified with handling. Some Chinese lines looked remarkably like Indian and Near Eastern types, but that could truly reflect their morphology and the long history of trade between India and China (Laufer, 1919).

The differences among some of the 353 cultivars are intergrading. The great polymorphism within many cultivars coupled with the apparently continuous variability among the cultivars was at least partly responsible for our inability to identify successfully all cultivars with groups.

We observed considerable bee visitation to sesame flowers in the nursery each season, and wondered whether they might be transferring pollen across lines with their daily foraging. If bee activity has continued for the years through which the collection has been maintained, it could also account for the considerable absence of pure lines from the USDA collection. Under particular environmental conditions, Yermanos (1980) recorded natural cross pollination levels up to 68%, in Moreno, California. Sesame was the only blooming plant material in the midst of a semiarid area with little other vegetation. Other scientists have reported natural cross pollination levels between 1-17% in India (Sikka and Gupta, 1947), between 3-15% in Mexico

(Martinez and Quilantan, 1963), and levels of 3-6% in Sudan (Khidir and El Awad, 1972).

It is important to note that the results of this study do not represent the entire diversity of sesame germplasm. There are cultivars of sesame in Sudan (Bedigian and Harlan, 1983) distinct from these. One new group is Kordofan Red, a tall, profusely branched, robust type with many large capsules, and brick red seeds high in oil content. Another line from Sudan is dinderawi that has grey seeds and capsules that are 50% longer than any others observed. It does, however, present a reasonable survey of the diversity of genetic variation in sesame cultivars.

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CHAPTER 3

SESAMIN, SESAMOLIN AND THE ORIGIN OF SESAME

3.1. ABSTRACT

Cultivars of sesame were screened to determine how widely lignans occur. All lines tested contained sesamin and sesamolin. The occurrence of sesamin and sesamolin in other species of *Sesamum* varied. Some other genera in the Pedaliaceae also possessed lignans. Phytochemical evidence as well as morphological data support the suggestion that the progenitor of sesame occurs in India.

3.2. INTRODUCTION

The wild progenitor of sesame, *Sesamum indicum* L., has not been established with certainty and the literature asserts with equal frequency that the center of origin of the crop is in Africa and Asia (Nayar and Mehra, 1970). A recent proposal that *Sesamum latifolium* Gillett is the progenitor of sesame and that the crop originated in Africa, was accompanied by a division of the genus *Sesamum* into four sections (Ihlenfeldt and Grabow-Seidensticker, 1979). The Pedaliaceae family, to which sesame belongs, has been considered related most closely to the Bignoniaceae, Martyniaceae and Acanthaceae (Hutchinson, 1973; Takhtajan, 1980; Cronquist, 1981).

Although the use of chemical data to establish phylogenetic relationships is important (Swain, 1963; Harborne, 1973; Young and

Seigler, 1981), lignans have not been widely used for these analyses. Lignans are widespread in the plant kingdom (Hearon and MacGregor, 1955; Robinson, 1980), occurring in heartwood, leaves, and resinous exudates of plant families as distantly related as the Gingkoaceae and the Asteraceae. Approximately 3 dozen compounds are known at present (Robinson, 1980). Relationships of members of several families including the Asteraceae (Hänsel, Schulz and Leuckert, 1964; Greger, 1979 and 1981) have been studied with lignans but these compounds have not been used to study the phylogeny of plant families related to the Pedaliaceae.

Seeds of sesame contain the lignans sesamin and sesamolin. These compounds are not found in other edible oils. The effects of strain, location grown, and aging and frost damage on the sesamin, sesamolin and sesamol content of sesame seed have been examined (Beroza and Kinman, 1955). In a related species, Sesamum angolense Welw., the isolation and structure of a novel compound, sesangolin, an insecticidal synergist, has been reported (Jones, Beroza and Becker, 1962). The presence of sesamin was not reported in angolense. These workers obtained the oil from Pearman et al., (Pearman, Raymond and Squires, 1951) who had submitted a seed sample to the director of the Royal Botanic Gardens, Kew, for identification; the seeds were believed to be those of S. angolense. Oil from the same seeds was reported to contain sesamin by Pearman et al.

The families considered to be the nearest relatives of the Pedaliaceae, the Bignoniaceae and the Acanthaceae, also contain lignans. Sesamin and another lignan, paulownin, were isolated from the wood of

Paulownia tomentosa Steud. (Bignoniaceae) (Takahashi et. al., 1963; Takahashi and Nakagawa, 1966); NMR spectral analysis of the stereochemistry of the latter compound shows structural similarity to sesamin and sesamolin. Roots and stems of Phyllarthron comorense and Tabebuia rosea (Bignoniaceae) yielded sesamin and paulownin, respectively (Joshi, Singh and Singh, 1976). Sesamin, asarinin and sesamolin, and a new compound, simplexolin, were isolated from Justicia simplex (Acanthaceae) (Ghosal, Banerjee and Srivastava, 1979). Recent reports of sesamin in other related families include Hyptis tomentosa (Lamiaceae) (Kingston, Rao and Zucker, 1979), Aptosimum spinescens Thunbg. (Scrophulariaceae) (Brieskorn and Huber, 1976) and Gmelina arborea Roxb. (Verbenaceae) (Birch and Smith, 1964; Anjaneyulu et. al., 1977).

Other taxa from which sesamin and sesamolin have been reported are Acanthopanax senticosus (Shih, 1981) and A. sessiliflorum (Araliaceae) (Yook et. al., 1977); Asarum sieboldii (Aristolochiaceae) (Hearon and MacGregor, 1955; Cameron, 1961); Anacyclus pyrethrum (Asteraceae) (Burden and Crombie, 1969); the Artemisia absinthium group (Dermanovic, Mladenovic and Stefanovic, 1976; Greger, 1979 and 1981; Greger and Hofer, 1980); Chrysanthemum cinerariaefolium (Asteraceae) (Doskotch and El-Feraly, 1969); C. frutescens (Winterfeldt, 1963); C. indicum (Asteraceae) (De Pascual et. al., 1980); Diotis maritima (Asteraceae) (De Pascual, Barrero and San Feliciano, 1977); Ageratina, Critonia, and Fleischmannia (Asteraceae), formerly part of the genus Eupatorium, (Bohlmann, Jakupovic and Lonitz, 1977); Otanthus maritimus (Asteraceae) (Bohlmann, Zdero and Suwita, 1974; Khafagy et. al., 1979); Alnus glutinosa (Betulaceae) (Weinges, 1961); Salicornia europaea (Chenopodiaceae) (Chiji, Aiba and Izawa, 1978); the Cupressaceae Austrocedrus chilensis (Cairnes, Kingston and Rao, 1981) and Chamaecyparis, a garden species that has hibalactone which upon reduction yields hinokinic acid and d-sesamin, (Masumura, 1955); Gingko biloba (Gingkoaceae) (Karyone, Kimura and Nakamura, 1958; Kimura, 1959); Machilus glaucescens (Talapatra, Ray and Talapatra, 1976 and 1978); Ocotea usambarensis (Lauraceae) (Carnmalm, 1956); species of Magnolia (Magnoliaceae) (Kakisawa, Chen and Hsu, 1972; Kamikado et. al., 1975; Talapatra, Mukhopadhyay and Dutta, 1975); Talauma hodgsonii (Magnoliaceae) (Talapatra, Mukhopadhyay and Talapatra, 1977); Picea abies (Pinaceae) (Weinges, 1961); Macropiper excelsum (Piperaceae) (Briggs, Cambie and Couch, 1968); the genus Piper (Piperaceae) (Hänsel and Zander, 1961; Atal, Girotva and Dhar, 1966; Banerji and Dhara, 1974; Dutta and Banerjee, 1976; Dutta et. al., 1977; Scharf et. al., 1978; Banerji et. al., 1979); Evodia micrococca var. pubescens (Rutaceae) (Cameron and Sutherland, 1961); Fagara xanthoxyloides (Rutaceae) (Carnmalm, Ertdman and Pelchowicz, 1955); Flindersia pubescens (Rutaceae) (Hollis et. al., 1961); and the genus Zanthoxylum (Rutaceae) (Pelter et. al., 1976; Waterman, Gray and Crichton, 1976; Deshpande and Shastri, 1977; Ishii, Ishikawa and Haginiwa, 1977; Bernhard and Thiele, 1978; Stermitz, Caolo and Swinehart, 1980).

Lignans are active constituents of certain medicinal plants (Robinson, 1980). Podophyllin, a complex resinous extract of may apple, Podophyllum peltatum, has been used as a powerful cathartic. The principal lignan constituent, podophyllotoxin, is of interest because it has cytotoxic action similar to colchicine. Podophyllotoxin and other lignans that possess the partially reduced naphthalene nucleus have shown some promise in treating certain types of neoplasms (Weiss, et. al., 1975; Robinson, 1980). However, when constituents of Hyptis tomentosa (Lamiaceae) were screened for anticancer agents, sesamin was found to be inactive (Kingston, Rao and Zucker, 1979).

It has been reported that sesamin and sesamolin may be involved in natural seed dormancy. Germination inhibition by sesamin and sesamolin is considerably greater with peanut and cucumber seeds than with rice, where only retarded coleoptile growth occurred (Bhiravamurty et. al., 1979). The effect is more pronounced on lipid storing seeds than on seeds containing carbohydrate as the storage product, and it has been suggested that they effect the end-product initiating enzymes controlling lipid mobilization (Bhiravamurty et. al., 1979).

A germination inhibitor isolated from Aegilops ovata (Lavie et. al., 1974) bears a close structural resemblance to sesame lignans. Leached hulls inhibited the germination of Lactuca achenes. Inhibition was considerably stronger in light than in darkness. The authors claimed that it was a lactone. This report was questioned (Anjaneyulu et. al., 1977) and the compound was later shown to be the lignan acanthotoxin (Roy, Guha and Chakraborty, 1977). This compound is also found in Zanthoxylum acanthopodium (Rutaceae) and has spectral properties identical with those of justicidin E, isolated from Justicia procumbens (Acanthaceae) (Roy, Guha and Chakraborty, 1977). Extracts of wild sesame seed from India inhibited the growth of seedlings of cultivated sesame (Sen, 1976).

Root exudates of sesame are repellant to root knot nematodes of eggplant, tomato, potato and okra (Atwal and Manger, 1969; Varma, Sharma and Pathak, 1978). Sesame was as potent a nematicide as marigold. Field trials showed that intercropping of these crops with sesame is beneficial economically because the nematode problem is eliminated; moreover, the sesame can be harvested.

The action of sesamin and sesamolin as inhibitors of mixed function oxidases (Yu, Wilkinson and Anders, 1980) is due to the methylenedioxyphenyl group, that has been recognized previously as an effective inhibitor of microsomal oxidation. Sesamin and sesamolin have been used for practical applications as antioxidants and insecticides. In the course of testing pyrethrum extracts in combination with a number of vegetable and fish oils, it was found that only sesame oil markedly increased the effectiveness of pyrethrum insecticides (Haller et. al., 1942).

Sesamin and sesamolin enable sesame oil to resist oxidative rancidity (Budowski and Markley, 1951; Seino, Isobe and Watanabe, 1981), an action that is also attributed to the methylenedioxyphenyl group.

Sesamin and sesamolin are used as active ingredients in antioxidants, antiseptics, bactericides, viricides, disinfectants, moth repellants and anti-tubercular agents. These uses are mentioned in a series of patents. Sesame oil has been used as a control in pharmacological experiments.

We undertook this study to learn more about the phylogenetic relationships of sesame within the Pedaliaceae. We were seeking new data to help ascertain the origin of the cultivated crop and to learn the extent to which sesamin and sesamolin occur in related taxa. Neighboring species, genera and families were examined. We were also interested in a practical procedure for the determination of sesamin and sesamolin by TLC as a means to screen seed oils of members of this group. We attempted to develop an analytical method to screen oils rapidly, as well as to isolate and identify sesamin and sesamolin with NMR spectroscopy in order to determine structure and to assess purity.

3.3. MATERIALS AND METHODS

3.3a. ISOLATION AND CHROMATOGRAPHY OF OIL COMPONENTS

Sesame seeds were crushed in a mortar and pestle with chloroform. The filtrate was passed through cotton washed with light petroleum to remove debris, and aliquots of the filtrate applied directly onto thin layer plates (silica gel G).

Triglycerides were removed by preparative TLC (silica gel G, light petroleum: diethyl ether: HOAc, 90:10:1). Plates were visualized with 2′,7′-dichlorofluoroscein (0.1% in 50% EtOH). Lipids other than triglycerides were desorbed from silica gel with chloroform, concentrated and rechromatographed (silica gel G: light petroleum: diethyl ether: HOAc, 70:30:1 or chloroform: benzene: MeOH 30:20:0.5).

Samples were flushed with nitrogen and stored under refrigeration after the final concentration step to protect the purified extracts from decomposition. All extracts were stored in the refrigerator.

3.3b. ISOLATION AND PURIFICATION OF LIGNANS

Sesamin and sesamolin were isolated from a preparative column of silica gel. The column was packed in chloroform. Sesame oil was placed on the column and eluted with light petroleum: diethyl ether (95:5). The column was then washed with light petroleum: diethyl ether (9:1) to effect complete removal of triglycerides. Lignans were removed with light petroleum: diethyl ether (50:50). Separation was monitored by TLC.

3.3c. HERBARIUM SPECIMENS STUDIED

taxon	MO #	date	country
Sesamum angolense	2652241	Aug. 20, 1976	Malawi
S. calycinum	2947307	Feb. 22, 1979	Malawi
S. capense	2341123	1974	Mozambique
S. pedaloides	2429666	11/5/1976	S W Africa
S. rigidum ssp. merenskyanum Ihl. & Seid.	2614251	Apr. 2, 1977	South Africa
Ceratotheca triloba	2832733	Jan. 1, 1979	Mozambique
C. triloba	2186743	Dec. 22, 1971	South Africa
C. triloba	2449087	Mar. 9, 1977	Swaziland
Holubia saccata	1602340	1948	Rhodesia
Pedalium murex	2829866	May 30, 1976	Ghana
Pretrea zanguebaricum	2448044	Apr. 14, 1973	Botwsana
Pterodiscus aurantiacus	2404153	9/3/1975	South Africa
Sesamothamnus busseanus	2892717	Nov. 1970	Kenya

3.4. RESULTS

Oils of the taxa studied were separated on silica gel by TLC or column chromatography. Sesamin and sesamolin were resolved from other seed oil compounds. We also defined a solvent system for TLC that would separate the lignans of sesame. After removing triglycerides, the best separation was obtained with a chloroform: benzene and MeOH mixture

(60:40:1). Sesamolin travelled nearest the solvent front (Rf 0.54) and sesamin lagged behind it (Rf 0.36). Up to six other spots were observed under u.v. light after spraying the plates with 2′,7′-dichlorofluorescein, or after acid charring, but these were found to be non-lignan lipids by NMR spectroscopy.

The first step in the taxonomic comparisons was to examine 50 cultivars of sesame that originated in different geographic regions of the world. We found no significant differences in sesamin and sesamolin content among the cultivars. All samples tested possessed both lignans. As no lines of sesame contained sesamol, a hydrolysis product (Budowski and Markley, 1951) of sesamolin, it did not appear that our procedure was accompanied by hydrolytic degradation.

We attempted to locate where in the seed the lignans are stored. Dissection of seeds to remove the oily endosperm that wraps around the embryo proved to be difficult and contamination of the embryo fraction with some endosperm tissue was unavoidable. Our results show that the embryo fraction lacks sesamolin, which is associated only with endosperm tissue. Sesamin was found in both portions.

We examined near relatives of cultivated sesame to see how widespread these lignans are in the genus Sesamum (Table 2). Sesamin and sesamolin were found in seed oils of S. angolense, S. angustifolium, S. calycinum, S. indicum, S. orientale var. malabaricum, and a weedy escape from Australia. Oils of S. latifolium and S. radiatum contained sesamin, but not sesamolin. The presence of lignans in other species was more difficult to establish. These compounds were absent from fresh seed of Sesamum alatum. Even when relatively large amounts of

Table 2. Lignan content of seeds of species of Sesamum.

	seed	sesamin	sesamolin
Sesamum alatum Thonn.	f	-	-
S. angolense Welw.	h	+	+
S. angustifolium (Oliv.) Engl.	f	+	+
S. calycinum Welw.	h	+	+
S. capense Burm.	h	-	trace
S. indicum L.	f	+	+
S. latifolium Gillett	f	+	-
S. orientale var. malabaricum Nar.	f	+	+
S. pedaloides Welw. ex. Hiern	h	trace	-
S. radiatum Schum. & Thonn.	f	+	-
S. rigidum Peyr. ssp. merenskyanum Ihl. & Sei.	h	-	-
S. triphyllum Welw. ex. Asch.	h	-	-
U of I #7308: weedy escape from Australia.	f	+	+

Seed source code: f=fresh seed; h=herbarium specimen.
Voucher specimen numbers given in MATERIALS AND METHODS section.

seed were extracted as described below, the sample contained only non-lignan lipids as indicated by NMR spectral analysis. TLC also confirmed that lignans were absent.

In this study, seeds of Sesamum angolense from herbarium specimens showed the presence of both sesamin and sesamolin. A spot identical in Rf to sesamin was observed; we cannot exclude the possibility, however, that the compound is sesangolin, not sesamin. Confirmation with fresh seed material and NMR spectroscopy could resolve this problem.

The use of TLC of lignans as a diagnostic tool can be illustrated by the following example: The germplasm collection maintained by the Agricultural Research Corporation, Kadugli, Sudan, contains line 144 that was identified as Sesamum indicum. The shape and color of the corolla, the overall plant habit, and the fact that this cultivar remained green well after all other lines in the nursery had begun to senesce, suggested that it differed greatly from other cultivars of sesame. It was the last line to be harvested. Testa ornamentation on seeds from line 144 appeared similar to those of specimens of Sesamum radiatum (D. Bedigian, unpublished data). Extracts of both samples were compared by TLC. The chromatograms were identical, suggesting that it is probable that line 144 is actually S. radiatum.

Other genera of the family Pedaliaceae were examined to determine the extent to which they contain lignans. These genera of Pedaliaceae vary considerably in their content of lignans (Table 3).

Fresh seeds of taxa in related families were studied (Table 4) (nomenclature according to Hortus Third).

Table 3. Lignan content of seeds of related genera of <u>Sesamum</u>.

	seed	sesamin	sesamolin
Ceratotheca sesamoides Endl.	f	+	trace
Ceratotheca triloba Meyer ex Bernh.	h	trace	-
Holubia saccata Oliv.	h	trace	-
Pedalium murex L.	h	trace	-
Pretrea zanguebaricum Gay	h	trace	-
Pterodiscus aurantiacus Welw.	h	-	-
Rogeria adenophylla Gay ex Del.	f	-	-
Sesamothamnus busseanus Engl.	h	+	+

Table 4. Taxa studied in plant families related to the Pedaliaceae.

Acanthus mollis L.	(Acanthaceae)
Catalpa bignonioides Walt.	(Bignoniaceae)
Paulownia tomentosa (Thunb.) Steud.	(Bignoniaceae)
Borago officinalis L.	(Boraginaceae)
Omphalodes linifolia (L.) Moench	(Boraginaceae)
Coleus x hybridus Voss.	(Lamiaceae)
Salvia verticillata L. var. alba	(Lamiaceae)
Proboscidea louisianica (Mill.) Thell.	(Martyniaceae) from Arizona
Proboscidea louisianica (Mill.) Thell.	(Martyniaceae) from Oklahoma
Digitalis purpurea L.	(Scrophulariaceae)
Mimulus cardinalis Dougl. ex Benth.	(Scrophulariaceae)
Pentstemon campanulatus (Cav.) Willd.	(Scrophulariaceae)
Torenia violacea (Azaola) Penn.	(Scrophulariaceae)
Clerodendrum fargesii Dode	(Verbenaceae)
Lantana camara L.	(Verbenaceae)

Sesamin and sesamolin were not found in the seed oils of representatives of other plant families that we tested. Although several of these did contain a similar series of non-lignan lipids, NMR studies showed that the compounds were not lignans. Traces of other lignans could be present, but they are not major components as they are in sesame.

The wild relatives of sesame, including S. latifolium, have dormant seeds; this was confirmed by Sudanese agronomists (M. O. Khidir, M. A. Mahmoud, pers. comm.). Dormancy of both S. latifolium and S. orientale var. malabaricum was broken only by leaching the seeds overnight in running tap water, followed by 3% hydrogen peroxide soaks. Germination was only 20% (D. Bedigian, unpublished data).

3.5. DISCUSSION

We have been able to confirm the identity of two lignans, sesamin and sesamolin in sesame oil. These are recognizable under u.v. light on TLC plates, and their identification was established by NMR spectroscopy. Employing the same methods, we have shown that S. alatum consistently lacks these constituents.

Sesangolin does not appear to be present in S. angolense. Although we cannot exclude the presence of other lignans, we saw no evidence for the presence of this compound, as the lignans of S. angolense had the same Rf values as those of sesame. As the materials previously studied were apparently not supported by voucher specimens (none are cited), we cannot be sure of the identification of the plant examined. Additionally, this report appeared prior to the description of S.

latifolium (Gillett, 1953), a species with which S. angolense might easily be confused, which makes the identification more tentative.

The absence of lignans from both S. alatum and S. capense is noteworthy as both are species with winged seeds in the section Sesamopteris, that is relatively isolated within the family (Ihlenfeldt and Grabow-Seidensticker, 1979). Annotations on herbarium specimens show that there is disagreement concerning the identification and synonomy of these two species (D. Bedigian, unpublished data).

Although sesamin and sesamolin are reported to occur in members of related families, investigation of a randomly chosen series of plants from these families revealed sesamin and sesamolin only in the Pedaliaceae.

As mentioned previously, Sesamum latifolium has been suggested as the ancestor of sesame (Ihlenfeldt and Grabow-Seidensticker, 1979). This species occurs in East Africa and, contrary to previous reports, is widely distributed throughout the Sudan (Bedigian and Harlan, 1983). The chromosome number of S. latifolium is 2n=32 (Ihlenfeldt and Grabow-Seidensticker, 1979). Reciprocal crosses between the crop and S. latifolium have been attempted repeatedly by Sudanese breeders (M.O. Khidir, pers. comm.) and by us, but without success. Only a few shrunken seeds were obtained from a few tiny twisted capsules. These seeds could not be germinated (D. Bedigian, unpublished data). Samples of seeds of S. latifolium consistently lack sesamolin.

We regard the nearest wild relative of cultivated sesame as the taxon known in India as the wild gingelly of Malabar, named Sesamum orientale var. malabaricum Nar. in the original description (John, Narayana and Seshadri, 1950). This taxon is the probable ancestor of the crop. Like cultivated sesame, it contains both sesamin and sesamolin. Numerical analyses of the patterns of morphological variation in sesame (Bedigian, Smyth and Harlan, 1984) confirm the nearness of relationship between this wild Indian variety and the crop. Nearness of relationship between the crop and its putative ancestor is shown also by reciprocal crosses, which were fully fertile using var. malabaricum as both male and female parent. The chromosome number of S. orientale var. malabaricum is 2n=26, the same as the crop (John, Narayana and Seshadri, 1950).

As no Latin description was given at the time of publication (John, Narayana and Seshadri, 1950), the report provides information about the plant but does not constitute a valid taxonomic description.

Evidence from chromosome numbers, reciprocal crossing experiments, and the absence of sesamolin from Sesamum latifolium support our proposal that Sesamum orientale var. malabaricum Nar. is the progenitor of sesame. These facts suggest a closer relationship between the Indian relative (S. orientale var. malabaricum) and cultivated taxa than between the East African taxon (S. latifolium) and the crop.

Toxicological studies with sesamol (Ambrose, Cox and DeEds, 1958; Budowski, 1964) reveal that a total of 20 proliferative lesions occurred in 134 rats fed sesamol. Sixteen of the lesions were benign, two were malignant and two were questionable. No such lesions were found in the controls, nor in rats receiving the two lowest dosages of sesamol. A report on toxicants occurring naturally in foods (National Academy of Sciences, 1973) states that one component of insecticidal synergism appears to be the placing of extra demands on the animal´s detoxification mechanism when they already have difficulty coping with the toxicant. The lignans in sesame oil are related to the hepatotoxin safrole (Fishbein et. al., 1967) that increases the incidence of benign proliferative lesions in rats (National Academy of Sciences, 1983). In view of what is now known about the biological activity of sesamin and sesamolin as insectical synergists and antioxidants, with an active methylenedioxyphenyl group, we question the use of sesame oil as a "control" in pharmacological experiments. It no longer seems appropriate to view sesame oil as "inert".

3.6. ACKNOWLEDGEMENTS

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CHAPTER 4

EVIDENCE FOR CULTIVATION OF SESAME IN THE ANCIENT WORLD

4.1. ABSTRACT

The existence and identity of Sesamum indicum L. as a Mesopotamian oil source have been controversial since 1966, when Helbaek reported that not a single seed of sesame has been found in the Near East until Islamic times. The Chicago Assyrian Dictionary and other scholars subsequently translated še-giš-i as "linseed." Helbaek's assertion that no ancient sesame remains have been excavated is inaccurate, but the reported finds (Karmir Blur in Armenia, ca. 600 B.C.; Hajar Bin Humeid in South Arabia, ca. 450 B.C.) are late. Sesame was a major item of commerce in the Urartian economy and that kingdom was a northern neighbor of Mesopotamia. In the fifth century B.C. Herodotus wrote that sesame was the only oil used in Babylonia. The botanical and textual evidence for sesame are presented in an attempt to show that sesame can be clearly distinguished from flax, and that their growing seasons differ as would be expected.

4.2. INTRODUCTION

Sesame (Sesamum indicum L.) is often described as an ancient oil crop (Joshi, 1961; Weiss, 1971). Its high regard by users has even earned it the poetic label 'queen of oilseeds', perhaps because of its resistance to oxidation and rancidity even when stored at ordinary ambient air temperatures. Identification of specific evidence for its cultivation in ancient times, however, is difficult. Archaeological sampling methods of early excavators often neglected the rudimentary fragments of plant remains in favor of searches for colossal sculpture and treasures of gold, silver, ivory, bronze and lapis lazuli artifacts. It was only after the national governments recognized that precious historical monuments were being removed from their native land that the interdisciplinary method of "scientific archaeology" emerged. These limitations severely restrict the kind and amount of data that exist concerning the crop inventory of early farmers. The research of archaeologists, historians, linguists and early travellers must be patched together to synthesize a realisitic model of early cultivation practices. Records of associated activities such as irrigation, land rental contracts, and loans for purchasing seeds for planting, contribute suggestions for this reconstruction.

Archaeological evidence for sesame has not yet been recovered from early Mesopotamian sites. It is known to have been abundant by Iron Age, however, at an Urartian outpost north of Mesopotamia. Many earlier Sumerian references to an oilseed, <u>še-giš-i</u>, are found in cuneiform texts concerning oil rations, ritual offerings and loans for stock seed. Literary evidence is admittedly weaker than actual seed remains for positive establishment of crop occurrence. But in the absence of seed remains, we are forced to rely more heavily on literary and linguistic evidence.

4.3. BOTANICAL TRAITS OF SESAME USEFUL IN INTERPRETING ANCIENT TEXTS

Sesame can be distinguished from other oilseeds, such as flax, mustard, rape or radish that may have been grown in ancient Mesopotamia. One important distinction is sesame's growing season. It is a warm season crop, and must be planted after any danger of frost is past; it adapts well to high temperature and drought stress, but it cannot tolerate waterlogged soil. Cultivars show a wide range of variation in date of maturity: some can be harvested after 70 days; others require 180 days to mature (Bedigian and Harlan, 1983). The crop can grow in a variety of soil types, with cultivars that are specially adapted to each. Sesame is not demanding in nutrient requirements and can follow more soil-exhaustive crops. Sesame seeds sprout readily, without special treatment to remove germination inhibitors.

Seed color varies from white to black, with intermediates ranging from ivory, beige, tan and olive green, to brick red, brown, and charcoal grey. The seed surface usually looks granular when viewed with a hand lens. Seeds are generally 2.5 to 3.5 mm long. The placental attachment (hilum) of the seed looks round as viewed end on, but the seed's flat sides and raised margin give it a rectangular appearance.

Seeds of sesame contain the lignans, sesamin and sesamolin. A special property of sesame oil is its stability against rancidity due to the presence of these natural antioxidants, that are not found in other edible oils (Bedigian, Seigler and Harlan, 1984). These compounds are also insecticides and powerful insecticidal synergists. Sesame oil is regarded, gastronomically and chemically, as a superior quality oil (Levey, 1959). Sesame seeds yield 50 to 60% oil (Weiss, 1971).

Sesame leaves exude a mucilaginous substance when injured (Levey, 1959; DB, pers. observ.). Many herbarium sheet labels indicate that sesame leaves are used for soap or shampoo (DB, unpubl. data).

Sesame fruits are capsules that vary in size from 1.5 to 4 cm, depending on the cultivar. The plant's indeterminate growth allows capsules to be initiated continuously throughout the season. Sesame capsules release their seeds easily when they dry, and spill them on the ground if the branches are not harvested in time. Therefore sesame branches are cut while still green and sun-dried; a few weeks later the bundles of branches are inverted and shaken onto sheets to collect the seeds. The easy-bursting (dehiscent) capsule may have inspired the "Open, Sesame" incantation in Ali Baba and the Forty Thieves.

Flax can be distinguished from sesame by its seasonal requirements. Flax thrives in moderately cool temperatures (Martin, Leonard and Stamp, 1976). It is grown as a winter annual in warm climates. Linseed is cultivated where the annual range in precipitation is 450 to 750 mm, or under irrigation in dry climates. Drought and high temperatures (>35°C) during and following the flowering stage reduce the yield, size and oil content of the seed as well as the quality of the oil. Cool weather during the early stages, followed by warm, dry weather, provides excellent conditions for fiber flax production. Flax grows best on well-drained, medium-heavy soils, especially silt loams, clay loams and silty clays. Light soils are unsuited to seed flax, particularly in regions of deficient rainfall (Martin, Leonard and Stamp, 1976).

The cultivars of flax grown for fiber have long stems with relatively few branches, while cultivars grown for oilseed have shorter and many more branches and produce a greater quantity of seed (Eckey, 1954). The fruits of flax are indehiscent or semi-dehiscent spherical capsules that terminate a branch. Traditionally, in regions without mechanization, flax is harvested by pulling the plant up by the roots and moving it to the threshing floor, where the seeds are beaten out.

Flax seeds are yellow, olive green, tan and brown, and are 3 to 6 mm in length. They are flattened and have no raised margin. The surface appears smooth and shiny, when viewed with a hand lens, resulting from a mucilaginous coating. There is a curve at the narrow end of the seed, known as the apical hook. This curve is more noticeable on flax seeds, though sesame seeds are also sometimes slightly curved at the apex. Oil flax contains 32 to 42% oil.

Linseed oil has a high degree of unsaturation that enables it to react readily with oxygen. The products formed as a result of this reaction make linseed oil highly useful in manufacture of paints as a standard drying oil (Eckey, 1954).

The earliest archaeological flax remains discovered are reported from Cayonu in Turkey and from the Bus Mordeh phase at Tepe Ali Kosh in Iran, before 6000 B.C. (Helbaek, 1969; van Zeist and Bakker-Heeres, 1975). Seed size indicates that these are domesticated forms.

Seed oils of several species of Brassicaceae may have been used in Mesopotamia. They too are cool season crops. The fruits are siliques, and are much smaller than sesame capsules. The round seeds are 1 to 2 mm in diameter, and seed color may be white, red, purple, brown or black. The seed surface is marked with hemispherical contours. The seeds yield approximately 40% oil (Eckey, 1954; Martin, Leonard and Stamp, 1976).

Remains of charred seeds of _Brassica_ sp. (mustard) or _Sinapis_ sp. (radish) were recovered from the Temple Oval at Khafajah, ca. 3000 B.C., (Delougaz, 1940). They are in the collection at the Oriental Institute, University of Chicago, but seed preservation is inadequate for more specific identification.

4.4. ANCIENT INDIA

Sesame seed remains have been found at the Indus civilization site of Harappa (Vats, 1940). Excavators uncovered "a quantity of lumped and burnt sesamum" specimens. Harappa is the only site in India and Pakistan where sesame has been found (Vishnu-Mittre, 1977). Sesame was found in mound F, trench IV, strata v, with some burnt grains of wheat and peas in the hollow of circular platform P8. A number of broken earthenware jars and an underground drain were also excavated there at a depth of 2 m in square L 12/4. "A rectangular platform with a mud core which is secured on all sides [is] surrounded by brick-on-edge laid lengthwise. This unsubstantial construction was probably due to the necessity of economising bricks" (Vats, 1940). The mortar was mud but the pointing was gypsum. The purpose of the platform is not clear. Vats reports that from stratum iv down, the Harappan site pre-dates Mohenjo-Daro, and attributes the sesame to ca. 3050 B.C.-3500 B.C.

Genetic, morphological and phytochemical evidence support the hypothesis that domesticated sesame originated on the Indian subcontinent (Bedigian, Seigler and Harlan, 1984; Bedigian, Smyth and Harlan, 1984). The crop progenitor proposed still occurs wild today in gravelly crevices of granitic rock outcrops, and is weedy in many parts of India. Archaeological evidence substantiates claims that sesame cultivation began there.

Hortus Malabaricus, a 12 volume opus on the plant wealth of Malabar is a landmark contribution on the plant resources of India. Rheede, a governor of Cochin, published information from his journals about local and ayurvedic medicinal practices. Three Brahmin priest-physicians dictated the names, and medicinal properties of plants listed in their authority, the Manhaningattnam, that has never been found. Thus Rheede preserved valuable ethnobotanical information about local plants that had been accumulated over thousands of years. His work is unsurpassed even today (Manilal, 1980).

Rheede's (1689) observations are accurate morphological descriptions and the accompanying sketches provide unmistakable verification of his identifications. Concerning sesame, he wrote "there are two species of Elu, Schit - Elu and Car - Elu; the first is called Davo - Tiloe by the Brahmans...Oil is extracted from the seeds, which they also call Oleum Sirgelim, for the benefit of nearly whomever is presented with pains, and the indigenous people use it in a washing solution most regularly, for annointing the body and as often as any are troubled by aches."

A list of local names for sesame in India reveals widespread adoption of the word ellu or its derivatives: Assam, Bengal, Maharashtra, Punjab, Uttar Pradesh and the Sanskrit, Hindi and Urdu languages use til; Gujarat uses tal; Kerala and Tamil Nadu use ellu; Karnataka uses yellu; Andhra Pradesh uses nuvvulu; and Bihar and Orissa use gingil (Kirtikar, Basu and An, 1918; Sampson, 1936; Indian Agricultural Research Institute, 1961). The Dravidian word for sesame, ellu, (Burrow and Emeneau, 1961) is presumed to be the origin of the Sanskrit word (Burrow, 1947). The appearance of ellu, in a non-Aryan language, (Kuiper, 1955; Masica, 1978), suggests an ancient source for the word. A full discussion of its etymology will appear in a future publication.

Parallel linguistic evidence from ancient India suggests that sesame (til) was probably the earliest oilseed in India because the word for oil, (taila) is derived from it (Dymock, Warden and Hooper, 1893; Prakash, 1961; Monier-Williams, 1964; Nayar & Mehra, 1970). The Vedic scriptures of ancient sacred Sanskrit literature, advise that sesame seeds be used in a ceremonial food symbolic of immortality (Dymock, Warden and Hooper, 1893). According to the Brahmapurana, tila was created by Yama, the king of death, after prolonged penance. The Grihyasutra of Asvalayana directs that in funeral ceremonies in honor of the dead, sesame seeds by placed in the three sacrificial vessels containing sacred Kusa grass (*Desmostachya bipinnata* Stapf. S. & B.) and holy water with the following prayer: "Oh Tila, sacred to Soma, created by the gods during the Gosava (the cow sacrifice, not now permitted), used by the ancients in sacrifice, gladden the dead, these worlds and us!" Sesame seeds with rice and honey are used to prepare the funeral cakes called Pindas, that are offered to the Manes in the Sraddh ceremony by the Sapindas, or relations of the deceased (Dymock, Warden and Hooper, 1893). Tilanna, sesame-rice balls formed in the shape of cows are offered to relatives and friends of the deceased after the funeral. This ritual is enacted to say a proper ´farewell´ to the departed. The offering of sesame seeds is considered effective in removing sins (Gupta, 1971). The word *tilanjali*, is a derived word that means ´to bid a final goodbye/to leave´ (Hindi-English Dictionary, 1970).

On certain festivals six acts are performed with sesame seeds, as an expiatory ceremony of great efficacy by which Hindus hope to be freed from sin, poverty and other evils, and secure a place in Indra´s heaven (Dymock, Warden and Hooper, 1893). These acts are *tilodvarti*, "bathing in water containing the seeds"; *tilasuayi*, "annointing the body with the pounded seeds"; *tilahomi*, "making a burnt offering of the seeds"; *tilaprada*, "offering the seeds to the dead"; *tilabhuj*, "eating the seeds"; and *tilavapi*, "throwing out the seeds." In proverbial language a grain of sesame signifies the least quantity of anything, eg. *til chor so bajjar chor*, "who steals a grain will steal a sack"; *til til ka hisab*, "to exact the uttermost farthing" (Dymock, Warden and Hooper, 1893). Mehra (1967) summarizes the recorded uses of sesame in India in historic times.

4.5. ANCIENT MESOPOTAMIA

The Sumerian word *še-giš-i*, used in the early literature, refers to some oilseed. The identity of this seed is uncertain. Various ancient names translated as ´sesame´ are *še-giš-i* (Sumerian), *šamaššammū* (Akkadian), *sumisumi* (Hurrian), *ssmn* (Ugaritic), *sasama* (Mycenaean Greek), *sapsama* (Hittite), *su(m)sem(in)* (Aramaic) and *simsim* (Arabic), (Hoffner, 1974). It is possible that še-giš-i referred to sesame since the beginning of writing. On the other hand, the word še-giš-i could have been applied initially to flax or to whatever crop was grown for oil, and later, when sesame was introduced, the name became affiliated with the sesame crop. The date of introduction of sesame to Mesopotamia is not yet established. However, is is known that there were trade contacts between the Indus valley and Mesopotamia as early as the 3rd millennium, B.C. (Hornell, 1941; Wheeler, 1968; Gelb, 1970; Dales, 1971; Lamberg-Karlovsky, 1972).

Records from Mesopotamia contain frequent references to the oilseed še-giš-i. Interpretation of these texts to establish the botanical identification of the oilseed requires use of a number of inferences. One way to distinguish sesame from other oilseeds that could have been grown in the region relies on the seasonal requirements of each. Other oilseeds that might have been grown in the region include flax, mustard, rape or radish. These, unlike sesame, are cool-season crops and should be grown during the winter in Mesopotamia.

Clarification of planting dates of the oilseed še-giš-i named in cuneiform texts during a specific era and at a defined location, would be useful to ascertain whether the crop is more likely to be sesame or another oilseed. Establishment of a spring planting date would be strong evidence in support of sesame as the oilseed še-giš-i. It would be desirable to find some coherent pattern of field rentals for sesame growing, and loans of sesame seeds for planting.

Early Old Babylonian documents contain numerous references to "i-giš = ullu/ellu, the ubiquitous sesame oil," according to Simmons,

1978. Texts list the expenditure of sesame oil "for the inner bolt," "for the fire offering," "for the prince," "for the royal purification rite," "for the inner bolt on the day of Akitu," "for the sizkur DN," for the Elunum DN," "for the regular offering," and "for annointing the banner." These documents report the delivery of sesame in month 12 or 1. Von Soden, (1961), also translates ellu as ′good sesame oil′ (i-giš = ellu).

The Akkadian word ellu, oil, is intriguing because of its resemblance to the early Indian word. Two products are extracted (ṣahatu) from sesame: "hilsu oil (should amount to) one third of the ellu oil" (CAD, 1962). The Assyrian Dictionary (CAD, 1958) entry for ellu gives definition 2, holy, sacred; 2′, "in connection with oil,...pure sesame oil, sesame oil of the first (pressing)," used for annointing and making perfume. The varieties of oil discussed by Goetze (1956) establish the value of i.giš at 30 times the value of še.

Land rental contracts can help elucidate the crops grown. Legal and administrative texts of the reign of Samsu-Iluna (Feigen, 1979) offer the following records of transactions involving the še-giš-i crop, that Feigen translated as sesame:

YBC#	Year	Month	Day	Text
3332	6	3	10	Rent of a field to grow sesame
6069	7	2	10	Rent of a field to grow barley and sesame
6039	7	3	25	Sub-rent of field to grow barley and sesame
5945	8	4	?	Rent of a field to grow sesame
6083	6	6	?	Rent of 2 types fields to plant barley and sesame
6073	27	2	20	Rent of ab.sin-field to grow sesame
5907	27	3	?	Rent of a field to grow sesame
5986	28	1	1	Rent of field to 2 tenants to grow sesame

A list of dated texts concerned with rentals of fields for the cultivation of sesame (Stol, 1984) show the greatest number from the months 2, 3 and 4.

Other records that might offer evidence of planting dates to identify the crop _še-giš-i_ are loan records. Some examples can be found in Finkelstein, (1972).

Tablet #	Month	Day	Text
MLC 1519	4	24	Loan of silver to purchase sesame to be repaid in sesame
MLC 1381	4	3	Sesame for seeding
YBC 8722	5	1	Sesame for seeding
YBC 3323	5	4	Sesame for seeding
MLC 1727	4	10	Joint tenancy field lease for growing sesame

A text from Nuzi (CAD, 1959) exhorts the reader to "plant _šamaššammū_ and millet!" (_šamaššammū_ _u_ _du-uh-na_ _eris_). Since millet, be it _Setaria_, _Panicum_, _Pennisetum_ or even _Sorghum_, is summer-grown, it is reasonable to conclude that _šamaššammū_ is a summer crop. The date of this text is ca. 1550 B.C. (M. Powell, Dept. of Ancient History, Northern Illinois University, pers. comm.). Herodotus, too, associates the summer planting of millet with sesame (1.193; 3.117).

Other bits of circumstantial evidence about the sesame growing season might be inferred from the following letters, both suggesting that sesame was growing after the barley harvest. One says it was growing at the time when barley was ready for shipment at Larsa, in May or June. Another Larsa letter shows that sesame needed irrigation while it was growing. It suggests an early summer irrigation. The principal use of irrigation water was in the autumn, to soak the fields before planting grain; after germination, they tried to rely on rain" (W. Doyle, pers. comm.).

A text instructing the farmer not to soak (irrigate) the _še-giš-i_ before you see Sirius (Kraus, 1968) firmly supports a summer planting of the crop, because Sirius rose ca. June 22 (see DISCUSSION section).

The _šamaššammū_ article written for the CAD, volume "Š" (galley-proofs of the unpublished manuscript, p. 510-520), mentions several important texts that help to identify _šamaššammu_ as sesame. A text concerned with processing the seed (p. 514, note c) says: "it came to 90 gur of _šamaššammū_, before it started raining. I managed to crush 40 gur of it and the rain did not arrive to ruin it" (TCL 17 5:4, Old Babylonian letter). The rains in Mesopotamia come in the fall, hence the text refers to a summer crop that was harvested in the autumn.

Šamaššammū is assigned to the constellation Taurus (April 21-May 20) (CAD, unpublished manuscript p. 519) and this contextual reference is likely to indicate planting time (H. Waetzoldt, pers. comm.).

The article contains many references to oil pressing, and one text (p. 516) specifies _šamaššammū peṣutu_ (white _šamaššammū_).

Stol (1984) indicates a textual reference to ´sweet´, _matqutum_, sesame, that reminds us of the folk classification by Sudanese farmers. Sesame used for its seeds were called ´sweet´, while sesame grown for its oil was considered to be ´bitter´ (Bedigian and Harlan, 1983). Often, the red-seeded sesame cultivars had the highest oil content, but the testae probably contained high levels of tannins or other bitter-tasting constituents. The ´sweet´ sesame was white-seeded.

A fragment of a tablet relates ants in a storage bin with šamaššammū: "If ants are seen in a man's house (ina i.dub šamaššammū), in the storage bin for šamaššammū," followed by a break. This may be strictly coincidental, but it might have considerable significance, in view of the role of the lignans of sesame as insecticides (DISCUSSION section, this paper; Bedigian, Seigler and Harlan, 1984).

Contributions from Waetzoldt (1983; 1984) indicate that the context of šamaššammū in third millennium texts much more strongly suggests the superior quality of sesame oil than the utilitarian quality of linseed. "Large quantities of the oil are used for nutrition, and for offerings, therefore we assume that it can be considered a good edible oil." It was used in temple offerings and for royal feasts. Waetzoldt, too, mentions that flax is cultivated in the winter, while gis.i is cultivated in the summer. Flax farmers are called engar-gu, while sesame farmers are called engar-giš-i.

Waetzoldt's experience as a scholar of cuneiform flax texts lends substantial support to our evidence by his opinion that the word šamaššammū should be interpreted as sesame.

"The thing that strikes me most about sesame in Mesopotamia is that the plant had no proper name, only "(the) oil plant" in both Sumerian and Akkadian, and that this term was universally adopted in points west. This shows that the plant was not known before the Sumerians, in Mesopotamia, and the Sumerian-Akkadian equivalence of terms makes it not unlikely that speakers of both languages encountered it at the same time" (W. Doyle, pers. comm.). Further support for this idea is the fact that the universal word for oil, in India, is taila, derived from til (see ANCIENT INDIA, above). Even in Swahili, the word ufuta means both oil and sesame (A. Scheven, Dept. of Linguistics, University of Illinois, pers. comm.). Further details concerning the relationship of sesame to the etymology of the word ´oil´ will appear in a forthcoming publication.

4.6. URARTU: THE KINGDOM OF VAN

This report cannot produce the evidence desired for a single sesame seed from a Mesopotamian site (Helbaek, 1966). It does, however, dispute Helbaek´s claim that "sesame was introduced to the Near East about 1000 years ago." Sesame is known to have been grown intensively during the Iron Age on the plains of Ararat, by the Urartu (900 to 600 B.C.), who processed the seeds for oil (Kassabian, 1957). Archaeological sesame seeds were excavated at Teishebaini, (Armenian=Karmir Blur), near present-day Yerevan. There oil was stored in ceramic jars that ranged in size, depending on their function: storage or shipping. Stores of sesame were found in four huge clay jars, placed together in a small pit (N. 7) on the north side of the citadel (Piotrovskii, 1966). Three areas of the citadel, on the northwest (N. 1-3) were devoted to the preparation of sesame oil. Large (ca. 1.5 m tall) clay storage jars were found in storerooms of a workshop consisting of over 150 rooms on the ground floor, where wine, beer and sesame oil were processed (Piotrovskii, 1950; 1952). Cakes of pressed sesame, the solid residue that remains after seeds are crushed for oil, were also uncovered.

Systematic excavations of the site started in 1939, carried out by a joint expedition of the Academy of Sciences of the Armenian SSR and the Hermitage Museum, Leningrad, were led by Boris B. Piotrovskii. Its ancient name, Teishebaini, is given in honor of Teisheba, god of war and of storm, and one of three major deities of the Urartian pantheon. Karmir Blur had once been an important administrative and economic center of the state of Urartu, that flourished from the 9th c. until its fall in 585 B.C. Its primary function was as a storehouse and processing center of agricultural produce. The size of the citadel reflects bulk storage of crops. The only Urartian plant remains identified to date have been found at Karmir Blur. Plant remains indicate that the principal cereals cultivated were barley and both einkorn and emmer wheat. Remains of rye and millet also occur.

Kassabian's report, written in Armenian, has probably been inaccessible to many scholars in the West due to the language and the obscure place of its publication. A summary of Kassabian's report is included here.

The Urartian empire is known for its innovations in engineering works. Extensive aqueducts, irrigation canals and channels carried snow meltwater from the mountains to fields in the valleys by an intricate network. This fact, along with the plant remains of cereals and fruits suggests that agriculture, arboriculture and viticulture were highly developed there by Iron Age.

In the 7th c. B.C. the Urartian city of Teishebaini (Karmir Blur) was a processing center for vegetable oil. Excavations reveal an oil press workroom, 30.9 m long and 3.9 m wide (Room 2 of their plan). Stone mortar and pestles were found on the north side of the room. The workroom's east and south corners each held a basin-shaped stone container, 79 cm in diameter, carved from a block of tufa. The basin joined a cylindrical pipe made of the same stone, that allowed waste liquid to drain out beyond the citadel. The basin or tub was used to moisten the sesame seeds before working them (Piotrovskii, 1950). Sesame seeds brought to the oil press were first washed in the basin to remove dust and soil, then soaked to ease the removal of the tegument. Stone mortars, pestles and graters were found that were used to remove the seed coats after the seeds had been soaked and dried.

The workrooms were furnished with fireplaces for parching the seed. Conical basalt rocks were used for the final pressing of the oil, expressed from a thick, viscous residue of sesame paste that was previously poured into baskets and macerated coarsely. The abundance of pressed cake residues, and the size of the stone vat suggest the large quantity of sesame oil processed at Teishebaini.

A wooden press for squeezing the oil, must have been burned during the fire that destroyed the citadel, and has left no trace (Piotrovskii, 1966). Both the area where the casks of sesame oil were stored and the pressroom bear marks of a fire, during which the clay bricks of the wall not only acquired a red color, but were also partly fused (Piotrovskii, 1966).

Sesame was also found in mixed stores of grain, among barley and seeds of two legumes: chickpea and lentil. It seems that roasted grains and seeds were thought to be delicacies, as shown by ethnographic parallels (Piotrovskii, 1950).

Urartian agriculture illustrates the excellent adaptation that a people could make to a severe environment. The extreme climatic conditions of the Armenian plateau made artificial irrigation a necessity for the development of the intensive agriculture, horticulture and viticulture that resulted from these efforts (Harutyunian, 1964). Their massive irrigation works and innovative technology permitted the entire landscape to be watered and devoted to crops. Excavations at Toprak-kale, just east of the citadel at Van, have yielded only a few agricultural tools: iron blades of plows or hoes, sickles, pitchforks, and remains of grain (incidentally, unstudied to this day) and fragments of huge storage jars, intended obviously for storage of grain and liquids, on which hieroglyphic and cuneiform marks indicated their capacities (Harutyunian, 1964).

4.7. SOUTHERN ARABIA: HAJAR BIN HUMEID

Reconstruction of the agriculture of ancient southern Arabia (5th c. B.C.) was established from seed impressions from nearby theshing floors that left imprints in clay vessels. Sesame is included among the list of useful plants identified in this manner (van Beek, 1969).

4.8. ANCIENT GREEK SOURCES

Ancient Greek travellers and historians provide some clues concerning the cultivation of sesame in the ancient world. These records make it clear that sesame was well-known in Mesopotamia by the Iron Age. Hesiod, writing in the 8th c. B.C., gives only one sowing date, before the setting of the Pleidies, October 23.

Herodotus, in the 5th c. B.C., observed that the only oil the Babylonians use is from sesame (1.193). "In winter, indeed, they have rain from heaven like the rest of the world, but in summer after sowing their millet and their sesame, they always stood in need of water from the river" (3.117).

Cultivation of sesame is documented for ancient Armenia by Xenophon, in the 5th c. B.C. In the Anabasis (4.4.13) he wrote: "In (western Armenia)... there was a scented unguent in abundance that they used instead of olive oil, made from pork fat, sesame grain, bitter almond and turpentine. There was a sweet oil also to be found, made of the same ingredients." Xenophon also places it in two other parts of Anatolia: In Cilicia, "This plain produces sesame plentifully, also panic and millet and barley and wheat" (1.2.22), and another location farther west, at "Calpe Haven in Asiatic Thrace," "Calpe lies exactly midway between Byzantium and Heracleia," has "good loamy soil...produces barley and wheat, pulse of all sorts, millet and sesame, figs in ample supply, numerous vines...indeed everything else except olives."

Aristophanes, in the 5th c. B.C. refers to confections and cakes made of sesame on several colorful occasions. In Peace (line 869, and note 2) a servant announces that nuptial preparations are commencing: "the cake is baked, and they are kneading the sesame biscuit." Note 2: "It was customary at weddings, says Menander, to give the bride a sesame-cake as an emblem of fruitfulness, because sesame is the most fruitful of all seeds." Herodotus (3.48) also refers to cakes of sesame and honey.

At the end of the play, The Acharnians (line 1092), during an uproarious rustic feast in honor of the blessings of peace and plenty, a herald announces: "Come quickly to the feast and bring your basket and your cup; ʹtis the priest of Bacchus who invites you. But hasten, the guests have been waiting for you a long while. All is ready--couches, tables, cushions, chaplets, perfumes, dainties and courtesans to boot; biscuits, cakes, sesame-bread, tarts and lovely dancing girls, the sweetest charm of the festivity."

In Thesmophoriazusae (line 570), Mnesilochus, a female-impersonator harrangues abuses against women. The assembly suspects at once that there is a man among them and finds him out. In the dialogue of the quarrel he threatens: "Iʹll make you disgorge the sesame cake you have eaten," by kicking her in the stomach.

In the 4th c. B.C., Theophrastus also identified sesame as a summer crop (8.1.2; 8.1.4; 8.2.6), along with millet, Italian millet, erysimon and horminon.

4.9. CLASSIC LATIN SOURCES

Columella, in the 1st c. A.D. recommended that sesame be sown earlier than flax, which he advised should be planted from October 1 to December 7; even February, on rich ground (2.10.17). "Sesame can be sown earlier, on well-watered ground, and from the autumnal equinox, September 21, to the Ides of October (Oct. 15) on ground that lacks moisture" (2.10.18). This is a strange recommendation for Italy. Columella is advising that it be grown there in the winter. He may not have known the sesame plant, because the olive was Rome's primary oil crop. He reports, more correctly, that "it usually requires loamy soil, but it thrives no less well in rich sand or in mixed ground."

"But I have seen this same seed sown in the months of June and July in districts of Cilicia and Syria, and harvested during autumn, when it was fully ripe" (2.10.18). This observation is more accurate. Also (11.2.56) "In some districts, such as Cilicia and Pamphylia, sesame is sown this month (late July-August); but in the damp regions of Italy it can be done in the last part of the month of June." This report might indicate that the Cilicians and Pamphylians grew sesame as a second crop, after harvesting an earlier crop.

Travel and trade in the Indian Ocean was described by an anonymous merchant of the 1st. c. A.D. in The Periplus of the Erythraean Sea, that claims to be the first record of organized trading with the East. "Ships customarily fitted out from places across this sea, from Ariaca and Barygaza, bringing to these far-side market towns the products of their own places; wheat, rice, clarified butter, sesame oil, cotton cloth and girdles, and honey from a reed called _sacchari_." Sesame oil was traded along with cloth and wheat, for frankincense." However, long before this document was written, India occupied a unique position in the commercial world as an important supplier of luxury goods (Mookerji, 1912; Ratnagar, 1981).

Pliny, writing in the 1st c. A.D. says that "sesame comes from India," and that it is a summer grain to be sown before the rising of the Pleidaes (18.10.49). "We have specified gingelly and common and Italian millets as summer grains. Gingelly comes from India, where it is also used for making oil; the color of the grain is white" (18.22.96). Pliny appears to be accurate and he seems to have known sesame well.

His advice for soaking sesame seeds prior to milling is reminiscent of practices at Urartu (Kassabian, 1957). "Gingelly is to be steeped in warm water and spread out, and then rubbed well and dipped in cold water so that the chaff may float to the top, and again spread out in the sun on a linen sheet" (18.22.98).

Gingelly is another name for sesame that is used often today in India and Europe. It is derived from the Arabic juljulan (Dymock, Warden and Hooper, 1893; Webster's Dictionary, 1967). The Spanish say ajonjoli, the French, jugleone, and present day Arabic medicinal and botanical works employ both al juljulan and simsim. Juljulan was used at least as early as the 8th c. in a poem quoted in Lisan al Arab (1981) by Waddah el Kubany-al Yamani (d. 709; Faroukh, 1965). Juljulan is defined as 'sesame before the seeds are removed', i. e. the capsule. The word might be derived from the Arabic word juljul, that means small bell (Qamus al Muhit, 1970). The first example given is that of bells worn around the necks of camels. The second is 'the horse jeljela', translated as the horse neighing rings. The Oxford Dictionary (1961) gives 'jingle' as one definition for the entry 'gingelly'. Sesame flowers are campanulate. The capsule could be described as bell-shaped too, after it has opened.

4.10. ANCIENT EGYPT

Convincing evidence for sesame in ancient Egypt does not appear until quite late. Both sesame and sesame oil are mentioned in the Tebtunis Papyri 3 (Part 2) No. 844, in 256 B.C., (Lucas, 1962). Select Papyri (Hunt and Edgar, 1932), mention sesame paste. Deines and Grapow (1959) list it as a medicine. The hieroglyphic word, translated smsmt, is similar to the Semitic simsim. Pliny says a large amount of oil in Egypt was obtained from gingelly (15.7.31).

4.11. ANCIENT CHINA

According to the Pen Ts´ao Kang Mu (1596), a classic ancient Chinese herbal and medical treatise, sesame was brought from the West by General Chang Chien during the Han dynasty (2nd c. B.C.). This information is repeated in many later Chinese herbals. The character indicates a foreign introduction: "hu-ma" means Barbarians´ seed.

4.12. DISCUSSION

The archaeological seed record from Mesopotamia is distressingly small. Sesame seeds might be absent because the collection is not sufficiently large. Sampling for plant remains was never done systematically from a wide variety of site types. Excavators have only recently incorporated the assistance of archaeobotanists or ethnobotanists on their study teams.

The absence of archaeological finds of sesame seeds in Mesopotamia might also be explained by their particular chemical composition and structure that could result in poor preservation. Cereals, such as wheat and barley, and flax, may retain their form upon carbonization better than sesame. The results of carbonization of sesame and flax, experimentally, in our laboratory, showed that seeds of sesame were more friable than flax. Carbonized sesame seeds flaked and disintegrated when rubbed between the thumb and the index fingers, whereas carbonized flax seeds remained intact. These experimental differences in preservation might also occur under natural conditions. In support of this hypothesis, it should be noted that the reported remains (Vats, 1940; Piotrovskii, 1950) are found in bulk, and not as single seeds.

It may be that flax seed has turned up archaeologically because linen was made in the places that have been excavated such as houses and palace workshops, while sesame seeds were pressed for oil out in the countryside. We can assume this since it was delivered to the towns as oil in the texts (W. Doyle, pers. comm.).

The texts concerning white-seeded šamaššammū are of considerable importance in helping to distinguish flax from sesame. The author of the CAD article about šamaššammū attempted to diminish the importance of these texts in the discussion section: "although šamaššammū is qualified as ´white´ in New Babylonian texts, it is not qualified as black and thus the argument from its color for its identification with sesame is not decisive." However, the foremost flax authority in the US, who maintains a world collection of flax germplasm, states that there are no white-seeded flax cultivars (J. Miller, Department of Agronomy, North

Dakota State Univ., pers. comm.).

The fragment of text that mentions šamaššammū in association with ants in a storage bin is very suggestive. Its fragmentary nature prevents conclusive interpretation, but the context is noteworthy because sesame oil contains the lignans sesamin and sesamolin that are powerful natural insecticides or insecticidal synergists (Bedigian, Seigler and Harlan, 1984). Also in this regard, a candy manufacturer in Khartoum said that he often wondered why ants avoided the halva (tahneeya) candy made of crushed sesame seeds with sugar, stored in his warehouses, although they were strongly attracted to the other sweets in his inventory (Hassan Daoud, owner of Saad Sweets, pers. comm., 1980).

The estimation for the rising of Sirius given by Kraus (1968) seems late by our calculation. If one takes precession into consideration, the date for the rising of Sirius ca. 3000 B.C. should have been June 22 (W. Doyle, pers. comm.; J. Kaler, Dept. of Astronomy, University of Illinois, pers. comm.).

No sesame pollen has been found archaeologically, except for a single grain reported by Woosley (1976). Mindful of possible contamination from modern cultivation, we cannot view the find of a single pollen grain as a substantial contribution to the record from the area.

4.13 SUMMARY and CONCLUSIONS

The evidence, as far as it goes, indicates that the sesame crop is of Indian origin and has some archaeological presence at Harappa.

It is well documented in Armenia, Arabia, Anatolia and Greece by the 1st millennium B.C.

Earlier evidence in Mesopotamia is linguistic only and unless sesame turns up archaeologically, the problem is one for cuneiform scholars to resolve. The possibility of transfer of the word and the crop ellu from the Indian subcontinent needs support from philologists to establish a connection with the Mesopotamian word ellu.

4.14. ACKNOWLEDGEMENTS

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CHAPTER 5

NUBA AGRICULTURE AND ETHNOBOTANY, WITH PARTICULAR REFERENCE TO SESAME AND SORGHUM

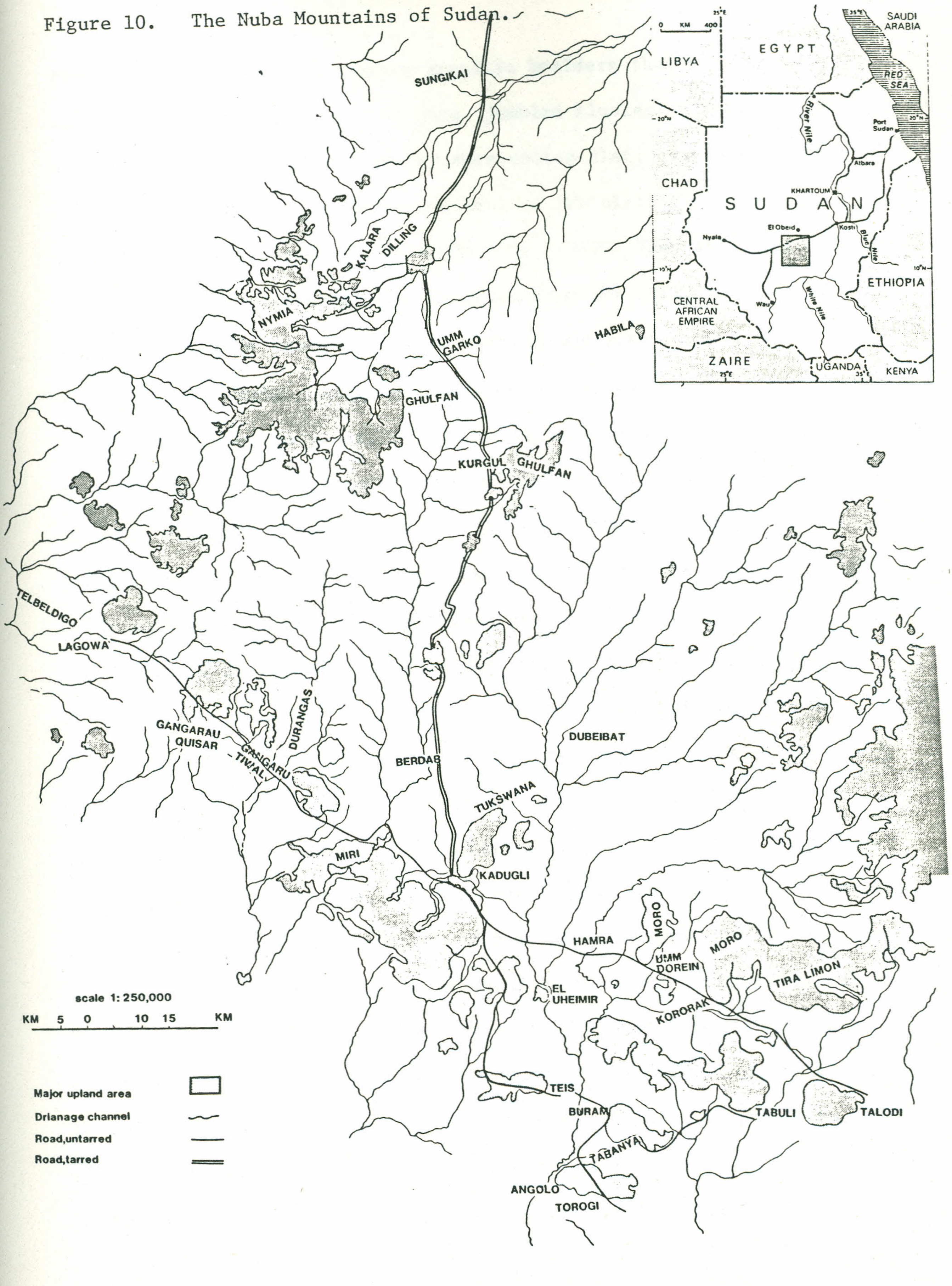
5.1. ABSTRACT

There is a remarkably high level of variation within cultivated sesame and sorghum in the Nuba Mountains of Sudan although the region is relatively small. The Nuba people are geographically isolated and culturally diverse in religion, language, material inventory, agricultural practices and in their rituals involving crop plants, and this contributes to the diversity in their cultivars. Nuba crop husbandry is sophisticated and high levels of genetic diversity are maintained by deliberate selection of crop varieties that are well adapted to each of the microenvironments of the region and best suited for different economic uses.

5.2. NUBA MOUNTAINS ECOLOGY

The topography of central Sudan is flat, interrupted occasionally by rock outcrops, called _jebels_ (vernacular names in Arabic are used by Nuba and Arab alike), which are not high but are often steep and rugged. Groups of _jebels_ in southern Kordofan Province, inhabited by the Nuba people, are called, collectively, the Nuba Mountains (Figure 10). The Nuba Mountains occupy an area about 250 km by 165 km extending from 10°30′ N to 12°30′ N latitude and from 29°00′ E to 30°30′ E longitude.

Figure 10. The Nuba Mountains of Sudan.



They consist of ranges of rugged granitic boulders that vary in height and distribution. Some occur in huge, jumbled clusters and others are solitary, rising abruptly from the surrounding flat, clay plains. Many are sufficiently high to modify weather, as the plain rises to some 600 m but the hills reach 1,500 m (Barbour, 1961). They are covered by shallow soils of coarse materials derived from the hills or interior pediments. Many of these hills are terraced and planted with crops adapted to the light, sandy soil, low in organic matter and clay.

Three ecological zones, the hills, pediplains and clay plains may be viewed as distinct microenvironments probably varying in the supplies of water stored in the soil profile, as well as the texture and composition of the soil. The clay plains soils, locally called _teen_, cover much of the Nuba Mountains. They are heavy, dark, cracking, alkaline, low in organic material, and capable of good water retention. Cultivation of the clay plains is limited by their distance from the hill community, lack of water during the dry season, and, to some extent, waterlogging during the heavy summer rains. The Nuba refer to farms on these clay plains as the "far" farms, to distinguish them from terraced household gardens, and the "near" farms, on slopes of hills.

The pediplain often consists of hard surfaced soils of low permeability that form an apron at the foot of steep slopes, composed of the detritus of gradually weathering rocks from above (Wood, 1971). A delicate sand veneer absorbs much water, but this "mulch" of coarse textured material is often eroded by wind. The finer soil fractions, the silt and clay and organic components, erode first, removing the most important components contributing to soil fertility, structural stability and water retention. Almost all the rainfall then runs off, because the extremely compacted, medium texture of the denuded soil cannot absorb moisture, even if the rainfall is sufficient. The compacted soil, locally known as gardud, is the least productive.

The hill region is often terraced and is devoted to food crops, primarily garden vegetables, but including sorghum (*Sorghum bicolor* (L.) Moench) and pearl millet (*Pennisetum americanum* (L.) Leeke). Sorghum, the most important staple food of the Nuba, is grown primarily on the clay plains where water is plentiful and soil is more fertile. Cotton (*Gossypium hirsutum* L.) is the primary cash crop of the plains. Pearl millet, the second most important cereal for the Nuba, is a fast-maturing grain that yields less than sorghum but has the advantage of growing well on light, relatively infertile hill soils. It is generally preferred as food. Peanut (*Arachis hypogaea* L.) is the main cash crop of the light soils. Sesame (*Sesamum indicum* L.) cultivars are grown in all 3 regions by using selections that are adapted to the local conditions.

The Nuba Mountains receive an annual average of 500 mm rainfall in the north and up to 800 mm in the south. Most of the rain falls between May and October, with the greatest amount during July-September, (Wernstedt, 1972). Although annual rainfall is not large, and evaporative rates are high (daytime temperatures exceed 42^{o}C in summer), it is sufficient to mature the crops. Long droughts follow crop maturation and allow ample time for harvesting and handling. Rocky hills, high temperatures and low rainfall make the Nuba Mountains marginal for agriculture, but yields there are usually sufficient to provide subsistence.

5.3. THE NUBA

The Nuba are regarded as the aboriginal population of Kordofan (Seligman and Seligman, 1932) and, like their environment, they are sharply separated from neighboring groups. Considered with other large ethnic groups in the Sudan, they appear as a racial unit. Considered by themselves, they are heterogeneous and some of this diversity probably reflects a mixture of peoples with different origins. Despite their collective name more than 62 distinct languages are spoken by the Nuba. Many of the languages are mutually unintelligible. Often, languages are shared among inhabitants of several nearby hills, but sometimes dwellers in different residential clusters on the same hill massif do not speak a common language.

According to Greenberg (1955, 1966), there is a single family of Kordofanian languages in the Nuba hills. It is extraordinarily diverse, and subdivided into 5 different language groups. Four of these groups, Katli, Koalib, Tegali and Talodi, are closely related. The fifth, Tumtum, is more distinct and is spoken over a large region which includes a number of hill groups. It is thought that there was an early, primal division, followed by greater diversification in one moiety than the other. The Kordofanian language group probably is related to the Niger-Congo subgroup of Bantu. The Nuba peoples and their languages, however, form a coherent unit amidst the neighboring Arabic-speaking nomadic clans and Shilluk and Dinka peoples.

The linguistic diversity of the Nuba hills reflects the isolation of the communities. Nuba culture, like its language, has undergone a long process of internal diversification. Residents of separate hills have distinctive styles of dress and ornamentation, body cicatrization, house architecture and granary designs. Some of the diversification also reflects modern, 20th century influences due to accessibility to vehicles during the last 3 decades. The most obvious differences are between the northern and southern sections of the mountains, subtly bounded at Kadugli, the district seat and provincial headquarters. Residents of the northern *jebels* have easier access to the paved road between Kadugli and Dilling. This has encouraged Greek and Arab traders from the cities of the north to bring merchandise for trade or sale. Islamic influence is strong among the northern Nuba, many of whom have adopted its standards of dress and behavior. The southern, non-Islamicized Nuba have seen fewer outsiders and have retained more of their ancient identity. Their isolation from the rest of Sudan, and from one another, is nearly complete during the rainy season. Pressures toward modernization have been minimal there because of the distance from Khartoum, lack of roads, few traders from the outside, and bureaucratic constraints. The presence of pigs in southern Nuba villages, which are absent in the northern, Islamic-influenced communities, is a conspicuous demonstration of the abrupt differences between the northern and southern hill communities. Northern Nuba generally wear traditional Arab garments, whereas southern Nuba wear few, if any, clothes.

The early history of the Nuba is obscure. There is no written language, and oral history goes back only a few generations to the Mahdist regime (1881-1898). Very little archaeology has been done in the Nuba Mountains and the only early accounts of the region are those by British expatriates.

The Nuba have probably occupied the region for millennia, with very infrequent intermarriage or even contact among the many different subgroups. Arab domination of north and central Sudan is thought to have solidified by the 14th century (Holt, 1961; MacMichael, 1967) but the Nuba, unconquered, retreated to their hills. The British accounts of Sudanese history (Sagar, 1922; Bell, 1938), emphasize that Nuba-Arab relations were dominated by Arab raids for Nuba slaves. During the second half of the 18th century, the Fung emperor, Badi II, annexed Nuba jebels as he expanded his empire to the west, and Nuba slaves were brought to the Fung capital at Sennar (Crawford, 1951).

The Nuba adapted the natural defenses of their rocky outposts by building houses in remote areas and surrounding them with stone walls. From a distance, southern Nuba hill communities resemble medieval European castle fortresses built of stone with round towers and turrets. House clusters are naturally fortified by large boulders and are totally enclosed to the outside except for a single entrance. Each house cluster is made up of 4-6 circular earthen rooms linked together by a stone or mud wall facing an inner court.

5.4. MAJOR PATTERNS OF AGRICULTURAL ACTIVITY

Agricultural practices in the Nuba hills suggest considerable antiquity. It is impossible without archaeological evidence to give a precise date for the earliest cultivation of sesame and other crops on the hillslopes. Cultivation probably was not limited to the hills because British sources (Sudan, 1912; Sagar, 1922; March, 1936, 1944, 1948) claim that the Nuba had once cultivated the plains extensively, but Arab raiding had driven them back into the hills. Baggara Arabs found piles of sesame stored on the plains near Jebel Simasim, 16 km north of Jebel Ghulfan in the northern mountains, indicating that the Ghulfan Nuba farmers were unmolested although far from their homes (Sagar, 1922).

Farmers of the Nuba Mountains have deliberately selected crop varieties and techniques suited to the diverse requirements of the environment. The Nuba populations remain on the same plots for long periods of time and it is thus necessary to maintain land productivity. Slopes are terraced to conserve soil and rainwater and perhaps to minimize the washing away of young seedlings with the early rains. Fertilizing of terraces with animal and crop residues avoids soil exhaustion. On gently sloping land, where rock terraces are not needed, ridging follows the contours of the land, conserving soil. Mulching with straw conserves water, reduces weed growth and keeps the soil and plant roots cool in the hot climate.

Rotation of crops and fallowing of land through shifting cultivation are common practices that prevent buildup of pest populations. Nuba cultivators know that rotation of sorghum with other crops, such as cotton or sesame, can reduce booda, a parasite (*Striga hermonthica* Benth.) on sorghum and other grasses. These "trap crops" stimulate the germination of *Striga* seeds, but do not provide a host for the parasite. The field is thus cleared of most seeds of the parasite, and sorghum may be planted again the following year. Sesame is considered to be a valuable "follow-crop". It is not demanding in nutrient requirements and typically follows cotton and sorghum in rotation.

Hariq cultivation, or weeding with fire, is a seasonal event. After the early rains have stimulated the growth of new grass, the dead grass is removed by burning, which adds nutrients to the soil, and kills the new grass which also contains some major early weeds. In an agricultural system of low technology, the *hariq* is advantageous because it reduces the labor of weeding with simple hand tools.

Fire plays a role in another practice of sanitary crop husbandry by the Nuba. After harvest, stalks of cotton, sorghum and sesame are burned to destroy pathogens in the crop residues which could infect seedlings in subsequent seasons.

Sesame usually is planted by broadcasting, although it is planted with a digging stick in some areas. The planting of crops at high densities decreases the labor of weeding by allowing less space for weeds to grow.

The agriculture of the Nuba is usually called hoe cultivation, although both spades and hoes are used, with regional preferences for style of implement as well as working motions. Farmers use a special kind of spade with a handle more than 2 m long on light, sandy soil or the cement-like _gardud_ soils in some northern hill communities. Cultivators can hoe a large area while remaining stationary. Hoe cultivation is less suitable in the southern _jebels_ of higher rainfall and predominantly clay soil. Here, hoes commonly have short (shorter than 1 m) wooden handles that are often artistically carved.

Adjacent hill communities often use similar implements in different manners. In some communities short-handled hoes are used only while kneeling whereas in other communities they are used only while squatting. Like the differences among pottery styles and shapes of harvest baskets or granaries, different work habits are another example of cultural diversity among Nuba subgroups. Sesame harvest practices also differ regionally. In some areas the entire plant is harvested by cutting it at the base below the branches with an iron sickle (_manjil_), whereas elsewhere every capsule-bearing branch is cut to an even length. Branches are piled upon a drying rack (_rakouba_) composed of wooden legs supporting a raised platform. ground. The height of the platform differs, ranging from 0.25 m in some settlements to as high as 1.5 m elsewhere. _Rakouba_ stacking designs vary also among communities. Some groups place the alternate layers horizontally at right angles forming a rectangle, others make a circular stack, and others form a triangular mound. These heaps of sesame branches are up to 1 m high. Occasionally Nuba sesame growers cut entire plants at the base, tie them in bundles, and stand them upright directly on the ground. Thorn branches sometimes are arranged around the bundles to keep monkeys away. The sesame bundles are ready to thresh after 2 wk of drying in the sun.

Granary architecture among the Nuba groups is quite variable, and each community has its own fashion. Staple crops are stored in clay, or occasionally in woven palm granaries, often raised on platforms of stones or branches as protection from mice and ants. But in the village of Kelara, situated primarily on the cement-like gardud soil, the granaries are constructed directly on the ground. On most northern jebels granaries are separate, free-standing buildings. On the southern jebels, where house clusters are common, granaries are included within the cluster. Granary heights vary; some are as tall as the houses, but others are only half that height. At Kelara where spade handles exceed 2 m, the granaries are the tallest observed anywhere, and rakoubas are also the highest, nearly 1.5 m from the ground.

All the lands surrounding a hill community are considered to be the property of that community (el Hadari, 1974). Each farm belongs to the person who clears it, and upon the death of the owner, it is inherited by his descendants.

Organization of agricultural labor is an important aspect of diversity among the Nuba subgroups. In some communities, more frequently in the southern jebels than in the Islamicized north, men and women work together on the "far" farms throughout the agricultural cycle, exhibiting impressive strength and endurance. Daytime temperatures at harvest are still well above 30°C, but women leave their houses at dawn and return in the late afternoon, carrying baskets on their heads weighing 40 kg or more, loaded with sesame, sorghum or cowpeas (Vigna unguiculata (L.) Walp.). Few men were seen, confirming reports concerning out-migration of Nuba males. A 1973 census shows a dramatic imbalance in sex ratio. There were just over 50 males for every 100 females in the age group 15-29 yr, which could seriously affect agricultural production.

The Nyima Nuba in the northern village of Kelara are heavily influenced by Islam, and sorghum is strictly a man's crop whereas sesame is a woman's crop. This may be leftover from the time of Arab raids when protection of women was essential and they were restricted to their homesteads. It may also reflect the Islamic custom of segregation of women. As a consequence, men cultivate sorghum on the far farms. Their sole contribution to the sesame plot, near the homestead, is to clear the land and construct an enclosure (zereeba), usually of thorn branches, to exclude browsing animals. Thereafter, women alone broadcast the seed, hoe weeds and harvest the crop. Men do not set foot inside the sesame nursery after it is planted.

The communal work party (nafir) is a Nuba custom which lessens the tedium of tasks, provides extra laborers who increase the farmer's production, helps an individual gain social prestige and assures an adequate harvest. Beer and food are provided to workers in exchange for their labor during weeding or harvesting. Usually 25-30 unrelated individuals work in a nafir, although there may be as many as 70. The arrangement is reciprocal and ensures that a farmer will have sufficient help when he needs it. Nafirs are held on sorghum land because it is traditionally the most important food crop. Cotton is not a community concern. The introduction of money and cotton into Nuba agriculture has caused the custom of the nafir to decrease (Bell, 1938), because the failure of this cash crop jeopardizes the individual's profit, but not his survival.

5.5. SESAME AND SORGHUM IN NUBA AGRICULTURE

The primary foods of the Nuba are sorghum and sesame, and their diet varies little throughout the year. Sorghum is the fundamental cereal staple used in baking a flat bread (kisra), as well as a very thick porridge (asida). Asida is always eaten with a sauce (mulah), made of any available vegetables or leaves such as sesame leaves, dried okra (*Abelmoschus esculentus* (L.) Moench), or moluchia (*Corchorus olitorius* L.), a commonly-eaten, native green vegetable. Fish or meat is sometimes added, or ground sesame or peanuts can be substituted. Sorghum is also fermented to make the local beer (merissa), which is consumed daily by all adults. Each cultivator routinely carries a calabash of merissa to the field. Sesame is the major source of protein as well as oil. There are, in addition, a multitude of ceremonial uses for which sesame oil is valued.

The diversity in sesame and sorghum cultivars (Yassin, 1978) in the Nuba Mountains is noteworthy and the area may realistically be called a microcenter (Harlan, 1951). Compared with the rest of the Sudan where relatively few distinct varieties occur, the Nuba Mountains constitute a small region with dozens of sesame landraces (DB, pers. observ.). This diversity probably is not a result only of the diversity of habitats in the Nuba Mountains because many races occur within a single habitat. The variation in sesame and sorghum is promoted by the many different uses for these crops as well as the cultural diversity of the cultivators. Often, the Nuba even identify specific cultivars of sorghum and sesame with different Nuba jebels and are aware of their particular oil content, seed color, and resistance to locust attack or disease. A variety of sesame with large grey seeds (morawi) originated in the Moro Hills. It is a successful cultivar grown today by Nuba outside the Moro jebels but retaining the name of the region where it originated. One of the most popular landraces grown in Tukswana and Dubeibat, 35 km NE of Kadugli, is abu sindook, "one distinguished by a trunk", suggesting its shape, multicarpellate condition, and abundant seeds.

The crop varieties grown by the Nuba are adapted to each specific environment. Selection of crops or cultivars for each ecological zone is based upon careful observation and experimentation. Early maturing crops are chosen for terraced land, or light, stabilized, sandy, qoz soils where water is scarce. These crops include sesame, pearl millet, and roselle (Hibiscus sabdariffa L.), which provides the national drink of the Sudan (karkadeh). It is frequently intercropped with an early-maturing sesame cultivar (hirehir) that matures in 70 days. In contrast, on the heavy clay soils with abundant water reserves, late-maturing "heavy" types of sesame and sorghum are planted that require up to 180 days to mature. Seeds from sesame and sorghum varieties growing on the qoz and on the clay plains range in color from white to black.

Selection of sesame cultivars according to their basis of oil content or flavor is common. The distinctive red-seeded sesame of Kordofan is a unique form with high oil content found exclusively in the

Sudan. It is grown primarily in the Nuba Mountains, and to a lesser extent in the sesame-growing region around Gedaref, but growers there say that their seeds originated outside the area. At the sesame auction in the main market depot of El Obeid, all red-seeded sesame varieties are called _jebeli_, suggesting their origin in the Nuba Mountains. Red-seeded varieties, containing up to 60% oil, are cultivated by farmers as oilseeds. These varieties seem to be particularly well adapted to the Nuba Mountains, for they can withstand high winds, heavy rains, and the bacterial leaf spot or "blood" disease (_Xanthomonas sesami_ Sabet & Dowson and _Pseudomonas sesami_ Malkoff). One local name for the red-seeded variety is _denemet_, meaning dynamite. This nickname stems presumably from its high oil content. Growers and middlemen, however, say the red-seeded type is bitter and hard to digest. Varieties with white seeds are "sweet" and are preferred in confectionary preparations.

At Tebeldiko, near Lagowa in the western _jebels_, Daju Nuba cultivate red and white varieties separately in adjacent fields. They understand that each variety will breed true. The 2 varieties have different heights, branching habits and other characteristics, so the Daju Nuba thin these varieties to different densities. Fields of the red-seeded variety mature earlier and are harvested in October, while adjacent fields of the white-seeded variety are still green. Red-seeded plants are 1.5-2 m tall, robust, profusely branched, with bicarpellate capsules ca. 1 cm wide and 3-4 cm long and with rugose seed coats. In contrast, plants with white seeds are ca. 1-1.2 m tall, less branched, with bicarpellate capsules ca. 2-3 cm long and with smooth seed coats.

Seeds for the next season are harvested separately according to maturity and color. Each type of seed is stored in a clay bowl with a lid made from a piece of calabash gourd (Lagenaria vulgaris Seringe) and sealed around the edges with mud, making a fairly airtight container.

In the southern jebels, a single field often contains several landraces of sesame growing intermixed. Plants of every height, branching pattern, seed color and maturity are sown, cultivated, harvested and consumed together. These mixtures insure against the results of seasonal variations in rainfall and temperature. In any particular year some varieties are likely to survive to harvest. Here sesame often is intercropped with sorghum, and kurgy is the favorite sorghum variety. It is a late-maturing, durra-type sorghum with a crooked neck, a large, compact, orange head, the widest leaves of any local sorghum, long secondary roots that adapt the plant to the heavy clay soils, and a decumbent habit, which causes Nuba cultivators to thin these stands, allowing a distance of up to 2 m between the plants.

Nearly 50% of the accessions in the sesame germplasm nursery of the Agricultural Research Corporation at Kadugli had quadricarpellate capsules. These were not special selections nor breeder's material, but local material collected by agriculture inspectors. In a world germplasm collection most sesame forms are bicarpellate. A notable exception are Chinese materials which are highly selected over thousands of years. In the southern Nuba jebels, where a greater mixture of varieties occurs, surprisingly many varieties have quadricarpellate capsules.

Average yields on Nuba farms are generally between 300 and 350 kg/ha of threshed grain and can reach 700 kg/ha (reported in the Lagowa area) if the crop is well managed (Roger Billington, pers. comm.).

5.6. BOTANICAL FEATURES AND WILD RELATIVES OF SESAME

Cultivars of sesame vary considerably among themselves. A single character often varies on the same plant or even on the same branch. This is true of shape of leaves, position of flowers, number of fruits per axil and number of carpels per capsule. Cultivars of sesame differ considerably from each other in their branching habit, flower color, in the size, shape and arrangement of capsules, and in the color and size of seed. There may be 1, 2 or 3 capsules per axil, and 1 or more axils per node. The capsules may be 2,3 or 4 carpellate (Weiss, 1971). In general the cultivated plant frequently can be distinguished from these wild relatives by its palmately compound leaves, hairy white or pale lavendar corolla, thin-walled, dehiscent capsules and smooth seed faces. Seeds range in color from white to black with intermediate colors of beige, tan, red, brown and grey.

Sesamum latifolium Gillett (_Thomas 3708_, K) is widespread in Sudan (DB, pers. observ.) and grows in disturbed and undisturbed habitats. It invades abandoned agricultural fields but also occurs in undisturbed gravelly soil near boulder outcrops. Nuba call it "dog′s sesame" or "wolf′s sesame" and they were bewildered that we collected its seeds which they regarded as useless and a nuisance. It often grows at the bases of _jebels_ in association with the _tebeldi_ tree, _Adansonia digitata_ L., the woody herbaceous species _Leonotis africana_ (Beauv.) Briq., and _Rogeria adenophylla_ Gay ex Del., another species of Pedaliaceae. This

Rogeria species is called "devil's sesame" because its woody capsules have long, spike-like thorns and its seeds are totally unpalatable.

Sesamum latifolium is a robust annual with a woody, many-branched stem, more or less cordate leaves with serrate to crenate margins, and a white corolla with several of fine purplish-red lines on the lower lip and pink shading deep inside the corolla. It flowers continually from July to December. There is generally 1 flower per axil, and often 3 axils per node. At each side of the corolla are extrafloral glands which are black when immature and yellow when mature. The woody capsule is indehiscent and sets black, radially reticulate seed which are dormant for several years. S. latifolium was not described until 1953 and was omitted from the only flora of Sudan published thereafter (e.g., Andrews, 1956). Consequently S. latifolium from Sudan is often misidentified as Sesamum radiatum Schumach.

S. latifolium is adapted to heavy clay soils and appears to be immune to the bacterial leaf-spot disease. Sudanese breeders have been unsuccessful in transferring these traits to cultivated sesame by interspecific hybridization and our attempts in the Crop Evolution Laboratory also were unsuccessful, yielding only a few sterile seeds.

In contrast, another wild species, Sesamum alatum Thonn., (Kotschy 106, K), grows on the sandy qoz soils and is a frequent weed in cultivated sesame fields or areas of abandoned cultivation. Its corolla is pink to red and radially symmetrical, unlike the bilaterally symmetrical corolla of cultivated sesame. Its capsule is slender and tapers at the tip, suggesting its local name "gazelle's sesame." Its black seeds are muricate with a paper-thin, broad wing at each end.

5.7. USES OF SESAME

Householders extract oil from sesame seeds for home use by pounding them to the consistency of a coarse paste in a wooden mortar and pestle (funduk). This paste is then transferred onto a stone, clay or gourd slab where it is kneaded repeatedly by hand into is a soft paste which is placed in a square metal can. Boiling water is poured over the paste, and the oil is skimmed off after it rises to the surface.

Sesame oil is extracted in quantity at a workshop called an asara. A blindfolded camel is harnessed to a wooden mortar and pestle made of the durable wood of *Acacia nilotica* (L.) Willd. ex Del. As the camel walks in a circle, the seeds are ground, releasing the oil. After the oil is expressed, the protein-rich residue makes an excellent livestock feed. This procedure may have inspired a Sudanese proverb: "Just like sesame, if you don't press it, it won't give oil."

Sesame oil is preferred for some purposes because it is denser than cottonseed or peanut oil. It is used cosmetically by Nuba as a body massage that makes the skin shine, and alone or mixed with red ochre, as a hair dressing. It is used medicinally to heal earaches. The oil of red-seeded sesame is recommended for many illnesses. A mixture of sesame seeds cooked with cowpeas and wild okra is recommended to relieve constipation and upset stomach.

Many other meals are prepared with sesame seeds or sesame oil. A sauce often eaten with sorghum bread is prepared by mixing sesame seed paste with water, salt, red pepper (*Capsicum annuum* L.) and, if available, onions (*Allium cepa* L.). A refreshing salad consists of chopped cucumber (<u>Cucumis</u> sp.), onion and toasted sesame seeds. A filtrate of the ashes of burnt sesame stalks is added to stews, for it is considered to have nutritional value because it contains many minerals. The filtrate is also used to tenderize okra or <u>moluchia</u> by breaking down the cellular structure of the vegetables.

Crushed white sesame seeds mixed with honey constitutes a favorite dessert. If sugar or honey is not available, salt is added to roasted sesame seeds for a teatime snack. Everywhere in the Sudan, a special candy is prepared with sesame seeds to commemmorate the birthday of the prophet Muhammad.

Sesame oil is used by the Nuba for a number of important occasions. Weddings require a gift of sesame seeds and sesame oil as part of the dowry and bride price. After birth, the umbilical cord is detached and annointed with sesame oil. Young girls anticipating their first menses are secluded for an extended period (up to a year) in a granary. Following the seclusion, gifts are exchanged, including sesame oil for annointing. To celebrate this occasion, marriage, and first pregnancy, a woman is newly scarred by cicatrization. These scars form geometric patterns of welts which decorate the otherwise naked body. The raw cuts are rubbed with saliva and sesame oil.

Expiation of guilt in premature consummation of marriage among the Nyima Nuba requires a ceremony. The bride is taken to the bridegroom's house by old women. She stands outside the gate of the compound, holding her hands above her eyes, palms up. The "best man" drops 4 cowrie shells into her cupped hands, touches her forehead 4 times with an iron blade and cuts off a lock of her hair. She is then dressed in the beadbelt and apron of married women by an old man and woman of the bridegroom's clan. She returns to her own home accompanied by 4 girls carrying large gourds filled with sesame oil. The gourds are then emptied, filled again with water and returned by the girls and the bride to the bridegroom's house. The same night the bridegroom will wash in this water and then sleep with his wife, for the first time legitimately. Failure to perform this rite would result in execution of the woman for the sin of unchastity (Nadel, 1947).

Negotiations to end blood feuds caused by homicide also utilize sesame oil. Arrangements to permit the murderer to return to his village usually begin after 4 or 5 yr. The relatives of the victim are paid in cattle. Families of the murderer and the victim meet in the house of the chief. They sit in a circle which contains beer, sesame oil and a little food "that is planted" (i.e., grain, sesame, cucumbers). The biggest bull of the cattle payment is then killed. A piece of wood is dipped into its blood and held up to the chief. He touches it with the little finger of his left hand, which he licks afterwards. One after the other, the oldest women of the victim's, of the culprit's family, then all the other women, do the same. The mother of the victim rubs sesame oil on the neck of the murderer's mother, who reciprocates with the same behavior. Simultaneously, a fire is lit in the center of the circle and the grain, sesame and other foods are thrown into it. As the smoke drifts around over both the groups it cleanses them so they may eat together. A common meal of the bull concludes the feast and with it the blood feud (Nadel, 1947).

Agricultural rituals are landmarks in the Nuba calendar and provide a social control whereby residents of individual hill communities see themselves as part of a wider social unit. From planting until harvest, and particularly during the ripening of the grain, the Nuba refrain from all singing and dancing because they believe that their mirth might disturb the grain spirits (Nadel, 1947). Completion of the harvest is, therefore, accompanied by festivity. One of us (DB) attended a harvest ceremony at the village of Teis, in the southern jebel region. Earlier that day a courtesy visit was paid to the local mek who rules Teis and 8 neighboring hill communities. The women of his compound were preparing for the celebration that night and washed and massaged their bodies with sesame oil until they glistened. They also employed sesame oil to renew their coiffures. The adolescent daughter of the mek carved a flute from bamboo (Oxytenanthera abyssinica Munro). The woody, outer portions of the bamboo were first stripped away and discarded. Then, working with the remaining pith (from a long internode of a section of bamboo), a thin rectangular reed was gradually carved with the sharp edge of a stone tool. A bivalve river shell was used to bore a hole in one end. Unwanted strips of bamboo were snapped off with fire from a burning twig. String equal to the length of a meter-long wooden wand was cut and wrappped around one end of the wand. The other end of the string was attached to the hole in the bamboo reed. As the wand is waved overhead, the reed catches the breeze and hums in a tone whose pitch varies with the speed of the movement. While she fashioned the instrument she nursed her baby and at the same time prepared tea and a snack of toasted, salted sesame seeds. Although she wore only a narrow, beaded belt around her waist with a tiny apron in front, she was entirely dignified.

Later, in the darkness of that moonless night all youths from the communities under the jurisdiction of the mek gathered in a wide field at the outskirts of Teis. The beat of the huge drum marked the rhythm of the dance. Everyone sang and stamped steadily to it's time, raising dust and celebrating the end of another agricultural year with expressions of music and dance that had been prohibited during the growing season.

5.8. ACKNOWLEDGEMENTS

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CHAPTER 6

SUMMARY

Sesame cultivars have been classified according to a plan that has both systematic and agronomic value. Intraspecific variability was analysed using morphological, chemical and cytogenetic evidence and data from controlled pollination studies.

The study includes data from three sources: herbarium specimens, field observations, and collections of living material grown under uniform conditions, in Urbana, Illinois. Data on vegetative and reproductive morphology was analysed using standard methods of numerical taxonomy.

The phylogenetic affinities among cultivars and their relationships with close wild relatives and weed associates are described. Fieldwork to collect a large sample of seed from wild as well as cultivated forms has helped represent the variation found in wild and domesticated taxa and their weedy relatives.

The lignans, sesamin and sesamolin, phenylpropanoid compounds found in sesame seeds, were isolated and identified using NMR specroscopy. Seed oils of other species of Sesamum, other genera of Pedaliaceae, and neighboring plant families, were also sampled to determine the extent of the occurrence of these lignans in related taxa.

The human context of sesame cultivation and use also received attention in this study, because cultivated plants are the products of man´s intervention and selection. The types of variability recognized

and preserved by native cultivators and their reasons for selecting them were sought.

6.1. PROCEDURES FOLLOWED

1) As many samples as possible have been obtained by correspondance and through plant introduction and plant quarantine services. Field collections were made in India and the Sudan. Visits to herbaria enabled the examination of the nearest wild relatives. The herbaria visited included Bombay, Coimbatore, Delhi and Poona in India; Khartoum, Shambat and Wad Medani in the Sudan; British Museum and Kew, Brussels, Florence, Hamburg, Paris, Vienna, St. Louis and New York. Specimens from Lisbon and Nairobi were obtained by correspondence.

2) Selection of descriptors most useful to distinguish sesame cultivars morphologically had not been attempted at the outset of this study. Nearly 100 characters were used in a preliminary study and evaluated by discriminate function and principal component analyses to determine which are the most important in partitioning the total variation. A smaller number of descriptors were then used too analyse the entire collection and cluster the accessions into groups. These results are presented in Chapter 2.

3) Interspecific hybrids were attempted between sesame and as many other species as we could obtain, to understand genetic relationships within the genus. It is important to find out which species can be hybridized with cultivated sesame and produce F1's sufficiently fertile for gene

transfer. This is the only way to define the usable gene pool for plant breeders.

4) Cultivars were compared with respect to oil quality by testing for sesamin and sesamolin, compounds of potential economic value as antioxidants and insecticidal synergists. These results support other data to establish the origin of cultivated sesame, and are presented in Chapter 3.

5) The early history of sesame in the Near East and Africa has been in a state of confusion. A thorough investigation with the aid of cuneiform scholars at a working session of the Sumerian Agriculture Group at Trinity College, Cambridge, June 29, 1984, finally appears to have resolved the controversy. These results are presented in Chapter 4.

6) Ethnobotanical information was assembled primarily from published sources and supplemented with herbarium sheet label information, field data and correspondence with scholars and students in Africa and Asia. Observations during four months of fieldwork in the Sudan provided firsthand data regarding selection, cultivation practices and cultivars currently extant and grown by traditional cultivators in the Nuba Mountains region, that is geographically and culturally isolated from the rest of the country. These were compared with local types grown by farmers of other ethnic backgrounds in regions of the country that are ecologically distinct, and are discussed in Chapter 5.

7) Collection and investigation of both the wild and cultivated germplasm has provided accessibility of an assembled resource to users.

Preservation of the collection would guard against genetic erosion. It can offer protection of material already in use, and make available valuable, though unknown, genetic resources for further improvement. An analysis of variation patterns was an essential first step in improvement of the crop.

The references included with each chapter of this dissertation form a fairly complete current bibliography of the published works about that topic of sesame research. A diverse and often obscure literature that has not been available before in a single place has been compiled. Areas of sesame studies that are not emphasized in this dissertation, are its cultivation requirements, and the pests and diseases of sesame. Both subjects are summarized by Weiss (1971).

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